Study deciphers the noise in the human brain

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Neurologist Josef Parvizi and his colleagues found that regions of the brain involved in memory recall work in concert, even during sleep. Credit: Norbert von der Groeben

By directly recording electrical activity from the human brain, neuroscientists at the Stanford University School of Medicine have shown that distinct, distant groups of brain areas that support memory retrieval act in concert, even during sleep.

The findings, in a study published online April 8 in *Neuron*, confirm for the first time that specific electrical patterns of coordinated neural activity in widely separated human brain structures during memory retrieval persist throughout our cycles of waking and sleeping. The findings confirm indirect observations made in previous studies that used brain imaging. They also shed light on why the brain paradoxically appears to exhaust so much of the body's energy in what, at first glance, seems akin to the idling of a car's engine.

The human brain is a greedy organ. Accounting for only 2 percent of the body's weight, it consumes 20 percent of the body's energy. Yet the rate at which the brain gobbles glucose (the fuel our brain cells run on) barely budges when we cease performing a physical or mental activity. Even at rest, the brain seems engaged in a blizzard of electrical activity, which neuroscientists have historically viewed as useless "noise."

"Increases in brain activity during conscious thoughts and actions represent only the tip of the iceberg," said Josef Parvizi, MD, PhD, associate professor of neurology and neurological sciences and the senior author of the *Neuron* study. "The vast amount of energy consumption by our brain is due to its spontaneous activity at all times when we are not consciously involved in a specific task."

What, then, is all this spontaneous noise for?

At rest, but not resting

Over the past decade, neuroscientists using brain-imaging methods like functional MRI scans, which track blood flow in the brain (believed to be a good stand-in for local neural activity), have started to reveal hidden patterns within this spontaneous neural noise, patterns that might provide a window into the organization of the brain. Dozens of networks—distributed, collaborative clusters of brain regions dedicated to various mental activities from solving math problems to recalling what one ate for breakfast—have now been identified, simply by grouping together brain regions with similar profiles of neural-noise activity. Numerous task-dedicated brain networks' constituent nodes appear to retain their shared activity (albeit at a slow, drifting rate) when at rest—that is, when their particular expertise isn't being called upon—or even when an individual is completely unconscious, such as when sleeping or under anesthesia.

But brain imaging provides only indirect assessments of electrical activity in various brain regions, and critics have suggested that "resting" network patterns of activity may be an artifact. In addition, while fMRI scans can map activity in the brain panoramically, their temporal resolution is imperfect.

Parvizi and his colleagues directly addressed these concerns and limitations by eavesdropping on the activity of distinct populations of nerve cells in the human brain. The technique they used, called intracranial electrophysiology, provides resolution at a scale of milliseconds and millimeters, letting researchers obtain meaningful results from inspecting a single individual's brain.

Spying on the brain

Intracranial electrophysiology's precision comes from making direct brain recordings in individuals who have undergone an invasive procedure for medical purposes. The subjects involved in the Neuron study were patients with frequent epileptic seizures who had checked into Stanford Hospital for about a week, during which time their brains were monitored in an effort to detect the exact spot—unique in each different patient's brain—where the recurring seizures are being initiated.

In a continuous experiment lasting several days, the researchers were able to spy on the circuitry within two key nodes of a very important network simultaneously in these patients. Known as the default mode network, this set of widely distributed brain structures may consume more energy than any other network in the brain. It is most active when an individual is nominally at rest—lying still with eyes closed or just staring off into space —or is retrieving an autobiographical memory ("What did I eat for breakfast?"). As soon as that same person is asked to perform any of a number of other specific mental tasks (for example, solving the equation, "How much is 32 times 5?"), this network shuts down. Previously, Parvizi and colleagues were the first to use direct brain recordings to confirm this unique property of the default mode network.

For the present study, Parvizi, who is director of Stanford's Human Intracranial Cognitive Electrophysiology Program, recruited three patients—two women and a man—for whom the ideal locations to place the electrodes covered both a region called the angular gyrus, near the outer surface of the brain's left parietal lobe, and another region called the posterior cingulate cortex, on the inside surface of the left parietal lobe, in the narrow space where the brain's two hemispheres nearly meet. In people, the angular gyrus and posterior cingulate cortex, both known to be key components of the default mode network, are several inches apart—a vast expanse, neurologically speaking.

Beyond the medical procedure already performed, the new study imposed no further invasive action. Using intracranial electrophysiology, the researchers found that electrical activity in these two distant regions of the default mode network responded with surprising simultaneity when the experimental subjects were asked to contemplate various statements of past personal events shown on a computer, such as "I ate a banana for breakfast this morning" (which requires autobiographical memory retrieval and engages the default mode network).

"There was effectively zero time lag" in the response of these regions, said the study's lead author, Brett Foster, PhD, a postdoctoral scholar in Parvizi's lab.

The technique's temporal precision allowed the researchers to plot the sequence of subjects' responses to autobiographical-memory queries, which triggered electrical activity in, first, the brain's vision centers; next, the angular gyrus and posterior cingulate cortex; then, the brain's decision centers; and finally, as subjects pushed a "True" or "False" key on the computer before them, the motor area.

Similar patterns of activity

Strikingly, the pattern of coordinated electrical activity observed in the default mode network regions when patients were performing an autobiographical-memory task persisted even when those individuals were at rest or asleep. Foster and Parvizi discovered this similarity by recording activity from these regions while subjects were resting with their eyes closed during the day and throughout the night while they slept. They then asked if the pattern of activity during these states was similar. What they found, hidden within the idling brain noise, were slow, drifting activity patterns during rest and sleep that directly matched those seen during effortful memory retrieval. Importantly, to show that such electrical patterns reflect those previously observed by brain-imaging researchers, they also performed fMRI scans in the same individuals, and confirmed that network activity patterns for electrical activity and blood flow were closely aligned.

The findings put one debate to bed—the coordinated resting-state network activity visualized by neuroimaging is real—but raise another: What advantage might an organism derive from the immense energy expenditure needed to keep all that activity going even during sleep? Parvizi and Foster speculated that this may be the brain's way of maintaining relationships within its network organization—tuning itself up in preparation for future action.

Sounding a word of caution, Parvizi said that referring to network organization should not mislead the reader into thinking the brain is some kind of computer. "The brain is much more than a bunch of ones and zeroes," he said.

More information: "Intrinsic and Task-Dependent Coupling of Neuronal Population Activity in Human Parietal Cortex" DOI: dx.doi.org/10.1016/j.neuron.2015.03.018

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