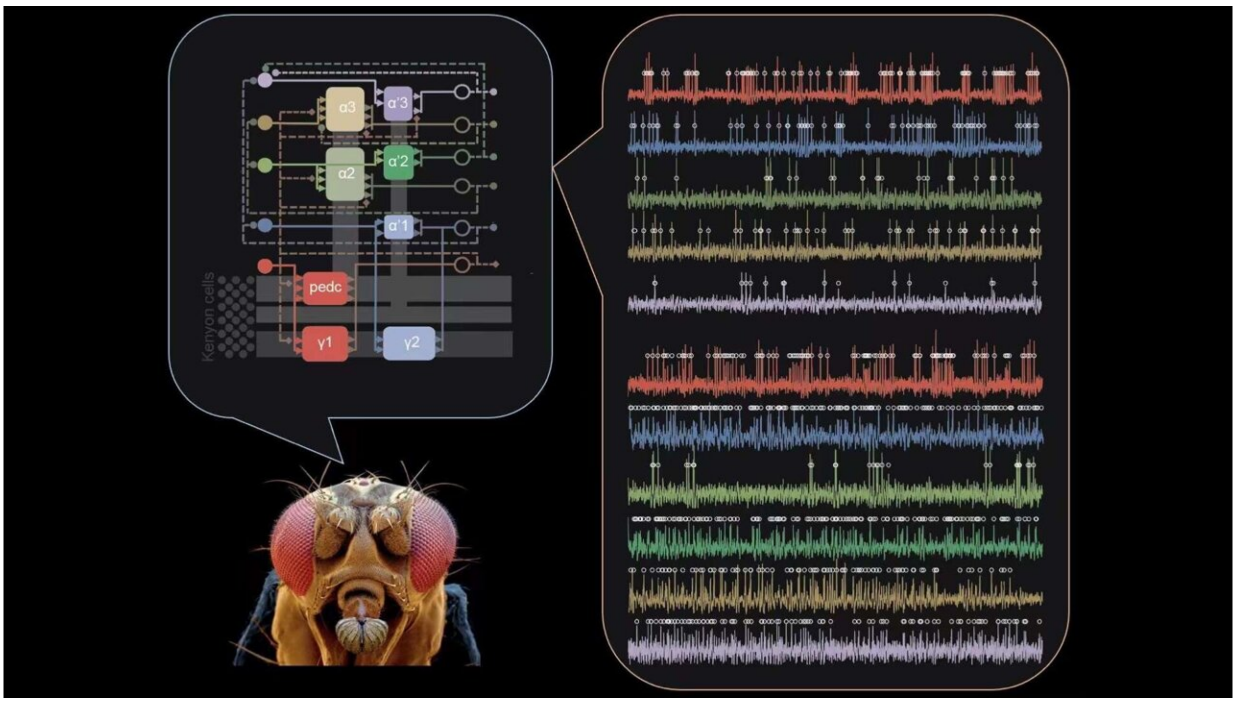
Scientists uncover the role of dopamine in mediating short-term and long-term memory dynamics

August 26 2024, by Tejasri Gururaj



Neural activity gives information about how fruit flies respond to various sensory stimuli, revealing insights into how they process and encode these experiences into short-term and long-term memories. Credit: Cheng Huang. Fly image credit: https://prints.sciencesource.com/featured/6-fruit-fly-drosophila-melanogaster-oliver-meckes-eye-of-science.html.

In a recent study published in *Nature*, researchers from Stanford

University and Yale University have explored the interplay between short-term and long-term memory in animals.

Learning and memory in insects are controlled by a structure known as the mushroom body, analogous to the hippocampus in mammals.

While previous studies have explored this in insects, the researchers wanted to understand how pre-existing, innate responses to stimuli influence learning new associations and how these memories are formed and maintained over time.

Medical Xpress spoke to the study's first author, Cheng Huang, Assistant Professor at Washington University School of Medicine. Speaking of what drove him to pursue this research, he said, "Since childhood, I have been fascinated by how vivid our memories can be and how they can shape an individual's behavior and personality."

The researchers focused on the Drosophila (fruit fly) brain. Using a combination of experimental imaging techniques and computational modeling, the researchers observed neural activity in the fruit flies as they underwent olfactory associative conditioning experiments.

Dopamine and memory

Dopamine release has been linked to rewarding experiences, reinforcing the memory of that experience. Essentially, dopamine acts as a signal that something good has happened, making it easier to remember.

This helps with encoding new memories and reinforcing learned behaviors, playing a role in short-term and long-term memory formation. It also aids in memory storage and retrieval, stabilizing memories over time.

Prof. Huang and his colleagues propose that dopamine neurons in the fruit fly brain integrate information from innate responses and learned experiences with sensory stimuli.

In other words, dopamine helps to process and unify information obtained from the two sources, influencing how the brain responds to sensory stimuli.

"Our work introduces a new conception of the interactions between the brain's short-term and long-term memory storage areas," Prof. Huang explains.

"Traditional conceptions focused on systems consolidation, in which memories residing in short-term storage areas are passed during offline activity to long-term storage areas. Here, we uncover a different interaction between short- and long-term memory compartments."

Voltage imaging to study neural spiking

For the experimental part of the study, the researchers used 500 fruit flies, exposing them to different odors. These fruit flies were genetically modified to target specific neurons and manipulate their activity.

Some of the odors were paired with positive or negative stimuli (like a reward or punishment). This tests how well the flies can learn and remember the association between an odor and the outcome.

Explaining why the Drosophila was used, Prof. Huang said, "The Drosophila brain provides an excellent model for understanding the fundamental logic and mechanisms underlying dopamine-mediated learning and memory."

"Despite having a significantly smaller number of dopamine neurons compared to mammals, the Drosophila dopamine system demonstrates more conserved functions in learning and memory processes."

To measure the flies' response to various stimuli, the researchers measured the neural spiking activity (communication between neurons) using voltage imaging.

This method captures electrical signals by measuring changes in voltage across the neuron's membrane. When a neuron fires, there's a shift in voltage, which can be imaged using special sensors or dyes.

For the computational part of their work, the researchers created a model of the mushroom body circuit, constrained by both the fly brain's wiring and their experimental spiking data, to explain and predict memory dynamics.

Gating, feedback, and dopamine's role

The researchers found that dopamine neurons in the fruit fly brain encode innate and learned responses to rewards, punishments, and odors, heterogeneously. These signals regulate how memories are stored and forgotten in the brain.

When short-term memories form, it triggers a process that opens the gate for certain connections between brain cells to weaken, allowing dopamine neurons to better process both innate and learned cues, which in turn helps form long-term memories.

"This gating occurs via a feedback interaction, whereby signals output from a short-term memory unit influence activity that is input to a long-term memory unit."

"After a short-term memory has been created, this feedback interaction allows a long-term memory to be rapidly formed during additional presentations of the same association that led to the initial short-term memory," explained Prof. Huang.

They also found that the strength of this gating depends on a linear sum of the innate and previously learned responses of the sensory cues.

Further, the computational model revealed how dopamine mediates the interaction between short- and long-term memory. The researchers found that the timing of memory extinction training and the natural significance of odors influence the strength and persistence of these memories.

Looking ahead

The findings of the study reveal how different parts of the mushroom body work together to form short-term and long-term memory.

They provide a mechanistic understanding of how innate and learned information interact in the brain to shape behavior. Additionally, the role of dopamine in mediating the interplay between short-term and long-term memory is also revealed.

"This mechanism could provide insights for identifying similar circuits in mammals. Ultimately, our findings may benefit the development of interventions or treatments for dementia-associated diseases in humans," said Prof. Huang.

Speaking of how their study might impact the field of neuroscience as a whole, Dr. Huang concluded by saying, "The biological implications of our data and modeling results are far-reaching and may offer important computational insights into the dynamic memory system and inspire new designs of learning algorithms and network architectures in artificial intelligence."

More information: Cheng Huang et al, Dopamine-mediated interactions between short- and long-term memory dynamics, *Nature* (2024). DOI: 10.1038/s41586-024-07819-w