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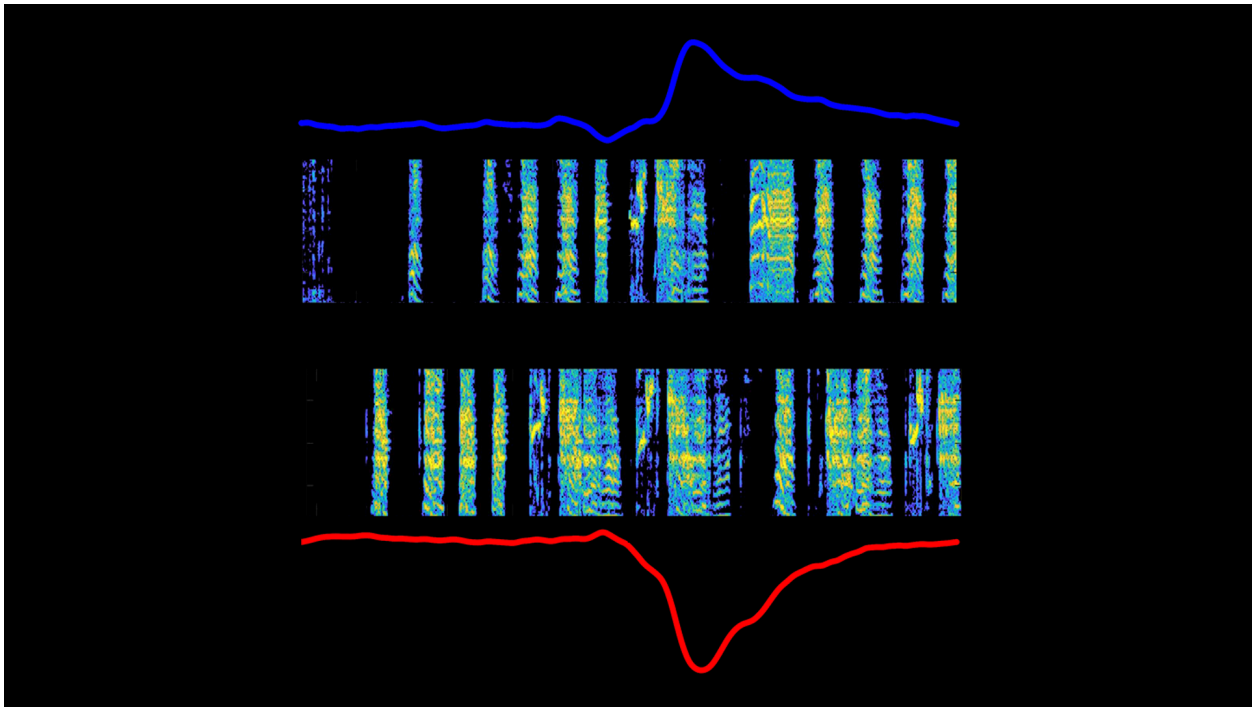
Songbirds Highlight Dopamine's Role in Learning

Researchers studying zebra finches see, for the first time, how dopamine guides trial and error learning.



A dopamine increase (blue graph) during singing that is similar to the adult version of a young bird's song (top spectrogram), and a dopamine decrease (red graph) during singing that is less similar (bottom spectrogram). (Credit: Gadagkar Lab | Columbia's Zuckerman Institute).

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NEW YORK, NY — Many everyday skills, such as speech, are not innate. They are learned through trial and error. Now, by analyzing young songbirds rehearsing their fathers' songs, researchers at Columbia's Zuckerman Institute have for the first time witnessed the role that the brain's reward machinery plays as the brain naturally learns over time through practice.

The scientists detailed their findings in a paper published online today in *Nature*.

"Understanding the process of learning by trial and error is key to understanding how we acquire many of our most important skills," said Jonathan Kasdin, co-lead author of the study and a graduate student in the lab of Vikram Gadagkar, PhD. "And understanding how learning works in the healthy brain is critical to understanding how learning goes wrong in various brain disorders."

The new findings bring to mind an anecdote for Dr. Gadagkar, senior author on the study and a principal investigator at Columbia's Zuckerman Institute. It starts with a pedestrian in New York asking a musician, "How do you get to Carnegie Hall?" The punchline is the musician replying, "Practice."

"We wanted to know how you get better with practice. When you get what you're practicing right, how does your brain know that you're correct?" said Dr. Gadagkar, who is also an assistant professor of neuroscience at Columbia's Vagelos College of Physicians and Surgeons.

Decades of research suggested that dopamine, a brain molecule linked to reward-motivated behavior, plays an essential role in this process of trial and error. The idea is that dopamine serves as this evaluation signal. When you get something right, dopamine should go up. When you get it wrong, dopamine should go down.

However, prior experiments that suggested a link between dopamine and learning often involved artificial situations in which lab animals were given a reward to learn a simple task. These scenarios might not reflect the typical process by which the brain learns natural behaviors.

"When it comes to most of the complex skills we learn, we don't learn them for external rewards like food or juice," Dr. Gadagkar said. "We have an internal goal we're trying to achieve."

In this study, researchers studied an animal with an innate drive to acquire a particular skill: male zebra finches, which need to sing well for courtship. These males learn to sing by memorizing and rehearsing their fathers's songs.

"Zebra finches are one of the few organisms we know of that acquire vocal abilities in a similar fashion to humans," said study co-author Nathan Nadler, a graduate student in the Gadagkar lab. "They present us with a unique opportunity to study natural learning in action."

The researchers recorded six young zebra finches for 40 days, analyzing how their songs changed with practice over time. "This is a lot of data — thousands and thousands of renditions of the syllables in songs per day," Nadler said.

With the help of an artificial intelligence system, over the course of six to seven months, the scientists identified all these syllables and checked whether each was closer to the final adult version than the syllables that had preceded it. They next wanted to see how these changes aligned with dopamine levels in the zebra finch.

The scientists detected how much dopamine was released in a song-linked part of their brains called Area X over the course of weeks. They found dopamine guided trial and error learning in these birds. Renditions of syllables that were more similar to adult versions led to a surge of dopamine, and renditions that were less similar suppressed dopamine production. "We're eavesdropping on dopamine's role in a completely natural learning process," Kasdin said.

Research that yields insights on dopamine "could also shed light on dopamine-related disorders such as Parkinson's disease, drug addiction and schizophrenia," Kasdin added.

This fundamental research into the brain may ultimately benefit the area of artificial intelligence. A major problem in the field is how absorbing a new bit of information can lead an AI system to catastrophically forget what it learned beforehand.

“Natural brains are capable of continually accumulating new knowledge over the course of an entire lifetime," said study co-author Kimberly Stachenfeld, PhD, an adjunct assistant professor of neuroscience at the Zuckerman Institute’s Center for Theoretical Neuroscience and a senior research scientist at Google DeepMind. “This new research could inform how we design AI.”

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The paper, "Natural behavior is learned through dopamine-mediated reinforcement," was published in *Nature* on March 12, 2025.

The full list of authors includes Jonathan Kasdin, Alison Duffy, Nathan Nadler, Arnav Raha, Adrienne L. Fairhall, Kimberly L. Stachenfeld and Vikram Gadagkar.

The authors report no conflicts of interest.