Brain waves found to travel in one direction when memories are made and the opposite when recalled

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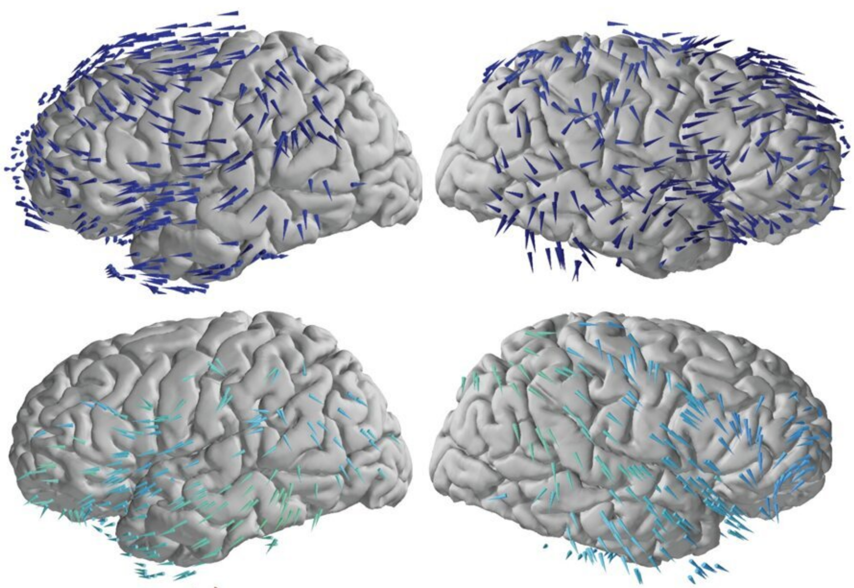

Traveling wave propagation directions in the memory task reveal how the brain quickly coordinates activity and shares information across multiple regions. Credit: Honghui Zhang

In the space of just a few seconds, a person walking down a city block might check their phone, yawn, worry about making rent, and adjust their path to avoid a puddle. The smell from a food cart could suddenly conjure a memory from childhood, or they could notice a rat eating a slice of pizza and store the image as a new memory.

For most people, shifting through behaviors quickly and seamlessly is a mundane part of everyday life.

For neuroscientists, it's one of the brain's most remarkable capabilities. That's because different activities require the brain to use different combinations of its many regions and billions of neurons. How it manages to do this so rapidly has been an open question for decades.

In a paper published March 8 in *Nature Human Behaviour*, a team of researchers, led by Joshua Jacobs, associate professor of biomedical engineering at Columbia Engineering, shed new light on this question. By carefully monitoring neural activity of people who were recalling memories or forming new ones, the researchers managed to detect how a newly appreciated type of brainwave—traveling waves—influences the storage and retrieval of memories.

"Broadly, we found that waves tended to move from the back of the brain to the front while patients were putting something into their memory," said the paper's co-author Uma R. Mohan, a postdoctoral researcher at NIH and former postdoctoral researcher in the Electrophysiology, Memory, and Navigation Laboratory at Columbia Engineering.

"When patients were later searching to recall the same information, those waves moved in the opposite direction, from the front towards the back of the brain," she said.

In the brains of some of the study's 93 participants, waves traveled in other directions.

"There was a lot of diversity across patients, so we implemented a framework based on the direction an individual's oscillations 'preferred' to travel," Mohan said.

The researchers say these findings advance fundamental neuroscience research and point toward diagnostic and therapeutic approaches for memory-related disorders.

"We think the work may lead to new approaches for interfacing with the brain. By measuring the direction that a person's brain waves move, we may be able to predict their behavior," Jacobs said.

Brain waves are patterns of electrical oscillations that reflect the state of hundreds or thousands of individual neurons at a particular moment. One major question, which remains unsettled, is whether brain waves drive activity or simply occur as a byproduct of neural activity that was already happening. Researchers who study brain waves have tended to treat them as a stationary phenomenon that occurs in a particular region, noting when oscillations in multiple regions seem synchronized.

In this study, Mohan and her colleagues contribute to a growing understanding of these oscillations differently, as "traveling waves" that spread across the brain's cortex, the outermost layer that supports higher cognitive processing. Mohan compares the traveling waves to the ripples that would spread outward after a pebble was thrown into a pond.

"We're looking at neural oscillations not as independent stationary things but as things that are constantly and spontaneously moving across the brain in a dynamic way," Mohan said.

This relatively new way of understanding brain waves is an exciting step in neuroscience because it offers a pathway to explaining how the brain quickly coordinates activity and shares information across multiple regions.

The study drew on data from participants who were being treated for drug-resistant epilepsy at hospitals across the United States. The experiments occurred while the participants had grids or strips of electrodes temporarily implanted on the surface of the brain, beneath the skull, to determine where the patients' seizures arise. For the researchers, these electrodes offer the chance to perform experiments that wouldn't otherwise be feasible.

"It's a rare opportunity to be able to see what's going on directly from the brain while the participants are engaged in different cognitive behaviors," Mohan said.

During the experiments, researchers recorded the participants' brain activity while they performed tasks that required memorizing and recalling lists of words or letters.

After the experiments, the researchers analyzed the brain activity from each participant in the context of what they were doing in the memory task and how well they performed.

"I implemented a method to label waves traveling in one direction as basically 'good for putting something into memory." Then we could see how the direction switched over the course of the task," Mohan said. This method builds on previous research from the Jacobs lab by expanding the mathematical framework used to make sense of the vast quantities of data these experiments produced.

"The waves tended to go in the participant's encoding direction when that participant was putting something into memory and in the opposite direction right before they recalled the word," she said. " Overall, this new work links traveling waves to behavior by demonstrating that traveling waves propagate in different directions across the cortex for separate memory processes."

The data also showed that participants tended to perform the memory task more accurately when the traveling waves were moving in the appropriate direction for memory storage and recall.

"These findings shed light on the mechanisms that underlie memory processing. More broadly, they help us better understand how the brain supports a wide range of behaviors that involve precisely coordinated interactions between brain regions," Mohan said.

Potential impact and future directions

As traveling waves are increasingly well understood, they could be the basis for a new class of diagnostic tools that recognize abnormal patterns in brain activity.

There is also significant therapeutic potential.

"If someone's waves are moving in the wrong direction when they're about to try to remember something, that might put them in a poor memory state," Mohan explained. "If you could apply stimulation in the right way, you could maybe push those waves to move in a different direction, bringing about a fundamentally different memory state."

Advances in understanding traveling waves offer significant potential for human-computer interaction.

In terms of both research and application, Mohan notes that memory is just the starting point.

"I am interested in how characteristics of cortical traveling waves change to support a wide range of cognitive functions, including attention and associative memory," she said.

"The direction of traveling wave propagation may tell us where information is moving across the brain at each moment, showing us how different parts of the brain transfer information during behavior," Jacobs said.

More information: The direction of theta and alpha travelling waves modulates human memory processing, *Nature Human Behaviour* (2024). DOI: 10.1038/s41562-024-01838-3.
www.nature.com/articles/s41562-024-01838-3

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