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How Do Brain Cells Tell Us Where We're Going?

New findings provide a more complex profile of the brain's "internal GPS"

By Moheb Costandi on January 13, 2017

Figure: Rousettus aegyptiacus
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How do humans and other animals find their way from A to B? This apparently simple question has no easy answer. But after decades of extensive research, a picture of how the brain encodes space and enables us to navigate through it is beginning to emerge. Earlier, neuroscientists had found that the mammalian brain contains at least three different cell types, which cooperate to encode neural representations of an animal's location and movements.

But that picture has just grown far more complex. New research now points to the existence of two more types of brain cells involved in spatial navigation—and suggests previously unrecognized neural mechanisms underlying the way mammals make their way about the world.

Earlier work, performed in freely moving rodents, revealed that neurons called place cells fire when an animal is in a specific location. Another type—grid cells—activate periodically as an animal moves around. Finally, head direction cells fire when a mouse or rat moves in a particular direction. Together, these cells, which are located in and around a deep brain structure called the hippocampus, appear to encode an animal's current location within its environment by tracking the distance and direction of its movements.
This process is fine for simply moving around, but it does not explain exactly how a traveler gets to a specific destination. The question of how the brain encodes the endpoint of a journey has remained unanswered. To investigate this, Ayelet Sarel of the Weismann Institute of Science in Israel and her

colleagues trained three Egyptian fruit bats to fly in complicated paths and then land at a specific location where they could eat and rest. The researchers recorded the activity of a total of 309 hippocampal neurons with a wireless electrode array. About a third of these neurons exhibited the characteristics of place cells, each of them firing only when the bat was in a specific area of the large flight room. But the researchers also identified 58 cells that fired only when the bats were flying directly toward the landing site.
“We have discovered a totally new kind of neuron, which we are calling 'goal-direction cells',” says Nachum Ulanovsky, senior author of the study, published this week in the journal *Science*. The findings, he adds, “fill a critical gap in our understanding of the neural basis of navigation” by explaining how the brain encodes navigational goals

The new cells, it turns out, continued to fire when the landing site was hidden from the bats' view by a curtain. “The bats knew where the goal was, but could not echolocate or see the goal behind the curtain, but the goal-direction neurons still represented the hidden goal. This means that the representation of goals in the bat hippocampus was not merely sensory-based, but was memory-based.”

Neuroscientist Hugo Spiers, who studies the cellular basis of spatial navigation at University College London, says the findings are “hugely important”—but he does not think goal-direction neurons are a new cell type. “To me the results show that place cells are capable of more diverse information processing than previously thought,” he says.

Nevertheless, the new findings echo the results of a brain scanning study published by Spiers and his colleagues in 2014. It showed that the human hippocampus contains a flexible guidance system that encodes both the distance to the goal as the crow flies—something like a homing signal—and the actual route that has to be taken to reach it. “That was quite unexpected,” Spiers says. “But this paper now validates it at the cellular level.” The findings could also explain why rats with damage to the hippocampus have difficulty remembering the location of a submerged platform within a water maze. In another series of experiments, Sarel and her colleagues identified another subpopulation of hippocampal neurons that appear to calculate and encode the distance to the goal. These “goal-distance” cells became highly active only when the bats came within 2 meters of the landing site.
In a separate study, just published in *Nature Neuroscience*, Jacob Olson of the University of California, San Diego and his colleagues recorded neuronal activity in the hippocampus of rats while the animals ran along six interconnected routes resembling a city grid, or foraged around an open space.

The scientists found that 47 of the 542 cells whose activity they recorded were strongly tuned to a specific axis of travel, firing only when the rats moved in either direction along a single axis. For example, some of these neurons were selectively activated when the rats moved from north to south, and also when they moved south to north, but not when they ran in either direction along the east-west axis. Others were activated in response to movements along other lines of travel—but again, only in orientations that were 180 degrees apart.

Olson and his colleagues argue that these “axis-tuned” neurons are distinct from head direction cells, because they only fired when the rats moved along specific paths—and fell silent while the rats foraged around the open space. Head direction cells, by contrast, fire when rats move through open spaces in a specific direction. But another recent paper provides evidence that head direction cells can encode opposite directions, so axis-tuned neurons may in fact be head direction cells after all, albeit ones that are performing a previously unknown function.

All of this makes the “brain’s GPS” even more complex than previously thought. The new work from Olson suggests that the hippocampus represents orientation by encoding the axes of travel, and these mental representations may enable us to stay on the right track despite having to navigate obstacles such as roadblocks. The bat study further suggests that the hippocampus not only encodes location by tracking the distance and direction movements, but also encodes a representation of both the direction and distance to the destination. The brain’s navigational system would thus have a “homing signal,” and also appears to be endowed with its own goal-finding neurons

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