Brain signatures of spontaneous thoughts

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Without prompting, they fill our stream of consciousness–Sudden amusement at a joke you heard yesterday, or a flash of panic over an important meeting that slipped your mind. Spontaneous thoughts constitute the majority of our mental landscape, yet little is known about how they arise. Because these events are harder to predict, manipulate or monitor than other experiences like seeing, speaking or paying attention, they pose unique challenges to studying in the lab. Recently, a team of Canadian researchers led by Kalina Christoff devised a clever approach to unveiling the neural underpinnings of a wandering mind. By tapping into the heightened internal awareness of experienced meditators, they unraveled the temporal progression of brain activity underlying the generation and evaluation of spontaneous thoughts.

Peering into a meditator's brain

Mindfulness meditators are exquisitely adept in their introspective abilities. Because of their exceptional accuracy at monitoring their internal experience, they are an ideal population in which to study conscious thoughts. Therefore, Christoff and her colleagues used fMRI to image the brain activity of 18 experienced (>3000 training hours) mindfulness meditators during a simple awareness task. In one condition, the meditators responded when they detected a word on the screen, while in another they indicated when a spontaneous thought arose. In both conditions, they classified the word or thought as an image, narrative, emotion or sensation.

To explore the evolution of brain activity preceding and ensuing the

arising of a thought, the researchers extracted the time course of the fMRI signal starting 4 seconds before and continuing 12 seconds after the meditator reported a thought. This signal was compared against the signal surrounding detection of words, to isolate activity related to introspective versus extrospective thoughts.

From memory, a thought is born

The hippocampus, parahippocampal gyrus and inferior parietal lobe activated during the seconds leading up to the onset of a spontaneous thought. Although unclear from these findings how engagement of these regions might spark awareness of a mental image, concept or emotion, past research on the functions of these areas offers some insight. The medial temporal lobe, which includes the hippocampus and its enveloping parahippocampal gyrus, is critical for forming and recalling memories for experiences. Given this essential role for memory, its activation may recruit a distributed neural memory trace strongly enough to trigger conscious awareness of a "thought." While theoretical, this explanation is consistent with prior findings showing that medial temporal neurons become more active right before a memory is recalled and their activity predicts recall. Although these regions have also been implicated in ancillary functions like imagining or pondering the future, these processes likely also rely fundamentally on memory. So perhaps, stimulation of a piece of a stored memory triggers the mind to revisit that memory in part or in whole, or may elicit creative elaboration to plan or day dream–the mental tidbits that make up our stream of consciousness.

Reflecting on a thought

When a thought arises, it doesn't immediately dissipate, but often becomes the focus of reflection. During and after the onset of

spontaneous thoughts, the researchers observed wider-spread activation in regions traditionally thought to support "meta-cognitive" or "elaborative" processes. Their recruitment might support the evaluation or conscious perception of a thought. For instance, the inferior parietal lobe, activated both before and during thought detection, is believed to subserve 'bottom-up' attention to a recalled memory, helping to redirect focus to the memory as it enters the mind. Other regions, including the medial prefrontal cortex (PFC), temporal pole and insula, which were engaged after detection of a thought, are believed to bind internally- with externally-generated information, thus integrating a range of emotional, cognitive and sensory content. The lateral PFC and anterior cingulate also activated after a thought arose, regions known to support monitoring, evaluation and abstract thinking.

A brain model of mind-wandering

Together, these results suggest a model of mind-wandering in which memory reactivation–supported by the medial temporal lobe–sparks the birth of a thought, followed by awareness, reflection and elaboration–supported by widespread cortical recruitment. This model fits in well with the concept of the hippocampus as the heart of an "indexing system" that coordinates activity across the far corners of the brain, promoting the reactivation of, and elaboration upon, a memory. These results expand upon other evidence for a central–but not exclusive–role for a distributed "default" brain network in mind-wandering, to highlight the importance of the brain's memory system in eliciting the constituent thoughts of our mental landscape.

These findings just scratch the surface of exposing the neural generators of our stream of consciousness, but offer a plausible and intriguing explanation, opening the door to further exploration. For instance, because of the relatively poor temporal resolution of fMRI, Christoff and her group "were surprised that we were able to observe such clear

differences in the timing of different regions' recruitment with fMRI. However, we are currently conducting a follow up study using EEG and the same paradigm, in order to investigate more precisely the temporal differences in recruitment across regions." Furthermore, as not all forms of mind-wandering are created equal, distinct internal experiences such as emotions, narratives or sensations, may have different neural origins. This is one question Christoff's team is exploring. Although they have found a "difference in the pattern of activity for different types of thought, we also observed overlap among all types of thoughts in the medial temporal lobe, consistent with the notion that spontaneous thoughts are initiated there, but then might develop differently as they spread throughout the brain, depending on their nature," Christoff explains.

While this and other studies provide a window into the brain signatures of spontaneous thoughts, they don't speak to their underlying biological or environmental driving forces. Is the onset of a thought purely random, determined by spontaneous neural activity? How much are these activation patterns guided by one's internal state or external stimuli? Multimodal approaches incorporating intracranial recordings or brain stimulation may enable us to better address these many outstanding questions. Yet because fMRI is invaluable for non-invasively peering into the living brain, Christoff says, "There have been many studies with intracranial recordings on epileptic patients, but no studies that have gotten as close to observing the non-memory spontaneous thought arising in healthy volunteers."

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