

Neuroscientists find evidence of an internal brain rhythm that orchestrates memory



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A new study sheds light on how our brains rhythmically organize memories at the level of individual nerve cells. Researchers in Germany have found that single neurons in the human medial temporal lobe tend to synchronize their activity with slow brain waves, particularly during memory formation and retrieval. These patterns, known as theta-phase locking, appear to reflect an internal rhythm that helps structure cognitive processes. The findings were published in [Nature Communications](#).

The study, led by neuroscientists at the University Hospital Bonn, the University of Bonn, and the University of Freiburg, examined how single-neuron activity in the human brain aligns with local electrical rhythms during memory tasks. The team focused on theta waves—slow oscillations typically occurring between 1 and 10 Hz—which have long been associated with memory processes in animal research. While studies in rodents have shown that hippocampal neurons often fire at specific phases of the theta rhythm, it has remained unclear whether similar dynamics hold in the human brain during real-time memory use.

"In [the Bonn Spatial Memory Lab](#), we study how the brain forms memories about places and locations. Previous research showed that single brain cells can synchronize with rhythmic brain activity. We wanted to understand this synchronization more deeply and explored its role during both learning and remembering of spatial memories," explained Tim Guth of the University of Bonn. "Our goal is to understand the memory system of the brain at the level of individual cells and populations of cells. Ultimately, we hope to help improve the treatment of memory disorders."

The research took advantage of a unique clinical context. Patients with treatment-resistant epilepsy often undergo surgery to implant electrodes in the brain, helping doctors locate the source of seizures. With informed consent, these electrodes can also record brain activity at an extremely fine resolution—down to individual neurons. This setup allowed the researchers to directly observe how nerve cells behave as people form and recall memories.

Eighteen patients took part in a virtual navigation task called "Treasure Hunt," which asked them to explore a computer-generated beach and memorize the locations of hidden objects. During each trial, participants navigated to chests containing objects, learned their locations, and later recalled either the object associated with a specific location or the location linked to a particular object. Each session provided dozens of such encoding and retrieval episodes. The researchers recorded both behavioral accuracy and neural activity throughout.

Using advanced computational techniques, the research team analyzed how well individual neurons fired in sync with theta waves. To do this, they estimated the phase of the local field potential—a measure of the average electrical activity near each electrode—across a broad 1–10 Hz frequency range. This approach allowed them to track the timing of each spike relative to ongoing slow-wave activity.

The results provide evidence that neurons in the human medial temporal lobe—including the hippocampus, entorhinal cortex, and amygdala—frequently exhibit theta-phase locking. That is, neurons tended to fire at the same point in the theta cycle across time. About 86% of neurons showed significant phase locking across the full task, and many of them were aligned near the trough of the theta wave.

“Much like musicians in an orchestra follow a shared rhythm, many brain cells in the human memory system time their activity to the brain’s electrical oscillations,” Guth told PsyPost.

Importantly, the strength of this phase locking varied depending on the characteristics of the brain’s electrical background. Neurons were more tightly synchronized with theta waves during periods of high theta power and when the field potentials displayed steep aperiodic slopes—conditions thought to reflect greater neural inhibition. This suggests that theta-phase locking is not a fixed feature but is modulated by moment-to-moment changes in the local neural environment.

The presence of clear theta oscillations, identified using a cycle-by-cycle algorithm, also predicted stronger phase locking. Yet, even outside of these clearly rhythmic periods, neurons continued to show non-random firing relative to theta phase, suggesting that some degree of synchronization persists even when oscillations are less apparent.

“While most brain cells fired at the same point in the rhythm during both learning and recall, a small group shifted their timing,” Guth said. “This shift may help the brain separate the processes of storing new memories from retrieving old ones.”

The researchers also examined whether this rhythmic coordination related to successful memory performance. Surprisingly, they found no strong evidence that theta-phase locking was more pronounced during correctly remembered trials compared to forgotten ones. This held true during both the encoding and retrieval phases of the task. While previous studies using static images or verbal tasks have reported such effects, the dynamic and continuous nature of the spatial navigation task used here may have played a role in blunting phase-reset phenomena that typically enhance phase locking at stimulus onset.

Even though the overall strength of phase locking didn’t predict memory success, the study did find that a subset of neurons shifted their preferred firing phase between encoding and retrieval. About 9% of neurons exhibited such phase shifts, and these shifts tended to be slightly more common during successful memory trials. This observation lends partial support to theoretical models like the SPEAR (Separate Phases of Encoding And Retrieval) model, which proposes that encoding and retrieval occur at different points in the theta cycle to avoid interference.

The degree of phase shift between encoding and retrieval was relatively modest—typically around 40 to 90 degrees—falling short of the full 180-degree separation proposed in some models. Yet even smaller shifts may help segregate memory-related processes and reduce crosstalk between new learning and recall.

Theta-phase locking also varied by brain region. The parahippocampal cortex showed the highest percentage of neurons exhibiting phase locking, while the hippocampus had the lowest. This was not explained by differences in spike count or theta power across regions, indicating possible functional specialization in how different medial temporal areas contribute to rhythmic coordination.

In their analysis, the researchers also explored how both oscillatory (periodic) and non-oscillatory (aperiodic) components of the local field potential shaped phase locking. Steeper aperiodic slopes—reflecting greater inhibition—were associated with stronger phase locking, while flatter slopes corresponded with reduced synchronization. The study used a method called SPRiNT to estimate these aperiodic features over time, offering a more granular view of how internal dynamics fluctuate during memory tasks.

Despite the robust evidence for theta-phase locking, the study has some limitations. The number of encoding and retrieval events may have been too small to detect subtle performance-related effects, and the lack of a sharply defined stimulus onset may have reduced the likelihood of observing phase resets. The wide frequency range used to define theta (1–10 Hz) may also differ from narrower bands used in other studies, potentially complicating comparisons. Additionally, while the presence of phase locking suggests temporal organization, the functional consequences for memory processing remain a topic for further research.

“Although this synchronization was active during memory processes, we still don’t know exactly why it happens or how essential it is for memory,” Guth said. “More research is needed to see how it changes across different memory tasks.”

The study, “[Theta-phase locking of single neurons during human spatial memory](#),” was authored by Tim A. Guth, Armin Brandt, Peter C. Reinacher, Andreas Schulze-Bonhage, Joshua Jacobs, and Lukas Kunz.