The Brain Doesn’t Think the Way You Think It Does

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Familiar categories of mental functions such as perception, memory and attention reflect our experience of ourselves, but they are misleading about how the brain works. More revealing approaches are emerging.

Neuroscientists have tried to map various categories of mental function to specific regions of the brain, but recent work has shown that the definitions and boundaries of those regions are complex and context-dependent.

Neuroscientists are the cartographers of the brain's diverse domains and territories — the features and activities that define them, the roads and highways that connect them, and the boundaries that delineate them. Toward the front of the brain, just behind the forehead, is the prefrontal cortex, celebrated as the seat of judgment. Behind it lies the motor cortex, responsible for planning and coordinating movement. To the sides: the temporal lobes, crucial for memory and the processing of emotion. Above them, the somatosensory cortex; behind them, the visual cortex.

Not only do researchers often depict the brain and its functions much as mapmakers might draw nations on continents, but they do so "the way old-fashioned mapmakers" did, according to Lisa Feldman Barrett, a psychologist at Northeastern University. "They parse the brain in terms of what they're interested in psychologically or mentally or behaviorally," and then they assign the functions to different networks of neurons "as if they're Lego blocks, as if there are firm boundaries there."

But a brain map with neat borders is not just oversimplified — it's misleading. "Scientists for over 100 years have searched fruitlessly for brain boundaries between thinking, feeling, deciding, remembering, moving and other everyday experiences," Barrett said. A host of recent neurological studies further confirm that these mental categories "are poor guides for understanding how brains are structured or how they work."

Neuroscientists generally agree about how the physical tissue of the brain is organized: into particular regions, networks, cell types. But when it comes to relating those to the task the brain might be performing — perception, memory, attention, emotion or action — "things get a lot more dodgy," said David Poeppel, a neuroscientist at New York University.

No one disputes that the visual cortex enables sight, that the auditory cortex enables hearing, or that the hippocampus is essential for memory. Damage to those regions impairs those abilities, and researchers have identified mechanisms underlying them in those areas. But memory, for example, also requires brain networks other than the hippocampus, and the hippocampus is turning out to be key to a growing number of cognitive processes other than memory. Sometimes the degree of overlap is so great that the labels start to lose their meaning.

“The idea that there’s some kind of strong parallelism between mental categories that neuroscientists use to try and understand the brain and the neural implementation of mental events is just wrong,” Barrett said.

And while the current framework has led to important insights, “it’s gotten us stuck in certain traps that are really stifling research,” said Paul Cisek, a neuroscientist at the University of Montreal — an outcome that has also directly hobbled the development of treatments for neurological and psychological conditions.

Lisa Feldman Barrett, a psychologist at Northeastern University, thinks that familiar categories of mental function such as perception and memory are "poor guides for understanding how brains are structured or how they work."

That is why Barrett, Cisek and other scientists argue that for us to truly understand how the brain works, concepts at the field’s core may need to be revised, perhaps radically. As they grapple with that challenge, they are uncovering new ways to frame their questions about the brain, and new answers: This month alone, one such approach revealed an unexpected link between memory formation and metabolic regulation. But even if a new framework succeeds in explaining the brain’s operation, some researchers wonder whether the price of that success will be a loss of connection to our human experience.

‘More Aliases Than Sherlock Holmes’

When functional magnetic resonance imaging (fMRI) and other powerful technologies made it possible to examine living brains in increasingly sophisticated ways, neuroscientists enthusiastically started searching for the physical basis of our mental faculties. They made great strides in understanding the neural foundations of perception, attention, learning, memory, decision-making, motor control and other classic categories of mental activity.

But they also found unsettling evidence that those categories and the neural networks that support them don't work as expected. It's not just that the architecture of the brain disrespects the boundaries between the established mental categories. It's that there's so much overlap that a single brain network "has more aliases than Sherlock Holmes," Barrett said.

Recent work has found, for instance, that two-thirds of the brain is involved in simple eye movements; meanwhile, half of the brain gets activated during respiration. In 2019, several teams of scientists found that most of the neural activity in "perception" areas such as the visual cortex was encoding information about the animals' movements rather than sensory inputs.

This identity crisis isn't limited to neural centers of perception or other cognitive functions. The cerebellum, a structure in the brains of all vertebrates, was thought to be dedicated almost exclusively to motor control, but scientists have found that it's also instrumental in attention processes, the regulation of emotions, language processing and decision-making. The basal ganglia, another ancient part of the brain usually associated with motor control, has been similarly implicated in several high-level cognitive processes.

Some of these confusing results may come from methodological problems. To find where the human brain performs different functions, for instance, neuroscientists typically correlate cognitive processes with patterns of brain activity measured by fMRI. But studies suggest that researchers need to be more alert to irrelevant muscle twitches and fidgets that may contaminate the readings.

“You think that your results are telling you something about high-level cognition,” said

György Buzsáki, a neuroscientist at the NYU School of Medicine, “when in fact, it may reflect nothing else except that, because of the task, [the subject’s] eyes are moving differently.”

But he and other scientists believe the recent findings also highlight a deeper conceptual problem in neuroscience. “We divide the real estate of the brain according to our preconceived ideas, assuming — wrongly, as far as I’m concerned — that those preconceived ideas have boundaries, and the same boundaries exist in brain function," Buzsáki said.

When the neuroscientist Russell Poldrack of Stanford University used machine learning to sort a massive database of behavioral data, the categories that emerged did not seem to correspond to recognizable mental classifications, such as learning or memory.

In 2019, Russell Poldrack, a neuroscientist at Stanford

University, and his colleagues set out to test how appropriate the recognized categories for mental function are. They gathered a massive amount of behavioral data — obtained from experiments designed to test different aspects of cognitive control, including working memory, response inhibition and learning — and ran it through a machine learning classifier. The resulting classifications defied expectations, mixing up traditional categories of brain results and sorting them into new groups that seemed to “move together in terms of some much more generic constructs,” Poldrack said — constructs for which we don’t yet have labels, and which might not relate directly to our conscious experience.

Another study by Poldrack’s colleagues found that tasks meant to measure either perception or memory “weren’t really measuring different constructs after all,” Poldrack said. “It suggests that those two categories are really imprecise.”

It’s not that “perception” or “memory” is a useless term, he emphasized. But “if we want to understand what the brain does, we probably need much more precise ways to understand particular functions.”

The fact that it’s not even clear how to differentiate tests of perception from those of memory suggests that those categorical constructs “may not actually be the real organizing features of the mind,” Poldrack said.

Some scientists push back, arguing that so long as we know that the visual cortex isn't just involved in vision, or that a memory network is doing more than its name suggests, we don't necessarily need to rethink the categories themselves. But "sometimes an overly broad, vague use of a term can have detrimental effects on the types of experiments and hypotheses we generate," said John Krakauer, a neuroscientist at Johns Hopkins University.

That's perhaps been most obvious in research on emotions and mood.

Fear and Confusion

Joseph LeDoux is a neuroscientist at NYU known for his pioneering work on the amygdala, which is often referred to as the fear center of the brain. But that framing, he says, is very wrong — and very harmful. "I kept being introduced over the years as someone who discovered how feelings of fear come out of the amygdala," he said. "But I would always kind of flinch when I would be introduced this way. Finally, I had enough.”

LeDoux has spent the past decade emphasizing that the amygdala isn’t involved in generating fear at all. Fear, he points out, is a cognitive interpretation of a situation, a subjective experience tied up in memory and other processes. The psychological phenomena that some people experience as fear may be experienced as something very different by others. Research shows that the feeling of fear arises in the prefrontal cortex and related brain areas.

The amygdala, on the other hand, is involved with processing and responding to threats — an ancient, subconscious behavioral and physiological mechanism. “The evidence shows that it’s not always fear that causes the behavior,” LeDoux said.

Calling the amygdala the fear center might seem innocuous, he continued, but “then the amygdala inherits all the semantic baggage of fear." That mistake can distort attempts to develop medications, including those aiming to reduce anxiety. When potential treatments are tested in animals under stress, if the animals behave less timidly or show less physiological arousal, it's usually interpreted as a reduction in anxiety or fear levels. But a medication can change someone's behavioral or physiological responses — those outputs of the amygdala — without curing feelings of anxiety, LeDoux said.

“The whole field is suffering because of this confusion,” he said.

Similar problems occur in other areas, he added, such as studies of perception, where the physical processing of the sensory stimulus and the conscious experience of it are often bundled together. In both cases, LeDoux believes “these need to be pulled apart.”

Functional in Context

But teasing apart the significance of different brain areas is further complicated by the discovery that the involvement of neural systems in particular functions isn’t simply all or nothing. Sometimes it’s contingent on the details of what’s being processed.

Take the part of the medial temporal lobe called the perirhinal cortex — a crucial component of the classic “memory” system in the cortex. Elisabeth Murray of the National Institute of Mental Health and others did experiments in which humans and monkeys were asked to select a desired image from a pair that were morphed to resemble each other to varying degrees.

They found that the perirhinal cortex was involved in the performance of the task only when a particular amount of feature overlap was present. If the images were more similar or less, the perirhinal cortex had nothing to do with how well the humans or monkeys did. Similarly, the inferior temporal cortex, traditionally assigned a role in visual perception, was found to be crucial for memory tasks, but only in certain contexts.

To the retired neurobiologist Steven Wise, formerly of NIMH, the findings imply that instead of categorizing cortical areas in terms of their specialized visual, auditory, somatosensory or executive functions, researchers should study the different combinations of information they represent. One region might be involved in representing simple combinations of features, such as “orange” and “square” for an orange square. Other regions might have evolved to represent more complex combinations of visual features, or combinations of acoustic or quantitative information.

Wise argues that this brain organization scheme explains why there’s so much unexpected functional overlap in the traditional maps of mental activity. When each region represents a particular combination of information, “it does that for memory, and for perception, and for attention, and for the control of action," Wise said.

That's also why the perception and memory tasks that Murray used in her experiments only sometimes involved the perirhinal cortex: As the images in each task morphed, the combinations of features that distinguished them changed.

Wise's representational framework is just one way of rethinking the brain's subdivisions. While other researchers agree that the parts list guiding most neuroscientific research has problems, there's little consensus about how to address it.

Paul Cisek, a neuroscientist at the University of Montreal, is using vertebrate evolution to identify meaningful categories of mental activity. University of Montreal

And even scientists in favor of a more radical rethinking of the field find it difficult to outline. “I’ve [often] caught myself using a whole lot of terms that I was criticizing the very use of. How can I say everything without saying ‘attention,’ ‘emotion,’ ‘motivation’?”

Cisek, in Montreal, is one of several researchers starting to rebuild the conceptual categories from an evolutionary perspective. For the past five years, he has been painstakingly making his way through vertebrate evolution, examining the progressive specialization of behavioral systems.

“Functional subdivisions do exist in the brain,” he said. “And they actually have an evolutionary history to them. If we could identify that history, it’ll help us identify the concepts better.”

Cisek has already used his new breakdown of brain activities to explain why, for instance, the basal ganglia plays a key role in some decision-making tasks but not others. “You realize that neither the term ‘decision-making' nor the term 'attention' actually corresponds to a thing in the brain," he said. "Instead, there are certain very pragmatic circuits in the brain, and they do certain things like 'approach' or 'avoid.' … Some of those things are going to look a bit like attention."

Buzsáki takes a similar view. "We have to look at brain mechanisms first, and why and how those things evolved," he said. For instance, memories, future planning and imagination are all partly encoded by the same neural mechanisms, which makes sense from an evolutionary perspective because the same system can be recycled for different purposes. “You may be better off thinking about all of [those] as one,” he said.

This approach is already leading to some intriguing discoveries. For years, Buzsáki has studied sharp wave-ripples, a type of brain activity in the hippocampus that enables the storage and retrieval of memories. But this month in

Nature, his former doctoral student David Tingley and others in Buzsáki's lab revealed an entirely new function for them: helping to regulate blood sugar levels.

"We are linking two very different extremes," Buzsáki said — a basic metabolic process and a high-level cognitive one. He's now hoping to uncover a deeper connection between the two, and to obtain insights into how sharp wave-ripples for body regulation might have been repurposed for memory formation.

Don’t Panic

Alternative approaches to studying mental categories are possible, too. Barrett, Pessoa and others, for instance, are considering whole-brain neural activity and an assortment of behaviors at the same time. “You study the whole system as its parts interact,” Barrett said. Functional categories such as memory, perception and attention can then be understood as “features of the brain state.”

Because of the counterintuitive groupings that emerged in his earlier study of behavioral data, Poldrack continues to be interested in model-free, data-driven searches for new categories. He thinks mental concepts could potentially be rewritten in computational terms — perhaps as a simplified version of the mathematical descriptions that define layers in artificial neural networks.

Each of these potential solutions has shortcomings. “But you don’t evaluate a new approach by all the questions it answers that the old one couldn’t,” Barrett said. “You evaluate it on the basis of what new questions does it stimulate.”

“There is no right way to do this,” she added. “There are only better ways and worse ways.”

Poldrack agreed. “I don’t think any of us would want to tell people: Don’t use the word ‘memory’ anymore,” he said. But to understand the brain, we might need to challenge our intuitions about how it works — "in the same way that quantum mechanics is challenging to comport with our understanding of physical phenomena in the world."

Another important consideration is how meaningful a new framework might end up being. "You may gain in terms of knowledge, but you may actually stop understanding yourself," Krakauer said.

When we wonder how the brain works, he explained, we want it to mean: What's happening in my brain when I fall in love? Or when I'm excited? If we move too far away from our subjective experience and familiar cognitive concepts, he worries that what we learn about the brain might be like "42" in *The Hitchhiker's Guide to the Galaxy*: the correct answer, but not to the question we had in mind. "Now, are we willing to live with that?" Krakauer asked.