Optimizing the mind: Brown researchers develop neural model to understand working memory

Researchers said the model could help scientists address symptoms of neurodegenerative diseases and other disorders.

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When you try to solve a math problem in your head or remember the items on your grocery list, you're engaging in a complex neural balancing act — a process that, according to a new study by Brown University researchers, isn't about your memory's storage capacity but how efficiently it's being used.

The researchers on the study created a computer model that simulates the interaction between the thalamus — which assists with short-term memory — and the basal ganglia in the human brain, revealing the strategies our brain employs to manage and encode sensory information. The researchers said despite the theoretical nature of the study, the model could help scientists learn more about neurodegenerative diseases and other disorders.

Researchers compared two models, each containing "stripes" that represented separate storage units. One contained eight stripes, while the other used a streamlined "chunking" method — which merged similar information into an averaged representation — with just two stripes.

According to Aneri Soni Ph.D. '23, lead author of the study, the "chunk model was able to efficiently use its stripes and actually outperform the model with eight stripes." She said the brain's ability to merge similar information into compact representations allows for more efficient processing, especially when the brain is overloaded with information.

Soni explained that while the brain has billions of neurons, and the potential to hold a vast amount of information, the challenge lies in preventing mistakes when there are too many items to process at once.

The model must not only store information, but also decide how to allocate its limited resources to place data and merge similar items. Soni said that sometimes, when the model was tasked with remembering four or five items using only two stripes, it learned to use one stripe and leave the other empty.

The researchers' findings dig into the underlying "management problem" of working memory — a challenge that, as Soni notes, sets the stage for further research on how these limitations might be addressed.

For her experiment, Soni used the color wheel task — a popular tool in visual working memory studies. In this task, the model is presented with colored bars of varying orientations and later prompted to recall the color associated with particular orientations.

"[The model] had to correctly associate the color of a bar with its orientation and then maintain that information over a delay," Soni said. The task allowed her to compare the model's performance with human behavior data collected by the lab in a previous study.

Inspiration for the model traces back to earlier research by Matt Nassar, an assistant professor of neuroscience and cognitive and psychological sciences at Brown University. The work showed how chunking can function in a computational model but did not explore how it could play out in humans.

Michael Frank, director of the Carney Center for Computational Brain Science at Brown University and principal investigator of the paper, explained the impact of the model extends far beyond theoretical neuroscience and could shed insight to working memory deficits seen in diseases like Parkinson's. He explained that these disorders may interfere with the hacking process described in the study, making it harder for individuals to filter out irrelevant information.

Frank noted that the basal ganglia, a critical structure involved in regulating cognitive control, acts as a gatekeeper for information entering working memory.

"It prevents you from accessing more than just a few items at a time by inhibiting excess input and forcing the system to focus on only a couple of different representations at once," Frank. The model shows that when the gating process fails, the system becomes overwhelmed by competing signals, making it difficult to manipulate information effectively.

Edward Awh, a professor of psychology and neuroscience at the University of Chicago who has spent over thirty years studying human memory, said understanding the neural processes that govern working memory is essential because "the contents of working memory define a hundred percent of your lived existence."

Despite having an abundance of neurons, Awh said, humans are typically limited to holding only three to four items in mind.

“If we want to understand working memory capacity limits, then the ultimate accomplishment would be to build a concrete neural model of how information is encoded into working memory,” Awh said. He added he’s excited about the model’s focus on efficient resource management.

Awh, though not involved in the Brown study, noted the clinical relevance of these findings for disorders such as ADHD and schizophrenia. He believes a concrete model of working memory could guide targeted interventions to help restore cognitive function in affected individuals.

“Anything we can do to learn about the systems that are challenged is going to help us to conceive of new interventions,” Awh said.