Distinct brain rhythms, regions help us reason about categories

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New research suggests that our brains employ different rhythms in different regions to recognize why each set of objects belong in the same category. The apples have a direct visual resemblance, but the screwdriver and drill bear a more abstract resemblance. Credit: Picower Institute for Learning and Memory/Pixabay

We categorize pretty much everything we see, and remarkably, we often achieve that feat whether the items look patently similar - like Fuji and McIntosh apples - or they share a more abstract similarity - like a screwdriver and a drill. A new study at MIT's Picower Institute for Learning and Memory explains how.

"Categorization is a fundamental cognitive mechanism," says Earl Miller, Picower Professor in MIT's Picower Institute for Learning and Memory and the Department of Brain and Cognitive Sciences. "It's the way the brain learns to generalize. If your brain didn't have this ability, you'd be overwhelmed by details of the sensory world. Every time you experienced something, if it was in different lighting or at a different angle, your brain would treat it as a brand new thing."

In the new paper in *Neuron*, Miller's lab, led by postdoctoral associate Andreas Wutz and graduate student Roman Loonis, shows that the ability to categorize based on straightforward resemblance or on abstract similarity arises from the brain's use of distinct rhythms, at distinct times, in distinct parts of the prefrontal cortex (PFC). Specifically when animals needed to match images that bore close resemblance, an increase in the power of high-frequency gamma rhythms in the ventral lateral PFC did the trick. When they had to match images based on a more abstract similarity, that depended on a later surge of lower frequency beta rhythms in the dorsal lateral PFC.

Miller says those findings suggest a model of how the brain achieves category abstractions. It shows that meeting the challenge of abstraction is not merely a matter of thinking the same way but harder. Instead, a different mechanism in a different part of the brain takes over when simple, sensory comparison is not enough for us to judge whether two things belong to the same category.

By precisely describing the frequencies, locations and the timing of rhythms that govern categorization, the findings, if replicated in humans, could prove helpful in research to understand an aspect of some autism spectrum disorders, Miller says. In ASD categorization can be challenging for patients, especially when objects or faces appear atypical. Potentially, clinicians could measure rhythms to determine whether patients who struggle to recognize abstract similarities are employing the mechanisms differently.

Connecting the dots

To conduct the study, Wutz, Loonis, Miller and co-authors measured brain rhythms in key areas of the PFC associated with categorization as animals played some on-screen games. In each round, animals would see a pattern of dots - a sample from one of two different categories of configurations. Then the sample would disappear and after a delay, two choices of dot designs would appear. The subject's task was to fix its gaze on whichever one belonged to the same category as the sample. Sometimes the right answer was evident by sheer visual resemblance, but sometimes the similarity was based on a more abstract criterion the animal could infer over successive trials. The experimenters precisely quantified the degree of abstraction based on geometric calculations of the distortion of the dot pattern compared to a category archetype.

"This study was very well defined" Wutz says. "It provided a mathematically correct way to distinguish something so vague as abstraction. It's a judgement call very often, but not with the paradigm that we used."

Gamma in the ventral PFC always peaked in power when the sample appeared, as if the animals were making a "does this sample look like category A or not?" assessment as soon as they were shown it. Beta power in the dorsal PFC peaked during the subsequent delay period when abstraction was required, as if the animals realized that there wasn't enough visual resemblance and deeper thought would be necessary to make the upcoming choice.

Notably, the data was rich enough to reveal several nuances about what was going on. Category information and rhythm power were so closely associated, for example, that the researchers measured greater rhythm power in advance of correct category judgements than in advance of incorrect ones. They also found that the role of beta power was not based on the difficulty of choosing a category (i.e. how similar the choices were) but specifically on whether the correct answer had a more abstract or literal similarity to the sample.

By analyzing the rhythm measurements, the researchers could even determine how the animals were approaching the categorization task. They weren't judging whether a sample belonged to one category or the other, Wutz says. Instead they were judging whether they belonged to a preferred category or not.

"That preference was reflected in the brain rhythms," Wutz says. "We saw the strongest effects for each animal's preferred category."

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