

Unlocking the Brain's Filing Cabinets

Soumya Nakka '26

The hippocampus, a small part of the brain located in the temporal lobe of each cerebral hemisphere, is primarily known for its role in storing spatial, verbal, and other cognitive memories. While scientists understand how the hippocampus encodes spatial (where) and temporal (when) information, its method for encoding object-related (what) information remains unclear due to the vast complexity of the object space (She et al., 2025). The object space is a conceptual representation of how objects and their respective features are organized and perceived in the brain. Searching through every individual image or item within the object space would make recall inefficient and demand excessive memory storage capacity; thus, the hippocampus does not store memories as isolated objects. Previously, scientists have hypothesized that the hippocampus simplifies this complexity by encoding memories into recognizable patterns, paralleling the function of filing cabinets. This article discusses recent findings from researchers at the University of Southern California who discovered significant insights concerning the presence of category specific coding in the hippocampus.

The concept of encoding categories is supported by extensive research in rodents, non-human primate, and other human studies, which have shown that during memory exercises, hippocampal neurons fire more frequently in response to images and places within the same category (She et al., 2025). Whilst earlier studies have primarily focused on a single neuron level analysis, the neuroscience department at USC explored spatio-temporal patterns within neuron ensembles. The individuals studied ranged from ages 20 to 62 and were diagnosed with medically refractory focal epilepsy. Working with this population allowed the team to make conclusions directly applicable to patients with memory dysfunction (She et al., 2025). The team

first implanted intracranial depth electrodes perpendicular to the longer axis of the hippocampus for seizure localization in 24 subjects. The majority of the research involved observing hippocampal CA1 and CA3 strikes in the subjects as they performed a visual delayed match-to-sample—a recall memory test with several image groups: animals, plants, buildings, vehicles, and tools (She et al., 2025). CA1 and CA3 strikes are short, high frequency bursts of electrical activity from a strip of neurons in the Cornu ammonia regions of the brain (Misuzeki et al., 2012).

Initially, subjects were instructed to remember an image that was temporarily displayed on a touch screen. After 3-5 seconds, the black screen was repopulated with multiple images, and the patients were prompted to choose the image they had seen before. The subjects participated in two sessions, each consisting of 100-150 trials. As the subjects completed the tests, the micro-macro electrodes reported the different frequencies needed to support the existence of two neural coding strategies (She et al., 2025). The results from the experiment suggest that the human brain encodes information in spike trains with temporal coding more than rate coding. Rate coding suggests that “information is conveyed by the average firing rate of a neuron over a defined time window,” while temporal coding proposes that “the precise timing of individual spikes, often at the millisecond scale, carries meaningful information.” (She et al., 2025). The significance of rate versus temporal coding has been debated for a long time, but the findings from this study exemplify the contributions of temporal resolutions in encoding visual objects as categories.

Though highly successful in discerning the categorical behavior and pivotal role of the hippocampus in sensory information, the team’s approach was restricted by a focus on short term memory and an assumption that there was little decay within the memory traces. Additionally,

the model included a finite set of images, which encompassed only five of the numerous independent categories that humans encounter in daily life (She et al., 2025). The limitations of this study prompt the scientific community to investigate how memory retrieval and representation evolve over time, specifically through the lens of neural dynamics in the hippocampus. As researchers continue to untangle the complexities of brain function, the understanding of memory related medical conditions such as Alzheimer's, Parkinson's disease, and dementia increases. The discovery of temporal coding's function also aids in progressing hippocampal memory prostheses—interfaces that can heighten and restore memory function. The work from USC's biomedical and neurological departments sets a foundation for the potential development of clinical tools and neurorestorative strategies capable of treating hippocampus dysfunction in cognitive disorders, assuring a future with a more comprehensive healthcare system for all.

References

Cleveland Clinic . (2024, May 14). Hippocampus. Cleveland Clinic.

<https://my.clevelandclinic.org/health/body/hippocampus>

Mizuseki, K., Royer, S., Diba, K., & Buzsáki, G. (2012). Activity dynamics and behavioral correlates of CA3 and CA1 hippocampal pyramidal neurons. *Hippocampus*, 22(8), 1659–1680. <https://doi.org/10.1002/hipo.22002>

X. She, B. J. Moore, B. M. Roeder, G. Nune, B. S. Robinson, B. Lee, S. Shaw, H. Gong, C. N. Heck, G. Popli, D. E. Couture, A. W. Laxton, V. Z. Marmarelis, S. A. Deadwyler, C. Liu, T. W. Berger, R. E. Hampson, D. Song, Distributed Temporal Coding of Visual Memory Categories in Human Hippocampal Neurons Revealed by an Interpretable Decoding Model. *Adv. Sci.* 2025, e02047. <https://doi.org/10.1002/advs.202502047>