Brain's compass relies on geometric relationships, say researchers (w/ Video)

October 15 2014, by Evan Lerner

Each of the virtual museums in the study was visually distinct, but had the same layout and geometry.

The brain has a complex system for keeping track of which direction you are facing as you move about; remembering how to get from one place to another would otherwise be impossible. Researchers from the University of Pennsylvania have now shown how the brain anchors this mental compass.

Their findings provide a neurological basis for something that psychologists have long observed about navigational behavior: people use geometrical relationships to orient themselves.

The research, which is related to the work that won this year's Nobel Prize in Physiology or Medicine, adds new dimensions to our understanding of spatial memory and how it helps us to build memories of events.

The study was led by Russell Epstein, a professor of psychology in Penn's School of Arts & Sciences, and Steven Marchette, a postdoctoral fellow in Epstein's lab. Also contributing to the study were lab members Lindsay Vass, a graduate student, and Jack Ryan, a research specialist.

It was published in *Nature Neuroscience*.

"Imagine coming out of a subway stop," said Marchette. "You know exactly where you are in the world, but you still have the experience of looking around to figure out which way you are facing. You might think, 'I'm looking at city hall, so I must be facing east.' It takes a second before it clicks.

"We're interested in how people are able to reset their sense of direction in the world and what cues they rely upon in the environment to do that."

To test how the brain makes these inferences, the researchers designed an experiment in which they introduced participants to a virtual environment, a set of four museums in a park, and had the participants memorize the location of the everyday objects on display in those museums. They then scanned their brains while asking them to recall the spatial relationships between those objects, such as whether the bicycle was to the left or the right of the cake.

In the scans, using a technique that measures blood flow to different regions of the brain known as fMRI, the researchers focused on a region known as the retrosplenial complex. People who have severe injuries to this region are able to recognize landmarks in their environments but are unable to recall how to get from one to another, suggesting that it plays a specific role in the type of memory used in navigation and orientation.

"The retrosplenial complex is very much underexplored," Epstein said. "While we don't have the ability to go in and look at individual neurons, like O'Keefe and the Mosers did in their Nobel Prize-winning work, one of the nice things about fMRI is that we didn't have to decide beforehand which areas of the brain to record from."

There are three ways the retrosplenial complex could conceivably encode this type of information and serve as part of a mental compass.

One way would be a "global" system, in which the brain tracks the absolute direction one is facing regardless of visual cues in the environment. In fact, there is good evidence that such a system exists in the brain, but the Penn team doubted that the retrosplenial complex was the central component of it.

An "idiosyncratic" system, in which the brain keeps tracks of direction for each environment independently, was another possibility. In such a system, remembering that your desk is on the north wall of your office would involve recalling the room itself and picking out the relevant features.

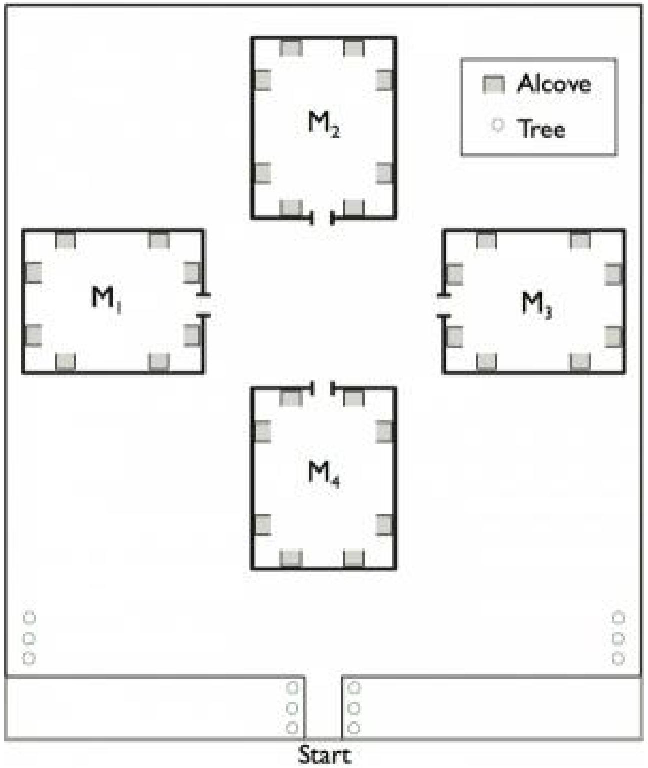
Finally, they considered a "geometric" system that is based on more generalized relationships between features in an environment. There, remembering that your desk is on the north wall of your office would involve recalling the relationship between the desk and the door—say, the desk is on the left when I enter the room—without having to specifically recall the room itself.

The architecture of the team's virtual park was critical for being able to distinguish which of these three types of systems participants were using to orient themselves in regards to the objects.

The park's four museums were laid out in a cloverleaf pattern around a central plaza, which itself could only be approached from the south. Each museum had a single door, all of which faced the center of the plaza. Each museum was visually distinct but all were identical in layout: a single room containing eight unique objects, two on each wall. The objects were contained in niches, such that participants could only see them from straight ahead.

"We designed it this way so that it was clear to the participants that each museum's back wall pointed in one of the cardinal directions," said Marchette. "And by placing the objects in the niches, we ensured that they could only see them when they were looking due north, south, east or west."

After being allowed to freely roam around the virtual environment, participants were tested about the locations of the objects. They were asked to return to the lab a day or two later, where they were given the opportunity to refresh their memories about the layout of the objects before entering the MRI scanner. There, they were shown words representing a pair of objects that were found in one of the museums and asked whether the second object was to the left or the right of the first.



The overall design of the park meant that each museum's back wall was pointed in a different cardinal direction.

The researchers used half of a participant's responses to calibrate their measurement of that participant's retrosplenial complex and then compared the activation patterns they saw there to responses in that participant's other half.

"If the retrosplenial complex supported a global system," Marchette said, "then it shouldn't matter whether people are imagining facing the back wall or the left wall; if you're looking north in one museum and north in the other, the activation patterns should be similar. As we expected, that doesn't happen.

"Likewise, for an idiosyncratic system, we would expect that remembering the back walls of two different museums would produce dissimilar patterns, since you would be remembering the room itself. That doesn't happen either."

Instead, the patterns look similar when participants imagined looking at objects that have the same geometric relationship to the surrounding room, regardless of the "true" direction the participant was facing. For example, remembering objects on the back walls of two different museums produced similar activation patterns, even though the back wall is north in one museum and east in the other.

"We can even reconstruct the location the participant is remembering based on those similarities," Epstein said. "Once we know what we are looking for based on the first half of a participant's responses, we can estimate the location of a given view entirely from the fMRI data, and they are reasonably close to where the views actually are. That's a pretty cool result. It's as if we can read out a 'floor plan' of the museums from each person's brain. And because the museums are geometrically identical, the retrosplenial cortex uses the same 'floor plan' for all of them"

The team's research provides a more complete picture of what is happening in the brain when people navigate from one place to another.

"Psychologists have long surmised that geometry is important for this kind of memory," Epstein said, "but this is beginning to show the neurological basis for it. We hope this opens the door for a deeper look at this region of the brain."

The research was supported by the National Institutes of Health and the National Science Foundation.

More information: "Anchoring the neural compass: coding of local spatial reference frames in human medial parietal lobe." *Nature*

Neuroscience (2014) DOI: 10.1038/nn.3834

Provided by University of Pennsylvania