Where is the sun?

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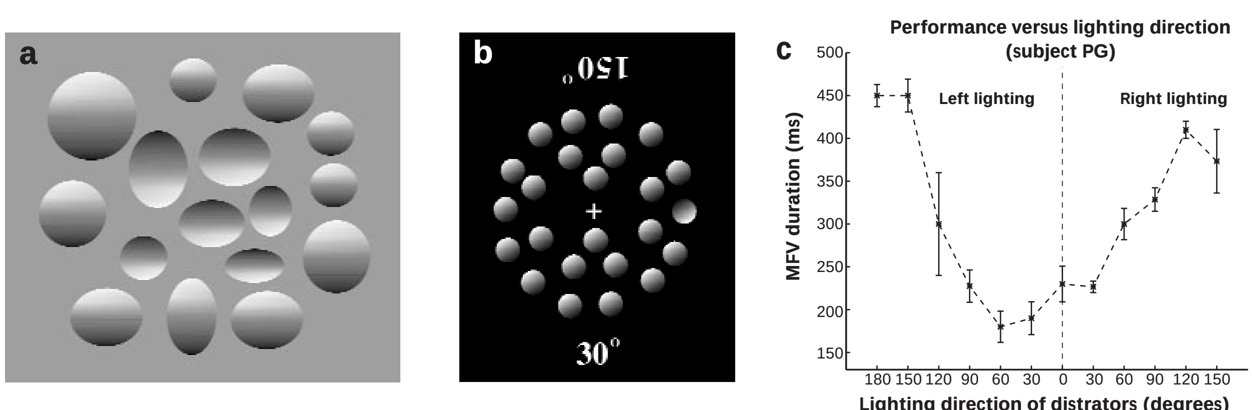
When we interpret a shaded picture as a three-dimensional (3D) scene, our visual system often needs to guess the position of the light source in order to resolve a convex-concave ambiguity. For more than a century, psychologists have known that the visual system assumes that light comes from above and have argued that this assumption is ecologically justified because our everyday light source (the sun) is overhead. Our experiments reveal that people's preferred lighting direction is not directly overhead, but rather shifted to the left, and this preference is reflected in art spanning two millennia. Furthermore, we find a strong correlation between people's handedness and their preferred lighting. We suggest that what counts is not so much where the sun is, but where you like the sun to be.

The shaded shapes in Fig. 1a are typically perceived as convex bubbles surrounding concave indentations, all lit from above. Note that this image is also consistent with a different physical scene: indentations surrounding bubbles, all lit from below. This second perception, however, is difficult to achieve. Such an asymmetry between the perceptual saliency of equally valid 3D interpretations demonstrates that our visual system prefers the assumption that light is coming from above[1–3]. Does this preference apply uniformly to all lighting directions that are above the horizon? Perhaps there is instead a preferred direction? If so, one might reason it to be directly overhead. Is this intuitive guess correct?

We addressed these questions by measuring the time it takes to detect, within a group of 'distractor' bubbles, a single 'target' bubble that is lit differently (Fig. 1b). Recent studies suggests that the light-from-above assumption is used by the visual system for interpreting quickly and in parallel some basic aspects of 3D scenes[4–8]; the target pattern may be detected quickly (pop-out) only when the distractors, but not the target, can be interpreted as convex and lit from above[5–9]. We simulated different directions of lighting by varying the shading gradient of the distractor bubbles. The target bubble was shaded to simulate illumination from the opposite direction (Fig. 1b).

Data from twelve naive subjects shows that the visual system does not respond uniformly to all lighting directions that are above the horizon (Fig. 1c). There is clearly a preferred direction of lighting where detection requires the shortest display time. Surprisingly, this preferred direction is not directly overhead (zero degrees). Subject PG, for instance, performs best with a lighting direction that is between 30 and 60 degrees left of the vertical (Fig. 1c). Furthermore, there is a consistent preference for left lighting over right lighting. This same marked left–right asymmetry is evident in the averaged data of all twelve subjects. As the angle of illumination increases, the preference for left lighting becomes increasingly pronounced (Fig. 1d).

This asymmetry in our data may explain a qualitative observation made by Gestalt psychologist Metzger, who noted that left-lit scenes have a superior perceptual value over right-lit ones[10]. He ascribed this asymmetry to the convention of setting up desk lamps on the left, presumably so that the writing hand does not cast a shadow on the page. Over time, he hypothesized, one learns to perceive left-lit scenes as being more 'natural'. Metzger's explanation may be somewhat restrictive: our visual environment extends beyond our writing desk. We tend to position a movable light



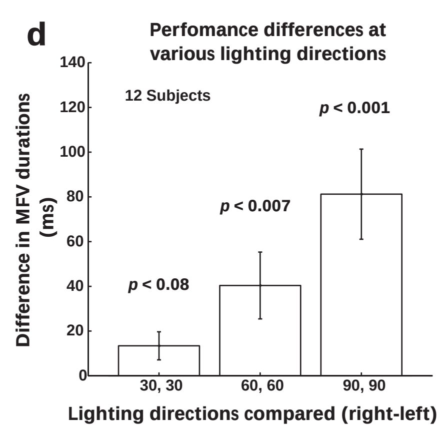


Fig. 1. Shaded displays that may be interpreted as 3D shapes and measurement of preferred lighting direction. **(a)** Rotate the page to invert the shapes. **(b)** Images were generated on a Silicon Graphics Indigo2. Each `bubble' spanned approximately one degree. One target pattern was present at random among 23 distractor patterns in 50% of the trials. The remaining trials contained 24 distractors and no target. The lighting direction is determined by the shading gradient of the distractors. Target-present test screens are shown for 2 of the 12 lighting directions used in our experiment. We denote a lighting direction by its deviation from the vertical in degrees. Positive degrees indicate lighting from the left, and negative degrees indicate lighting from the right. Accordingly, lighting from directly overhead is designated as 0 degrees, and lighting from directly below as 180 degrees. **(c)** We used a two-alternative forced-choice stimulus onset asynchrony (SOA) design with masking. Data was collected using a staircase method that converged at 67% accuracy performance. The most frequently visited (MFV) duration within each block was used to estimate 67% accuracy performance. The duration necessary for 67% accuracy for each lighting direction is shown for subject PG. **(d)** We computed the mean difference in necessary display duration between pairs of corresponding left-right lighting directions over all 12 naive subjects. The necessary duration for a left-lighting condition is subtracted from the necessary duration for the corresponding right-lighting condition.

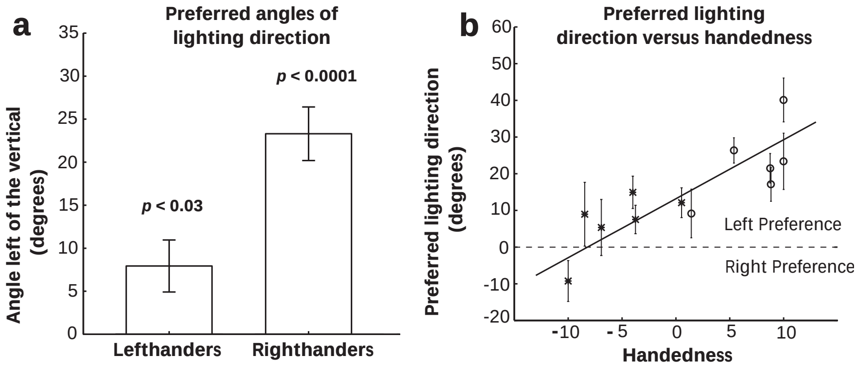


Fig. 2. The preferred light direction correlates with handedness. **(a)** Subjects were categorized based on which hand they used for writing. The mean preferred lighting direction was compared between the six right-handed and the six left-handed subjects. Although both groups show a preference for left-lighting, right-handers, as a group, prefer a larger angle left of the vertical (23.3 degrees) than do left-handers (7.9 degrees). **(b)** Preferred lighting direction is correlated with handedness (r = 0.83, $p<0.01$). * lefthander, p righthander.

source, or position ourselves in relation to a fixed light source, such that our hand does not cast a shadow upon the object of our manipulation. Right handers would then develop a preference for left-lighting, and, as suggested by van Fieandt[11], left-handers may well show the opposite lighting preference.

To investigate this possibility, we derived the preferred lighting direction and handedness for our subjects. We defined each subject's preferred lighting direction to be the lighting direction for which target detection performance was best. This was estimated by fitting a parabola to the central portion of each subject's time versus direction curve (e.g. Fig. 1c). and calculating the direction for which the parabola reached a minimum. When preference for lighting direction is considered for left- and right-handers separately, we find that both groups have a preference for left-lighting. However, the right-handers as a group prefer a lighting direction that is significantly more toward the left than the left-handers' preference (Fig. 2a).

Handedness, however, is not a strictly binary trait; rather it varies in a continuum[12]. We used a standard ten-item questionnaire that evaluated the relative strengths of our subjects' handedness[13]. The resulting score ranges from -10 to 10, with positive values indicating a bias for the right hand, and negative values for the left. When each subject's preferred lighting direction is plotted against this handedness score, a strong correlation is found (Fig. 2b).

If lighting preference is indeed related to handedness, why isn't the effect mirror symmetric, with left-handers having a preference for right-lighting instead of left? This may be explained because left-handers live in a right-handers' world and are often forced to function in environments that are designed for right-handers. If lighting preference is not determined by a biological trait correlated with handedness itself, but rather by handedness-related experience, then one would expect that right-handers would prefer left-lighting, whereas left-handers, because of their mixed experience, would exhibit a weaker preference for either left or right lighting.

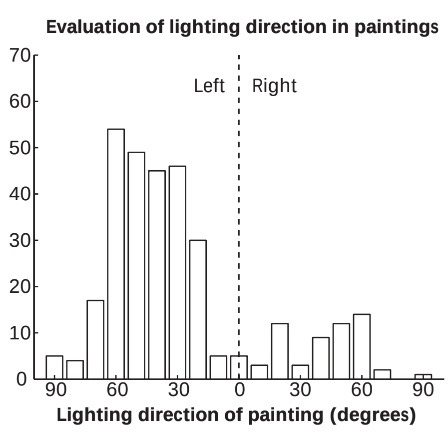


Fig. 3. Painters tend to light scenes from top-left. 100, 100 and 25 paintings were randomly selected from catalogues of the Louvre, the Prado, and the Norton Simon Museum. Two naive subjects evaluated these paintings for lighting direction. Using a protractor, 77 ± 0.55% of the paintings were classified as being lit from the left ($p<0.05$). The artists most often selected lighting directions that are between 30 and 60 degrees to the left of the vertical.

Quantitative measurements of the perception of shape from shading using static displays have revealed no asymmetry between left- and right-lighting conditions[14,15], thereby failing to confirm Metzger's observation. One might, therefore, suspect that the preference for left lighting we observe with our fast-presentation paradigm is confined to the earlier stages of visual processing, and that this effect may become negligible under ecological viewing conditions. We have reason to think otherwise. We asked two naive subjects, one right-hander and one left-hander, to survey 225 master paintings and determine the predominant angle of lighting for each. The histogram of the measurements (Fig. 3) shows that the artists most often chose a lighting direction that is left of the vertical. This preference for top-left lighting may have resulted from an accidental artistic convention. However, this is unlikely, as preference left-lighting is found across schools and periods: from Roman mosaics, through Renaissance, baroque, and impressionist art. It is therefore possible that top-left lighting may actually have a higher perceptual value than top-right lighting in natural viewing conditions, which involve frequent saccades over the entire scene. Perhaps when subjects are required to make their shape judgments under prolonged scrutiny of a localized portion of the test stimulus[14,15], the effect drops below a measurable level.

Acknowledgements

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