Neuroimaging study reinforces theory of mental 'foraging,' inspiring new understanding of schizophrenia

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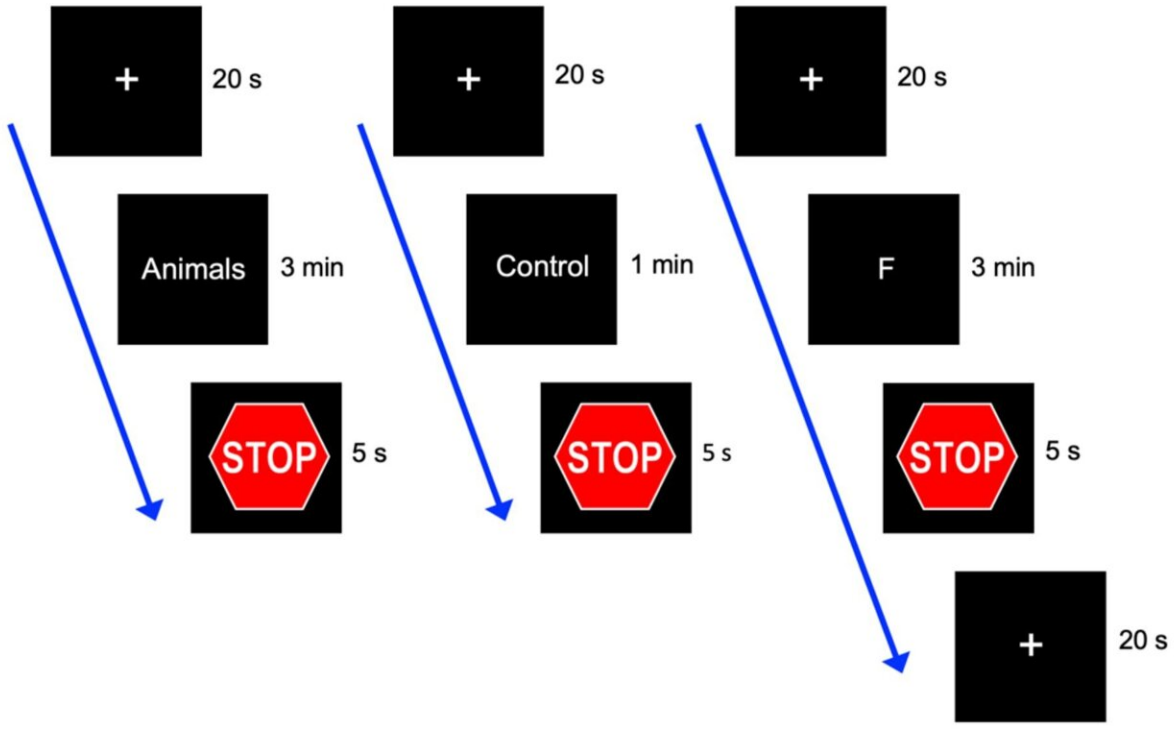

Schematic of an example fMRI run consisting of 1 category verbal fluency test, 1 control speaking condition, and 1 letter verbal fluency test. Black boxes illustrate examples of the stimuli present on the MRI projector screen throughout task performance. There were 4 total runs for each participant. Credit: *Proceedings of the National Academy of Sciences* (2023). DOI: 10.1073/pnas.2312462120

How the mind searches for words and concepts in memory may have its origins in age-old patterns by which human and nonhuman animals search for food and other resources in their physical environment. That is the theory which received fresh support from a neuroimaging study which examined the brain activity of study participants as they searched their long-term memories for words related to various concepts.

In addition to teaching us about the basic strategies that people use to find relevant information, this work may also inspire a novel approach to understanding schizophrenia and other forms of psychosis, in which disorganization of speech and thought is a fundamental symptom.

The study was published in the *Proceedings of the National Academy of Sciences* by researchers in the Indiana University Department of Psychological and Brain Sciences in the College of Arts and Sciences and their collaborators. Its findings provide neural evidence of a continuity between foraging in space and mind.

Principal investigator Peter Todd, whose research into the evolutionary roots of cognitive processes set the team's project in motion, explained how search patterns for finding external resources like food, water or shelter may also explain the way humans search for internal concepts stored in memory.

"People don't just search externally, we also search internally," said Todd, Provost Professor in the IU Department of Psychological and Brain Sciences and Cognitive Science Program. "And these strategies that evolved to help other organisms find what they want in the physical world also look like they're driving the way we search for information in libraries and on the web, and in our own heads for things we have stored in there and want to get back out and make use of."

The common feature between external and internal search strategies lies

in the movement from one patch of items with a high concentration of a particular resource to a new patch when the previous one becomes depleted. If a bear is searching for berries, for example, it will spend time at one bush until it has eaten most of the berries there, prompting the bear to switch to another bush in hopes of finding more.

This pattern of exploiting one patch until deciding it's time to look for another, of making an "exploitation/exploration tradeoff," is a strategic process by which an organism can maximize the amount of food found over time by deciding when it is advantageous to leave one location to look for new sources of food.

The search for concepts in the semantic spaces of memory, the researchers have shown, replicates this strategic switching between local search in clusters of items and global search for new clusters. Thirty participants, while undergoing functional magnetic resonance imaging (fMRI) of their brain activity, were asked to say all the words they could think of for three minutes, in each of a series of conceptual categories (such as animals, food, occupations) or beginning with a certain letter.

In such memory search tasks people typically produce words in clusters or patches. So, for example, a participant told to list animals might begin with farm animals until their memory of farm animals runs dry, leading them to move on to a new cluster consisting of "pets" or "African animals."

With the expertise of IU Professor Josh Brown in the Department of Psychological and Brain Sciences, who has used fMRI to study other kinds of decision-making processes, the researchers then investigated study participants' brain activity during moments of switching between patches and during periods of searching within patches leading up to switches.

As Nancy Lundin, lead author on the study and a former Ph.D. student in the IU Department of Psychological and Brain Sciences and the IU Program in Neuroscience, explained, "We tried to characterize these cognitive search processes at times when people were clustering (or finding related words in their memory) versus the times when they were switching (or transitioning to a new patch).

"We used information from computational models of semantic and phonetic distances and from participant reports on when they were switching. We found that the hippocampus and the posterior cerebellum showed greater activity during switching compared to clustering, which provides some evidence that these cognitive search processes are meaningfully distinct."

Brown, who is also in the IU Cognitive Science Program and Program in Neuroscience, elaborated on the implications of this brain activity. The study, he suggested, confirms that the hippocampus, a part of the brain that helps form long-term memories, "is not just a passive way station for memories on the way to more permanent storage."

It's also, he said, "a kind of scratch pad that allows you to represent and play with these memories. When subjects had to try something different like switching to a new part of semantic space, that's when you got this activity in the hippocampus. This suggests that something is going on that is helping you generate new ideas, that is finding new things, trying something different."

Lundin, now a postdoctoral fellow in the Department of Psychiatry and Behavioral Health at the Ohio State University College of Medicine, likewise remarked that the study adds to recent research (including that of her Ph.D. advisor and fellow author on the study, Professor Bill Hetrick in the IU Department of Psychological and Brain Sciences) on the cerebellum's understudied role in cognitive processes. Historically,

the cerebellum was believed to be primarily involved in motor coordination and control.

"Here," she said, "posterior regions of the cerebellum more recently shown to be associated with cognitive processes, were implicated in switching to new parts of cognitive space for both semantic and phonetic word retrieval tasks."

Clinical Implications

As a clinical psychologist, Lundin sees the current study as foundational to her future plans to study the organization of speech and thought in individuals with psychotic illness and other forms of psychopathology. Schizophrenia, as she pointed out, a term initially coined in 1908 by Swiss psychiatrist Eugen Bleuler, was characterized from the beginning as a disorder of loosened associations, or a fragmentation of thought, language, behavior and emotions.

"A lot of research goes into understanding the disorder of thought and disorganized speech in psychosis," Lundin says, "but we don't understand the underlying mechanisms, why some people have more trouble communicating in a clear way than others. One question that my colleagues and I are continuing to explore is, 'Do these cognitive foraging processes, decisions of when to explore and exploit, relate to organization of speech and thought in psychosis? Are some people using suboptimal foraging strategies by either staying in a patch of concepts for too long or leaving too early?'"

Lundin has now looked at these cognitive search strategies in individuals with psychosis in several studies. So far, she said, "We are finding some differences in the patterns of local exploitation and global exploration during semantic search between those with psychosis and those who are neurotypical."

However, more work remains to be done. She will soon start collecting new data at the hospital in which she works to get a better grasp of how more open-ended, everyday speech might relate to the foraging process explored in the current study. And she has strong hopes, she said, that this new way of conceptualizing how we search for words and concepts in memory "can really get to the root of the illness and point toward novel treatments for people struggling with psychosis."

More information: Nancy B. Lundin et al, Neural evidence of switch processes during semantic and phonetic foraging in human memory, *Proceedings of the National Academy of Sciences* (2023). DOI: 10.1073/pnas.2312462120

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