Where is the Sun?

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The shaded shapes in Figure 1a are typically perceived as concave indentations that are surround by convex bubbles, all lit from above. Note that the figure is also consistent with a different physical scene; bubbles that are surrounded by indentations, all lit from below. This perception, however, is difficult to achieve. Such an asymmetry between the perceptual saliency of equally valid 3-D interpretations demonstrates that our visual system prefers the assumption that light is coming from above[1–3]. However, what exactly does "light from above" mean? Does our visual system prefer similarly all lighting directions that are above the horizon, or does it have a more specific preference? Is this preference inborn, or is it acquired through experience?

Preference for lighting direction may be measured using a pop-out task. Recent evidence from 3-D pop-out experiments suggests that the light-from-above assumption is used by the visual system for interpreting fast and in parallel some basic aspects of 3-D scenes[4–8]. In particular, pop-out involving stimuli like the shaded bubbles in Figure 1a occurs when the distractors, but not the target, can be interpreted as convex and lit-from-above[5–8]. Similar shaded bubble stimuli were used in our present experiment (Fig. 1b). Different directions of lighting were simulated simply by varying the shading gradient of the distractor patterns, while the target pattern was shaded to simulate illumination from the opposite direction.

We find that the visual system does not respond uniformly to all lighting directions that are above the horizon (Fig. 1c). Surprisingly, the 'preferred' direction of lighting, instead of being directly overhead, is tilted to the left. Subject PG, for instance, performs best with a lighting direction that is between 30 and 60-degrees left of the vertical (Fig. 1c). Furthermore, a marked asymmetry is seen between the various left-lighting and right-lighting orientations: 30 degrees is preferred over -30 degrees, 60 degrees is preferred over -60 degrees, and 90 degrees is preferred to an even larger extent over -90 degrees (Fig. 1d).

What might this asymmetry be due to? We speculate that this left-right asymmetry may be related to other biological asymmetries that occur in human beings. One obvious asymmetry is handedness. Most of us are either right-handed or left-handed. Very few of us are exactly ambidextrous. Perhaps our preference for left or right lighting is related to our handedness.

In order to study this question we measured the 'preferred' lighting direction, i.e. the lighting direction for which target detection performance was best (Fig. 2a), in 12 subjects. Our subjects consisted of 6 left-handers and 6 right-handers, as categorized by their writing hand. We found that both the right- and the left-handers have a preference for left-lighting. However, the right-handers' as a group prefer a lighting direction that is significantly more towards the left than the left-handers' do (Fig. 2b). Since handedness is not a strictly binary trait [9], we used also a 10-item questionnaire to evaluate the relative strengths of our subjects' handedness [10,11]. We found a strong correlation between this handedness score and the preferred lighting direction (Fig. 2c).

Another biological asymmetry that might influence lighting preference is the lateralization of our brain. Most people are left-hemisphere dominant for language and analytical tasks and right-hemisphere dominant for spatial-perceptual tasks [12,13]. As a result, in general, verbal tasks are processed preferentially when presented in the right visual hemifield, while spatial-perceptual tasks are processed preferentially when presented in the left visual hemifield [14,15]. When convex scenes are lit from the left, higher contrast and, therefore, increased information result in the left visual hemifield, which is processed by the right hemisphere. Perhaps those of us who are right-hemisphere dominant for a spatial-perceptual task, resulting in a left-hemifield processing advantage, would also display a preference for left-lighting when performing such a task. Approximately 30% of left-handers and 5% of right-handers display brain lateralization that is inverted with respect to the norm [16]; perhaps these subjects would show the opposite hemifield and lighting preferences.

We were able to assay our subjects' hemifield preference for our spatial-perceptual task using the original data collected in the previous experiment (Fig. 3a). As expected, the vast majority of our subjects displayed a left-hemifield advantage, achieving significantly better performance when the target appeared in left visual hemifield (Fig. 3b). Only two subjects, both left-handers, displayed right-hemifield advantage; they performed better when the stimulus was presented in their right hemifield.

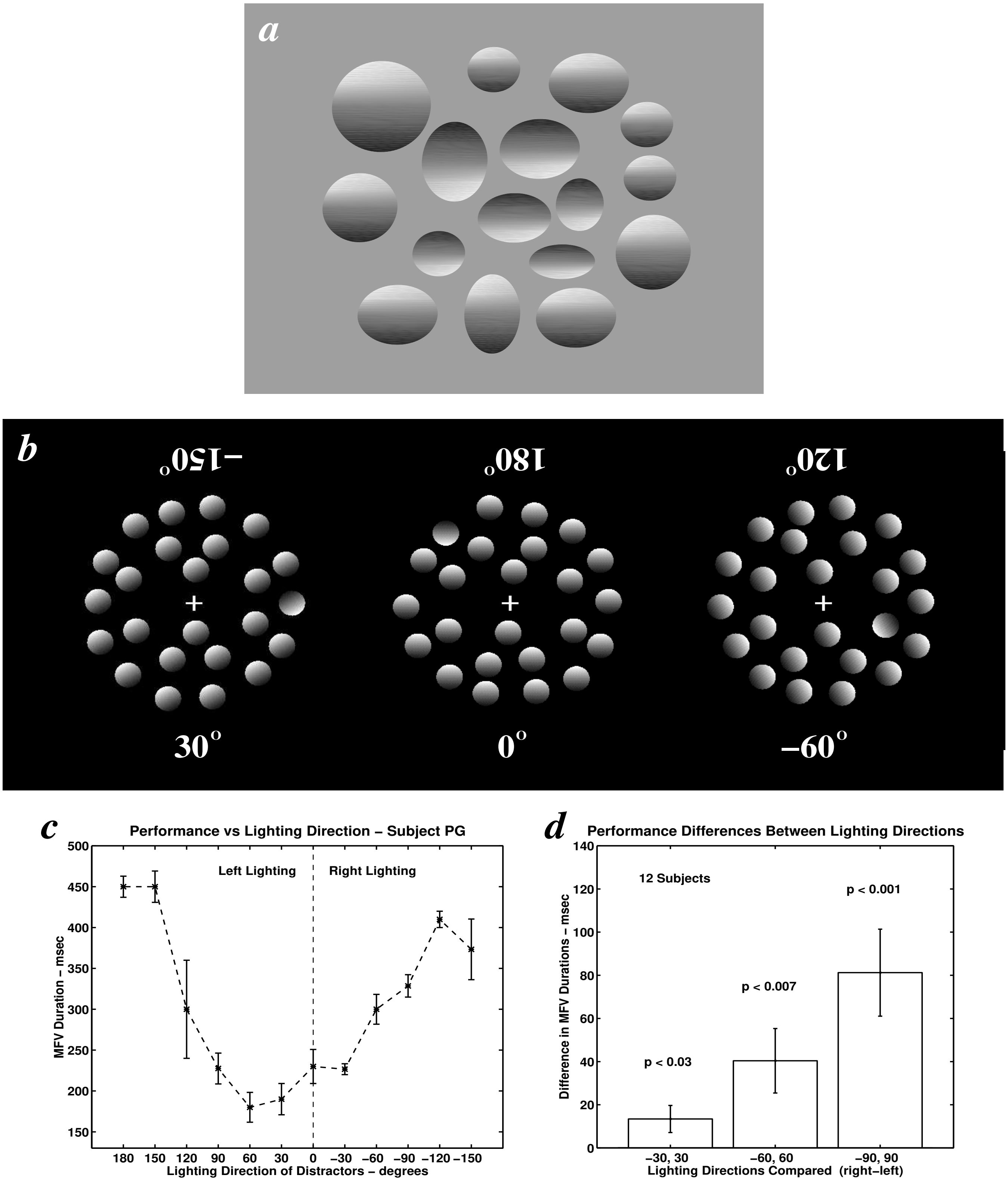
Preferred lighting direction is weakly correlated to hemifield preference (Fig. 3c). This correlation may indicate that hemifield advantage is a small, but contributing, factor to the direction of lighting preference, or it may be merely due to the fact that hemifield advantage itself is correlated with handedness. Analyzing the data using Minor Axis Regression [17], we found that the residuals from correlating preferred lighting direction with handedness cannot be attributed to hemifield advantage (Fig. 3d). The converse analysis shows that the residuals from correlating preferred lighting direction with hemifield advantage are still significantly correlated with handedness ($p < 0.05$). Our data is consistent with the hypothesis that handedness, not hemifield preference, is a relevant factor in determining preference of lighting direction. If hemifield advantage is taken to be an indicator of hemispheric dominance, then our results suggest as well that hemispheric dominance is not the relevant factor either.

If handedness determines lighting preference, one might expect the effect to be mirror symmetric, resulting in left-handers having a preference for right-lighting instead of left. Yet, we see from our data that left-handers, while exhibiting an effect that is less pronounced, still, as a group, prefer lighting from the left. We suggest that lighting preference, instead of being directly linked to the inborn handedness of a person, may be the result of experience that is in turn related to handedness.

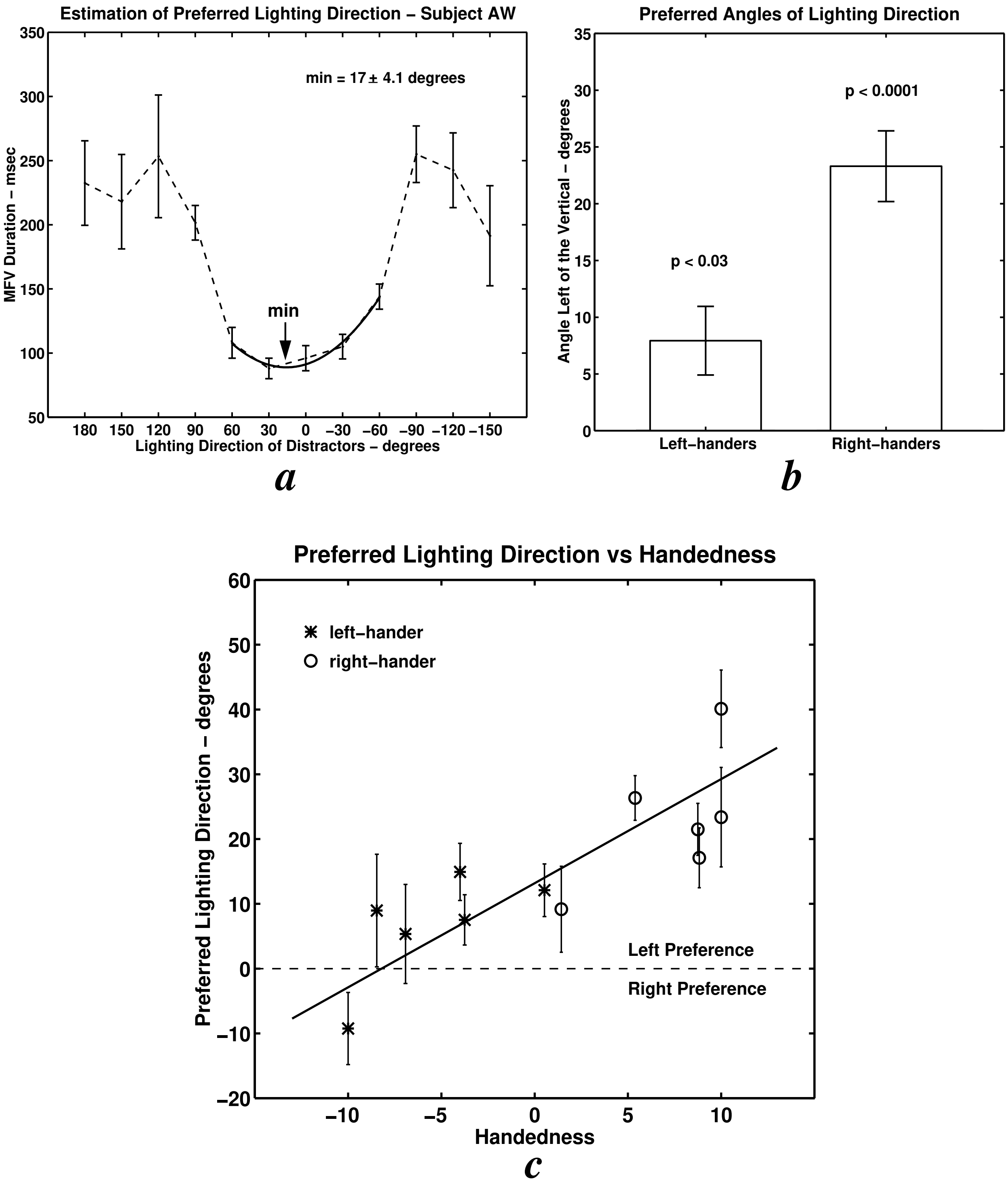
One of our distinctive traits as humans is our ability to use our hands for manipulating objects and tools. When we engage in these tasks, it makes sense to position a movable light source, or position ourselves in relation to a fixed light source, so that our hand does not cast a shadow upon the object of our manipulation. A right-hander, for example, would be expected to place his/her desk lamp on the left (Fig. 4a), and preferentially orient his/her desk so that the window is on the left. Over years, this may result in higher visual performance under left-lit conditions. For left-handers, however, the situation is more complicated. While we might expect left-handers to do the opposite, thus resulting in a preference for right-lighting, we must consider the fact that left-handers live in a right-handers' world, and are often forced to function in environments that are designed for right-handers. For instance, most classrooms are designed such that when the pupils face the instructor, the windows are on their left. If handedness-related experience is indeed what determines lighting preference, we would then expect right-handers to have a marked preference for left-lighting; left-handers, due to their mixed experience, would exhibit a weaker preference for either left or right lighting. This is consistent with our observations.

No asymmetry between left and right lighting conditions has been reported so far in studies that measured perception of shape from shading using static displays [18,19]. One might, thererefore, suspect that the preference for left lighting we observe is confined to the earlier stages of visual processing, and that this effect disappears under ecological viewing conditions. We have reason to think otherwise. In a survey of paintings, we found that artists choose most often a lighting direction that is between 30 and 60 degrees to the left of the vertical (Fig. 4b). This preference for top-left lighting may have resulted from an accidental artistic convention. However, it is found across schools and periods: from Roman mosaics, through Renaissance, baroque, and impressionist art, to contemporary graphic design (Fig. 4c). It is therefore very likely that top-left lighting actually has a higher perceptual value than top-right lighting.

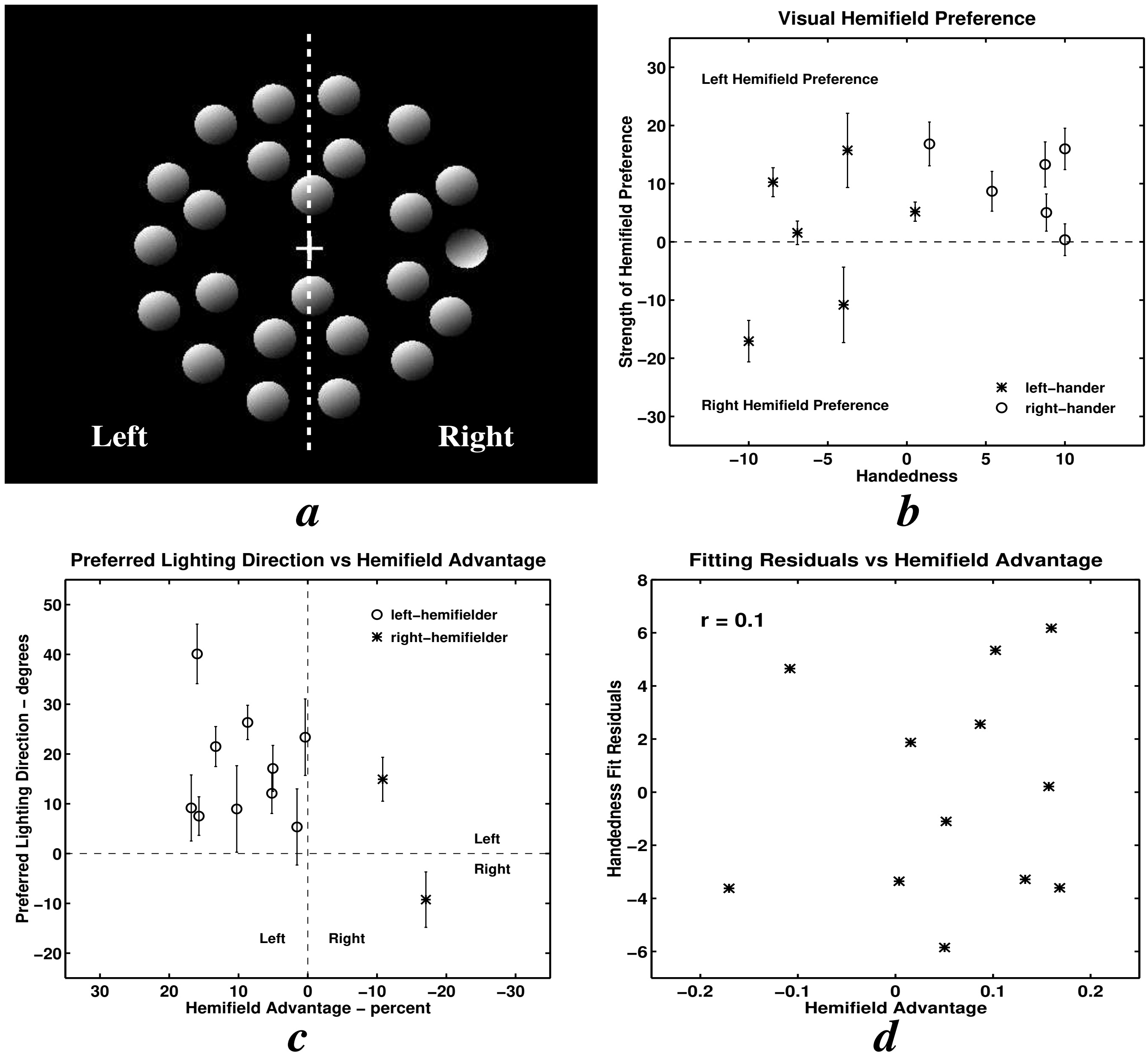
The human visual system's preference for top-lighting over bottom-lighting has been known for centuries. Our findings demonstrate that there is also a preference for left-lighting over right-lighting, with right-handers exhibiting a significantly stronger preference than left-handers. We suggest that this preference may be shaped by visual experience that is in turn influenced by handedness and environment.



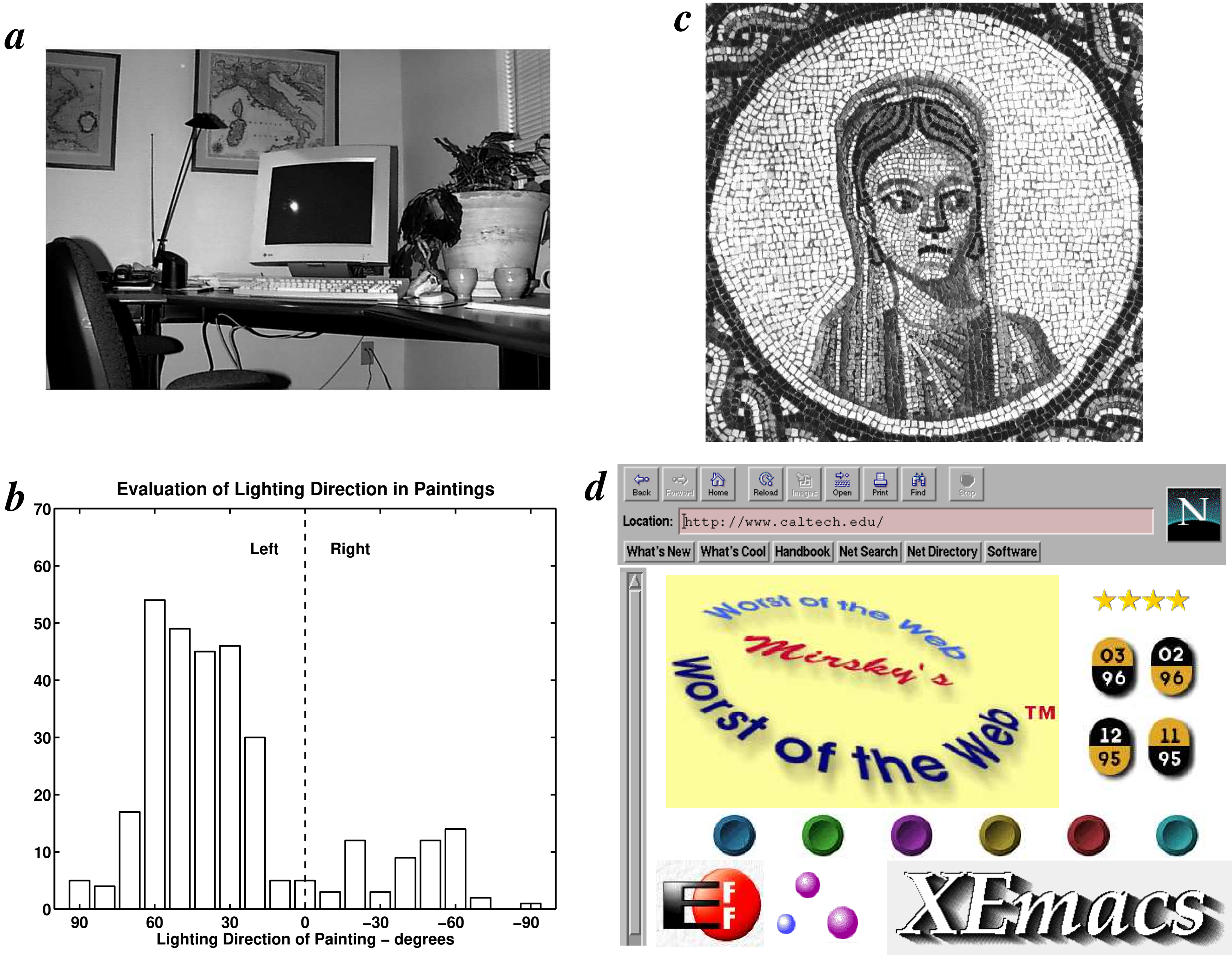
Sun & Perona, Fig. 1



Sun & Perona, Fig. 2



Sun & Perona, Fig. 3



Sun & Perona, Fig. 4

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1 Figures

1. Figure 1

   (a) These shaded patterns are more easily perceived as indentations surrounded by bubbles instead of the converse. When the page is inverted, however, the effect is reversed: it is now easier to perceive bubbles surrounded by indentations. This asymmetry in ease of perception implies a preference for interpretating 3-D scenes based on an assumption of top-lighting.

   (b) Images were generated on a Silicon Graphics Indigo[2]. Each stimulus pattern spanned approximately 1 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. Lighting direction is determined by the shading gradient of the distractors. Target-present test screens are shown for 6 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. Target detection is easier when the distractors can be interpreted as convex and top-lit (upright conditions) than when they are interpreted as concave or bottom-lit (upside-down conditions).

(c) We used a 2afc stimulus onset asynchrony (SOA) paradigm 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 durations necessary for 67% accuracy for each lighting direction is shown for Subject PG. Lighting directions from 90 to -90 were lighting directions from above the horizon. Performance was best when the distractors were shaded to simulate a lighting direction that is between 30 and 60 degrees left of the vertical. A systematic preference for left-lighting over right is seen for angles of 30, 60, and 90 degrees.

(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. The preference for left-lighting over right-lighting is apparent.

2. Figure 2

(a) A parabola was fitted to the relevant portion of the psychometric curves collected from each subject. The lighting direction at which the minimum of the fitted parabolas occur were used to estimate the subject's mean preferred lighting direction. For Subject AW, the mean preferred lighting direction is 17 ± 4.1 degrees left of the vertical.

(b) Subjects were categorized based on which hand they used for writing. The mean preferred lighting direction of the 6 right-handed subjects is compared with that of the 6 left-handed subjects. While 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).

(c) Each subjects' handedness was evaluated using the 10-item Oldfield Inventory [10]. This questionnaire results in a score ranging from -10 to 10, with negative numbers indicating an overall preference for the left hand, and positive numbers indicating an overall preference for the right hand. A larger absolute value of the score indicates a stronger preference. Each subject's preferred lighting direction is plotted against this handedness score. Preferred lighting direction is correlated with handedness with $r=0.83$ ($p<0.01$).

3. Figure 3

    (a) Most people are right-hemisphere dominant for spatial-perceptual tasks, resulting in a processing advantage for the left visual hemifield. For our task, which may be classifield as a spatial-perceptual task, we would expect most subjects to perform better when the target appears in the left hemifield than when it appears in the right. For those who are instead left-hemisphere dominant for such tasks, targets that appear in the right visual hemifield would be easier to detect.

    (b) We subtracted a subject's score, in percent, for trials in which the target appears in the right visual hemifield from the score for trials in which the target appears in the left hemifield. Only the data for which the display duration was 180 msec or less was considered, so as to minimize the effect of eye movements. All right-handed subjects and all but two left-handed subjects performed better when the target appeared in the left visual hemifield, suggesting right-hemispheric dominance for this task. The right-hemifield preference displayed by two of the left-handers suggest a brain lateralization that is inverted with respect to the norm. This distribution is consistent with the statistics given in the literature [13].

    (c) Preferred lighting direction is plotted against our measurement of hemifield advantage. The correlation is weak ($r=0.50$, $p>0.05$).

(d) We used Minor Axis Regression [14] to determine whether hemifield advantage may be a contributing factor to preference of lighting direction. The residual effects of lighting preference left unaccounted for by the fitting to handedness (See Fig. 2c) is plotted against hemifield preference. A lack of correlation ($r=0.11$, $p>0.1$) shows that hemifield advantage does not factor into lighting preference.

4. Figure 4

   (a) We suggest that lighting preference may be the result of experience that is related to handedness. For instance, a right-hander might habitually organize his/her workspace with the light on the left. This would prevent the shadow of the right hand from falling onto the relevant areas of the workspace. An accumulation of experience in prevalently left-lit scenes may result in a preference for left-lighting.

   (b) 100, 100, and 25 paintings were randomly selected from catalogues of the Louvre, the Prado, and the Norton Simon Museum. A random number generator was used to generate page numbers. If the selected page contained more than one painting, the next successive page that contained one painting only was chosen instead. 2 naive subjects evaluated these paintings. They first categorized each as being left, right, or centrally lit, then, using a protractor, they estimated the angle of lighting direction. $77\% \pm 0.55\%$ of the paintings were classified as being lit from the left ($p < 0.05$). The histogram of the reported lighting directions shows that artists selected most often lighting directions that are between 30 and 60 degrees to the left of the vertical.

   (c) Top-left lighting was used to illuminate this figure in a Roman mosaic portrait from Aquileia (circa 320 B.C.).

   (d) Graphic design also show a preference for top-left lighting, as illustrated by this selection of icons and logos from the WWW.