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The Perception of Curvature Can Be Selectively Disrupted in Prosopagnosia

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A brain-damaged patient with prosopagnosia and a group of age- and education-matched control subjects evaluated curved and straight versions of different sorts of stimuli in different tasks. The patient consistently required more time to encode curved than straight stimuli, relative to the control subjects. Specifically, he had a deficit when he compared curved lines that were simultaneously visible, when he compared curved lines with those previously seen, when he examined a curved shape to determine whether an X was on or off the shape, and when he read curved script. He also made more errors when he named pictures of curved objects. Implications of these findings for some types of clinical disorders and for the role of "end-stopped" cells in visual cortex are discussed.

People use many different kinds of information to recognize and identify objects. Not only do we use shape, color, and texture but we also use distinctive patterns of movement (e.g., see Farah, 1990; Kosslyn & Koenig, 1992). One of the advances of cognitive neuroscience is that it is beginning to reveal the underlying componential structure of many

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types of information processing. For example, neurons have been reported that are sensitive to wavelength, to motion, and to faces (for example, see reviews by Desimone, Schein, & Albright, 1984; Desimone & Ungerleider, 1989; Kosslyn & Koenig, 1992; Maunsell & Newsome, 1987; Perrett, Smith, Potter, Mistlin, Head, Milner, & Jeeves, 1985). In this article we provide evidence that shape itself is not encoded by a unitary system. We describe a brain-damaged patient who has a selective deficit for encoding curved lines and contours, which suggests that information about curvature is processed separately from information about straight lines and contours.

The possibility that the perception of curved contours involves different neural mechanisms than the perception of straight contours is interesting in part because distinct "curvature detectors" have never been reported in visual cortex. Whereas wavelength, motion, orientation, and other visual properties do appear to activate specific types of neurons (e.g., see Desimone *et al.*, 1984; Maunsell & Newsome, 1987), there is no evidence that curvature selectively activates neurons. Nevertheless, we see curvature. A possible hint as to the solution to this puzzle was offered by Lehky and Sejnowski (1988a,b), who report a neural network model that was trained to compute shape-from-shading. This network was given parabolic shapes and trained to classify the degree and direction of curvature of the surface. After such training, Lehky and Sejnowski examined the types of stimuli that would strongly activate the "hidden" and "output" units of the network. They found that some output units exhibited "end-stopped inhibition;" they responded to the termini of bars, and responded much less well when the bars were extended further. This is of interest because the model was not trained to detect ends of bars; it was trained to encode curvature. This finding is nonintuitive: Apparently, as the network as a whole attained the ability to compute curvature, individual units incidentally also became sensitive to the ends of bars. Neurons with similar properties have been reported in visual cortex (e.g., see Hubel & Wiesel, 1962). It seems unlikely that the brain evolved neurons that help us to encode ends of lines; there are not many such important stimuli in the natural world. Rather, it is possible that sets of such cells work together to compute curvature, just as occurred in Lehky and Sejnowski's model (for an analytic treatment of this idea, see Dobbins, Zucker, & Cynader, 1987).

Hence, we conjectured that curvature is not encoded by distinct "curvature detectors," each of which detect some portion of a curved surface. Rather, curvature might be computed only by the joint action of numerous neurons, each of which individually would not encode curvature. We hypothesized that this population of neurons may have some special property that makes them selectively vulnerable to some types of brain damage. For example, perhaps they are particularly small, are located in