'Traveling' nature of brain waves may help working memory function

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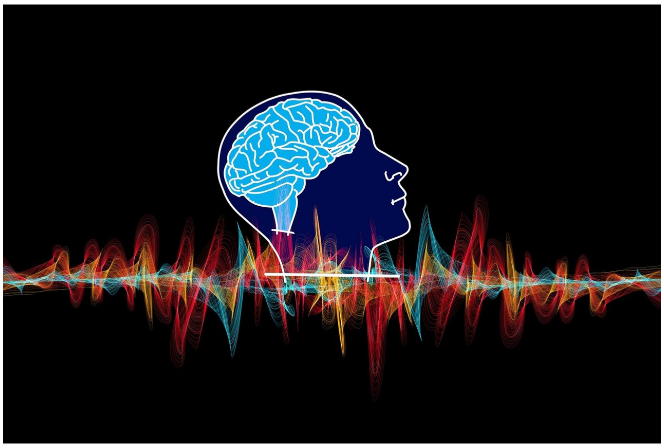

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After more than a century of study, the significance of brain waves—the coordinated, rhythmic electrical activity of groups of brain cells—is still not fully known. An especially underappreciated aspect of the phenomenon is that waves spatially propagate, or "travel," through brain regions over time. A new study by researchers at The Picower Institute for Learning and Memory at MIT measured how waves travel in the brain's prefrontal cortex during working memory to investigate the functional advantages that this apparent motion may produce.

"Most of the neuroscience literature involves lumping electrodes together and analyzing for time variations," like changes in power at a particular frequency, said lead author Sayak Bhattacharya, a postdoctoral Picower Fellow in lab of senior author and Picower Professor Earl Miller. "It is important to appreciate that there are spatial subtleties, too. Brain oscillations move across the cortex in the form of traveling waves. These waves are similar to stadium waves where nothing actually moves, but sequential on-and-off of neighbors give it the appearance of a traveling wave."

In other words, while the neurons under an eavesdropping electrode might burst with activity at a particular frequency, it's also true that just before they perked up, neurons nearby in some direction had done so and very soon some other neurons on the opposite side will follow suit. Bhattacharya, Miller and their co-authors conducted the study published in *PLOS Computational Biology* to learn what that might mean for the vital brain function of working memory, where we must hold new information in mind to put it to use. It's how we remember the directions to the bathroom we were just told, or today's specials at the restaurant.

To do this, they cracked open some old data they had recorded from animals while they played a simple working memory game. The animals would see a single image on a screen and after a brief pause they would then see it along with a few other images. To get a little reward, they had to fix their gaze on the original image. It's a simple game but the little stages (look at the new image, remember it during the pause, recognize and stare at it in the group) provide distinct moments of perception, memory and then putting them to use. By combing over electrode recordings made in the animals during sessions of the game, Bhattacharya could analyze whether the recorded waves were traveling at each moment and how.

What he found was that there were many distinct waves at various frequency bands washing back and forth across the electrodes in various directions. Careful calculations revealed that the waves were actually rotating in circle-like patterns around central anatomical points within the prefrontal cortex (again, like the wave in a football stadium rotates around the field of play). That's notable because in other traveling wave studies usually the waves are planar, meaning they just move across from one place to another rather than going around as if on a race track.

Moreover, Miller said, the waves changed direction in particularly important ways. When the animals were idle, different directions of motion (e.g. clockwise vs. counterclockwise) were pretty much evenly mixed but at different times during the task, specific directions became significantly more prominent in various frequency bands. This was especially true among beta frequency waves, which became much more uniform in their direction only while the animals played the game. Other frequencies became more weighted toward particular directions during specific phases of the game (like when the first image was presented). These changes suggested that the directions matter to how the brain organizes its response to the task.

"The waves are generally traveling but the brain can change how the waves travel to suit different cognitive functions," Miller said.

Indeed there are several ways that rotating traveling waves could aid a task like working memory, he noted. For one example, a key requirement of working memory is being able to keep information at the forefront of conscious thought while it's needed. A stationary wave (one in which all the neurons involved were "on" or "off" in unison) would mean that information could be unavailable when activity was off across the whole group. With a rotating traveling wave there is always activity somewhere around the circle—just like how in a stadium of fans doing "the wave," the next section stands up as soon as the preceding one sits down.

For another example, rotating waves could provide neurons with a regularly recurring stimulation with precise timing, Miller continued. That may promote strengthening connections within these coordinated groups via a phenomenon called spike-timing dependent plasticity in which the timing of input to a neuron influences how strongly it will connect with the partner that delivered the signal. The researchers also speculate that timing might also matter in another prefrontal cortex function: making predictions.

More work needs to be done to know with certainty how traveling waves aid working memory. Bhattacharya said new insight could come from investigating how they look when working memory doesn't work.

"This working memory task was pretty easy and our animals did them without much error," he said. "We want to study more complicated tasks—maybe multi-item working memory—and check if the traveling waves are disrupted somehow during the error trials. This would lead to interesting insight about the computational abilities of these waves."

More information: Sayak Bhattacharya et al, Traveling waves in the prefrontal cortex during working memory, *PLOS Computational Biology* (2022). DOI: 10.1371/journal.pcbi.1009827

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