encoding in visual short-term memory is delayed quite significantly, by crossmodal multitasking in the PRP paradigm.

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The oblique effect and three-dimensional shape

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The classical *oblique effect* refers to the finding that observers are faster and more accurate in discriminating the orientation of a line or edge when it is at or near vertical or horizontal than when it is at an oblique orientation (Appelle, 1972; Mach, 1861). Based on the finding that observer sensitivity to orientation of simple symmetric shapes like an ellipse or the letter “X” also exhibits an oblique effect, Li and Westheimer (1997) suggested that the effect does not arise solely from inequality of simple orientation-tuned receptors in early visual processing, but also involves later orientation processing that can encompass more complex inputs such as shape axes. In this work, we examined how the oblique effect impacts three-dimensional shapes defined by texture cues.

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Stimuli were upright and obliquely oriented convex and concave wedges (see Figure 1). The texture pattern consisted of sine-wave gratings of the same three spatial frequencies, oriented at 90, $\pm$67.5, $\pm$45, and $\pm$22.5 degrees with respect to the 3-D axis, and added in randomized phases. The shapes were projected in perspective, and presented at the correct distance and height to be viewed monocularly. In Experiment 1, we varied either the orientation (Experiment 1A) or the location (Experiment 1B) of the axis in small increments around the 90 and 45 degree diameters of the disk. All shapes presented to an observer had the same simulated depth, set at twice the minimum depth required to discriminate convex from concave at any orientation. Observers judged whether the axis was rotated clockwise or counterclockwise in relation to an on-screen reference (two small circles at the stimulus edge indicating a vertical or oblique orientation), or if the axis was shifted to the right or left of centre (i.e., the location of central peak with respect to the reference).

On average, the angular threshold for orientation discrimination around the vertical orientation was 62% lower than around the oblique orientation ($SE = 13\%$). Similarly the average distance threshold for location discrimination of the vertical shape was 53% lower than for the oblique shape ($SE = 9\%$). Thus, the results indicate that sensitivity for 3-D texture-defined shape mirrors that of the traditional oblique effect for 2-D stimuli.

Is this a 3-D effect or is it based on 2-D image properties? Li and Zaidi (2000, 2004) showed that the perception of 3-D shapes from texture cues depends critically on the visibility of orientation flows parallel to the axis of

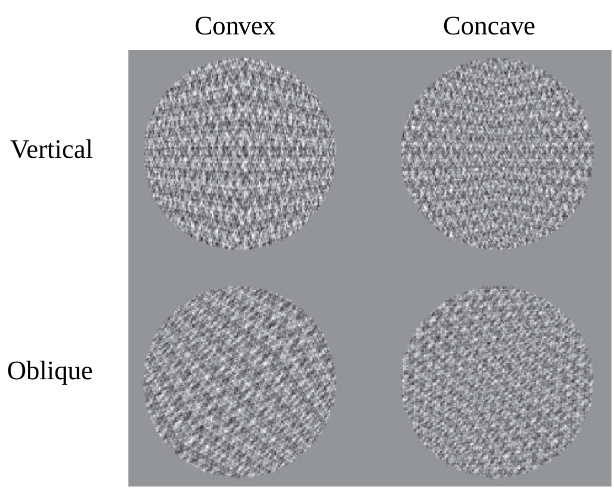

Figure 1. Demonstrates representative stimuli of both shape types (convex and concave) at the two presented orientations.

maximum curvature, i.e., orthogonal to the 3-D shape axis. These orientation flows are apparent in Figure 1. For example, in the vertical shapes, they converge from left to right for right-slanted 3-D segments, and from right to left for left-slanted 3-D segments. Figure 1 also illustrates that the orientation flows for the vertical 3-D shape vary around the horizontal axis of the image, whereas the orientation flows for the oblique shape vary around an oblique axis of the image. Therefore, before concluding that sensitivity to orientation of 3-D shapes is inherently superior for vertical than oblique orientations, we sought to determine if decreased sensitivity to 2-D oblique orientation flows weakens the percept of an oblique 3-D shape. In that case, the axis discrimination inequality could then arise from the imprecision of the weakened percept.

For this purpose, in Experiment 2, we first measured the minimum 3-D depth required to discriminate convex from concave shapes. Observers judged whether each stimulus was concave or convex, as shapes were varied in depth in a method of constant stimuli. The threshold depth for vertical shapes was 40% lower than the threshold for oblique shapes ($SE = 10\%$). This oblique effect reflects the classical 2-D oblique effect as manifested in detecting small orientation changes from linearity (Westheimer, 2003).

In Experiment 3, the orientation and location discrimination tasks of Experiment 1 were repeated except that, for each subject, 3-D shapes for each orientation were set at twice their discrimination threshold depth. The oblique shapes were thus of much greater simulated depth than the vertical shapes. We reasoned that if 3-D shapes were equated for 2-D oblique effects, differences in performance could be attributed to identification of the 3-D axis. If there is an inherent 3-D oblique effect, we would expect observers to always perform better for the vertical than the threshold-matched oblique shapes. Results from the threshold-matched experiments showed that performance for the vertical condition was no better than the oblique (it was, in fact, worse on average). The oblique effect for 3-D shapes defined by texture cues can thus be attributed entirely to early orientation processing inequalities.

CONCLUSIONS

This study shows that there exists a substantial oblique effect for discrimination of 3-D shapes defined by texture cues, but that it can be completely explained by differences in sensitivity to the different 2-D orientations in texture flows, rather than sensitivity to the orientation of the 3-D axis. An interesting ancillary finding is that observer sensitivity to sign of 3-D curvature is far superior than sensitivity to 3-D orientation or location. Subjects were able to reliably determine shape type for very shallow shapes, but increased depth was necessary to accurately judge shape orientation or location. A model of 3-D shape extraction built on template-matching to critical orientation flows could explain the discrimination of convexity from concavity despite uncertainty about other shape properties.

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Testing the relatability hypothesis: Inducer offset, not turning angle, is critical for visual interpolation

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Perceptual organization of cluttered scenes requires identification and grouping of image fragments and their perceptual completion. Despite

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