Science, Vol 281, Issue 5376, 500-501 , 24 July 1998
[DOI: 10.1126/science.281.5376.500]

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NEUROBIOLOGY:

How the Brain Sees in Three Dimensions

Marcia Barinaga

When Renaissance painters solved the problem of depicting three-dimensional (3D) scenes on flat canvases, their paintings blossomed into realistic representations of the world. Our brain must solve this problem every day to reconstruct 3D views from images that fall on the 2D surface of our retinas. Researchers have long known that we use various cues to accomplish this, such as the stereoscopic effect of binocular vision and the relative sizes of objects. Now, a team at the California Institute of Technology in Pasadena has made a surprising discovery about the neurons that apparently translate distance cues for the brain.

Most neuroscientists thought that neurons sensitive to object distance would be located in the so-called "where" processing stream, a set of brain areas that receive information from the primary visual cortex and use it to compute spatial relationships that, among other things, guide movements, such as the reach of a hand toward an object. But on page 552, Caltech's John Allman and Allan Dobbins and their co-workers report finding brain neurons outside the "where" stream that register depth, as indicated by correlations between their firing rates and the absolute distances of objects.

Summary of this Article

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"This paper is going to attract a lot of interest," predicts Robert Desimone, director of intramural programs at the National Institute of Mental Health. Terrence Sejnowski, a neuroscientist at the Salk Institute in La Jolla, California, agrees, noting that it suggests that depth-sensing neurons are found throughout the visual cortex, their information combining with the 2D map that already exists in each visual cortical area to provide the areas with full 3D maps of visual space.

The Caltech team identified the depth-perception neurons by recording the activity of neurons in monkeys' brains as the animals looked at bars of light displayed on a computer screen at various distances from the monkeys. The team looked in two brain areas, the primary visual cortex and a nearby area called V4, and found that some neurons in each area respond best to light bars that produce a particular size image on the retina. Because the size of the retinal image changes with the screen's distance, that means the brain's response to any bar would also change with distance--no surprise there.

But when the researchers kept the size of the retinal image constant by varying the size of the light bar as they changed the position of the screen, they still found, Allman says, that "distance was having a very powerful modulatory effect" on some neurons. There were "farness neurons" whose responses increased as the screen moved away, "nearness neurons" whose responses grew stronger when the screen moved near, and other neurons that peaked in between.

The researchers then monitored the firing rates of these neurons as they selectively removed visual cues for distance. Some neurons stopped registering distance when one eye was covered, suggesting that they depend on binocular cues. Others worked monocularly as long as the monkey had a broad view of the room and the monitor, but lost depth perception when the monkey viewed the image through a tiny hole. And some neurons continued to register distance when both context and binocularity were removed. Allman and Dobbins think those neurons may respond to cues such as the focus of the eye, which varies with distance, or the angle of gaze, which shifts inward toward the nose as an object gets nearer.

"It is interesting that different cells appear to be tuned to different kinds of depth cues," says neuroscientist Mel Goodale, of the University of Western Ontario, in London. But perhaps the most intriguing aspect of the work, he says, is that the Caltech team found neurons sensitive to object distance, not in the "where" stream, where conventional wisdom suggested it to be, but in primary visual cortex and in V4, which is part of a second processing stream, the "what" stream, which specializes in the identity of objects. This could mean the trait may occur throughout that stream, and perhaps the whole visual cortex.

This invites researchers to "rethink the 'what' pathway" and the role distance information plays in its mission, says Sejnowski. Size is relevant to an object's identity, he says, and the "what" stream would need distance information to compute size. "In retrospect," says Desimone, "it makes perfect sense" that visual maps in the 'what' stream would be three-dimensional. "But honestly," he adds, "I was surprised."

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