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Brain rhythms are key to learning

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Neuroscientists have long known of the existence of brain waves — rhythmic fluctuations of electrical activity believed to reflect the brain's state. For example, during rest, brain activity slows down to an alpha rhythm of about eight to 10 hertz, or cycles per second.

It has been unclear what role, if any, these waves play in cognitive functions such as learning and memory. But now, a study from MIT neuroscientists shows that a switch between two of these rhythms is critical for learning habitual behavior.

In a paper appearing this week in the *Proceedings of the National Academy of Sciences (PNAS)*, the researchers report that as rats learn to run a maze, activity in a brain region that controls habit formation shifts from a fast, chaotic rhythm to a slower, more synchronized pace. That switch, which occurs just as the rats start to master the maze, likely signals that a habit has been formed, says MIT Institute Professor Ann Graybiel, senior author of the *PNAS* paper.

This is a major clue to how the brain reorganizes itself during learning, says Graybiel, who is also a principal investigator at the McGovern Institute for Brain Research at MIT.

Rhythms in the brain

Several brain waves of different frequencies have been observed in humans and other animals. This paper focused on beta waves, which range from 15 to 28 hertz, and high gamma waves, which range from 70 to 90 hertz. The beta band is associated with a lack of movement, and gamma with highly attentive states.

Graybiel and graduate student Mark Howe, lead author of the paper, set out to see if they could link these rhythms with the changes in brain state that accompany learning.

Graybiel's lab has previously shown that patterns of electrical activity in a part of the brain known as the basal ganglia are critical for habit formation. Habits begin when you gain some benefit for taking a particular action, but eventually the behavior becomes ingrained and you do it even when you no longer get the reward. In extreme cases, this could mean continuing to scratch part of the body even after it stops itching, for example.

In this study, Howe looked at brain rhythms in a region at the very bottom of the basal ganglia, known as the ventral striatum. This area is necessary for responding to pain or pleasure, and is also highly involved in addiction.

Brain activity was measured as rats ran along a T-shaped maze, in which they had to learn to turn left or right in response to a sound. If they made the correct turn and reached the end of the maze, they received a reward: chocolate milk.

In the first few runs, while the rats were still learning the maze, the researchers saw bursts of ventral striatum activity in the gamma frequency range shortly before the rats finished the maze. This activity was dispersed throughout the ventral striatum: Cells synchronized with the rhythm at different times, in a fairly uncoordinated fashion.

When the rats began to catch on to how to earn the reward, the gamma activity faded away and was replaced with short bursts of activity in the beta band, a lower frequency, just after they finished the maze. The activity also became much more coordinated throughout the entire ventral striatum.

“Although there has been a lot of work on studying brain oscillations, there’s really no work looking at how oscillations in different frequency bands impact different parts of the learning process, and that’s what this paper does,” says Michael Frank, an associate professor of cognitive, linguistic and psychological sciences at Brown University who was not involved with the work.

Reinforcing habits

To get a deeper view of what was happening during this frequency shift, the researchers also measured activity from single neurons in the ventral striatum, and found that activity in two groups of neurons coordinated with the oscillations. Output neurons, which control the ventral striatum’s communication with the rest of the brain, spiked during the peaks of both gamma and beta oscillations. Another type, which inhibits the output neurons, spiked at the troughs of the oscillations.

“Whenever you have a strong rhythm, these two populations of neurons oscillate in opposite directions,” Howe says.

This finding suggests that while the rats are learning a new behavior, the high-frequency activity in the output neurons of the ventral striatum sends messages to the rest of the brain directing it to learn a new behavior, reinforced by the chocolate reward. Then, once the behavior is learned and a habit is formed, those messages are no longer needed, and are shut off by inhibitory neurons during the beta oscillations.

“As the rats were learning, that reinforcement signal goes away, because you really don’t need it,” Graybiel says. This is beneficial to the brain because once that habit is formed, “what you want to do is free up that bit of brain so you can do something else — form a new habit or think a great thought,” she says.

The researchers, including Howe, Graybiel, and other lab members Hisham Attalah, Dan Gibson and Andrew McCool, are now planning to investigate whether habit formation is interrupted if they alter the brain rhythms in the ventral striatum. They also want to identify more specifically the neurons that are involved. Identifying and controlling such neurons might offer a new way to help combat addiction — an extreme form of habitual behavior.

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