The brain science of tiny birds with amazing memories

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Black-capped chickadees have an incredible ability to remember where they've cached food in their environments. They are also small, fast, and able to fly.

So how exactly can a neuroscientist interested in their memories conduct studies on their brains? Dmitriy Aronov, Ph.D., a neuroscientist at the Zuckerman Mind Brain Behavior Institute at Columbia University, visited Duke recently to talk about chickadee memory and the practicalities of studying wild birds in a lab.

Black-capped chickadees, like many other bird species, often store food in hiding places like tree crevices. This behavior is called caching, and the ability to hide food in dozens of places and then relocate it later represents an impressive feat of memory. "The bird doesn't get to experience this event happening over and over again," Aronov says. It must instantly form a memory while caching the food, a process that relies on episodic memory. Episodic memory involves recalling specific experiences from the past, and black-capped chickadees are "champions of episodic memory."

They have to remember not just the location of cached food but also other features of each hiding place, and they often have only moments to memorize all that information before moving on. According to Aronov, individual birds are known to cache up to 5,000 food items per day! But how do they do it?

Chickadees, like humans, rely on the brain's hippocampus to form episodic memories, and the hippocampus is considerably bigger in food-caching birds than in birds of similar size that aren't known to cache food. Aronov and his team wanted to investigate how neural activity represents the formation and retrieval of episodic memories in black-capped chickadees.

Step one: find a creative way to study food-caching in a laboratory setting. Marissa Applegate, a graduate student in Aronov's lab, helped design a caching arena "optimized for chickadee ergonomics," Aronov says. The arenas included crevices covered by opaque flaps that the chickadees could open with their toes or beaks and cache food in. The chickadees didn't need any special training to cache food in the arena, Aronov says. They naturally explore crevices and cache surplus food inside.

Once a flap closed over a piece of cached food (sunflower seeds), the bird could no longer see inside—but the floor of each crevice was transparent, and a camera aimed at the arena from below allowed scientists to see exactly where birds were caching seeds. Meanwhile, a microdrive attached to the birds' tiny heads and connected to a cable enabled live monitoring of their brain activity, down to the scale of individual neurons.

Through a series of experiments, Aronov and his team discovered that "the act of caching has a profound effect on hippocampal activity," with some neurons becoming more active during caching and others being suppressed. About 35% percent of neurons that are active during caching are consistently either enhanced or suppressed during caching—regardless of which site a bird is visiting. But the remaining 65% of variance is site-specific: "every cache is represented by a unique pattern of this excess activity in the hippocampus," a pattern that holds true even when two sites are just five centimeters apart—close enough for a bird to reach from one to another.

Chickadees could hide food in any of the sites for retrieval at a future time. The delay period between the caching phase (when chickadees could store surplus food in the cache sites) and the retrieval phase (when chickadees were placed back in the arena and allowed to retrieve food they had cached earlier) ranged from a few minutes to an hour. When a bird returned to a cache to retrieve food, the same barcode-like pattern of neural activity reappeared in its brain. That pattern "represents a particular experience in a bird's life" that is then "reactivated" at a later time.

Aronov said that in addition to caching and retrieving food, birds often "check" caching sites, both before and after storing food in them. Of course, as soon as a bird opens one of the flaps, it can see whether or not there's food inside. Therefore, measuring a bird's brain activity after it has lifted a flap makes it impossible to tell whether any changes in brain activity when it checks a site are due to memory or just vision. So the researchers looked specifically at neural activity when the bird first touched a flap—before it had time to open it and see what was inside. That brain activity, as it turns out, starts changing hundreds of milliseconds before the bird can actually see the food, a finding that provides strong evidence for memory.

What about when the chickadees checked empty caches? Were they making a memory error, or were they intentionally checking an empty site—even knowing it was empty—for their own mysterious reasons? On a trial-by-trial basis, it's impossible to know, but "statistically, we have to invoke memory in order to explain their behavior," he said.

A single moment of caching, Aronov says, is enough to create a new, lasting, and site-specific pattern. The implications of that are amazing. Chickadees can store thousands of moments across thousands of locations and then retrieve those memories at will whenever they need extra food.

It's still unclear how the retrieval process works. From Aronov's study, we know that chickadees can reactivate site-specific brain activity patterns when they see one of their caches (even when they haven't yet seen what's inside). But let's say a chickadee has stored a seed in the bark of a particular tree. Does it need to see that tree in order to remember its cache site there? Or can it be going about its business on the other side of the forest, suddenly decide that it's hungry for a seed, and then visualize the location of its nearest cache without actually being there? Scientists aren't sure.

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