New insight on the role of the primate orbitofrontal cortex in value-based decision-making

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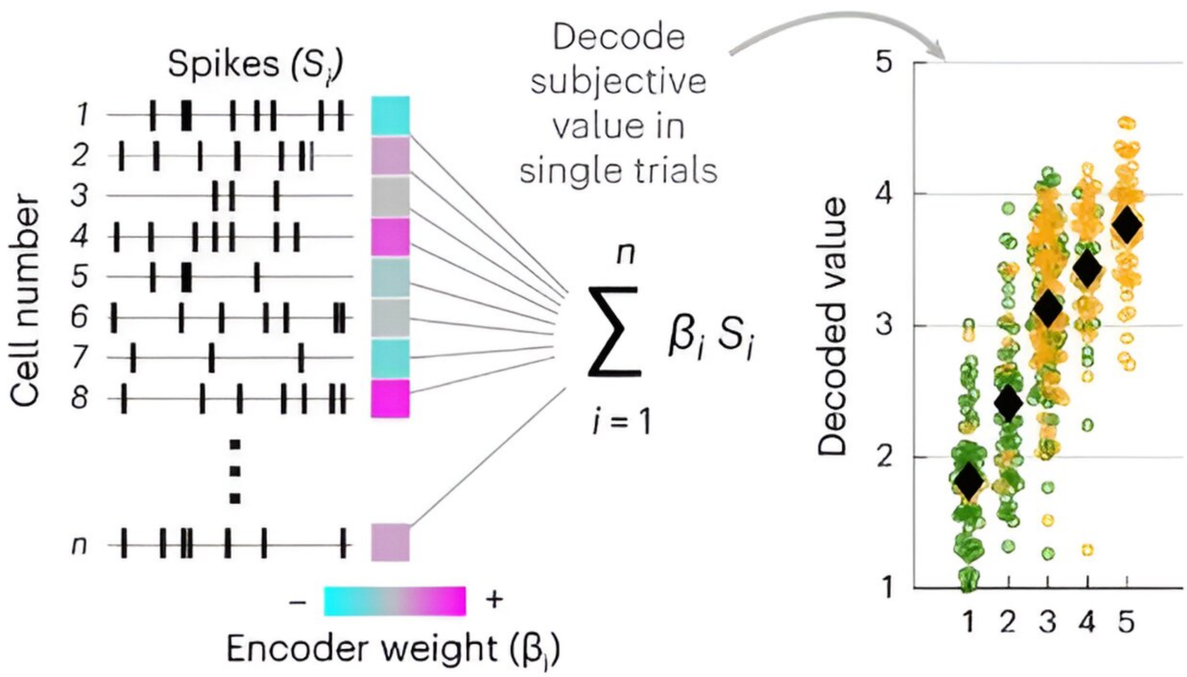

Illustration of population decoding method, which finds the weighted sum of activity in many simultaneously recorded neurons, and uses it as a neurally derived estimate of the monkey's subjective representation of value. Credit: McGinty and Lupkin

The orbitofrontal cortex (OFC), a subsection of the brain's frontal lobe, is known to play a part in value-based decision-making, the process of mentally weighing the outcome of different decisions and then selecting one. Value-based decisions include, for instance, choosing what to buy while shopping at a grocery store or deciding what apartment to rent among available options.

For many years it's been hypothesized that one of the OFC's most important functions is to represent the values of different decision options. However, the neural mechanisms through which this brain region transforms the represented values into actual decisions remain poorly understood.

Researchers at Rutgers University-Newark recently carried out a study aimed at better understanding the OFC's contribution to value-based decision-making in primates. Their paper, published in *Nature Neuroscience*, found a consistent relationship between the choices made by monkeys and the value signals encoded by groups of neurons in their OFC while they were choosing between different options.

"The project was inspired by three different lines of research," Vincent B. McGinty, co-author of the paper, told Medical Xpress. "First, our overall research question concerns how the brain organizes value-based decision-making. For a long time, it's been known that a part of the prefrontal cortex known as orbitofrontal cortex (OFC) is incredibly important for value-based decisions."

Past studies found that when primates are evaluating different available decisions, neurons in their OFC, dubbed value-coding neurons, create a subjective representation of each of the offers' values. Essentially, the rate at which these neurons fire varies, depending on how desirable or undesirable a decision is for the primate.

While this finding is well-documented, the role of these value-coding

OFC neurons in value-based decision-making has not yet been clarified. McGinty and his colleague Shira M. Lupkin thus set out to better understand how these neurons contribute to the decision-making process.

"This is an important question because harmful changes in decision behavior as well as OFC function occur in many neuropsychiatric disorders, including substance abuse, depression and obsessive–compulsive disorder (OCD)," McGinty said. "To answer it, we took inspiration from a second line of research, a different branch of decision neuroscience that focuses not on subjective preferences, but instead focuses on visual perception and visual judgments."

In the context of this study, the term "visual judgment" refers to decisions that primates make based on something they see. An example of this would be the judgment made by a soccer goalkeeper who is trying to decide what direction the ball is going in, so that he/she can move in that direction.

Notably, visual judgments have an objectively correct answer (i.e., in the goalkeeper example, the direction the ball will ultimately go in), and this answer can be derived from sensory information encoded by the primate visual system. The neuroscientist Bill Newsome was among the first to closely examine these visual judgments, through a series of experiments engaging macaque monkeys.

"In these experiments, macaque monkeys were asked to judge the direction of motion that they perceived in a field of moving dots on a visual display (e.g., left vs. right). In some trials, the net direction was very easy to judge because the dots all moved in one consistent direction," McGinty explained. "But in other trials, the direction of net motion was ambiguous, and in those instances, the decisions that the monkey made—their perceptual judgments—were variable."

Decades ago, Newsome and his colleagues found that the variability in the choices of macaque monkeys during their experiments could be explained as a function of the activity of single motion-sensitive neurons in their visual system. In other words, they found a link between the behavior of the monkeys and the variability in the activity of individual neurons.

"This was a very powerful finding because it showed that even subtle fluctuations in neural activity were 'read out' by downstream neural circuits in a way that directly affected perception and judgment," McGinty said. "This and other follow-up studies showed that these motion-sensitive neurons are most likely to drive the perception of motion in the primate brain."

In their study, McGinty and Lupkin tried to find a neural-behavioral link resembling that observed by Newsome in his experiments. However, instead of focusing on visual judgments, they looked for a similar link between value-based decisions and the activity of value-coding OFC neurons.

"Previous studies that looked for this link found only a very weak association between the activity of individual OFC neurons and value-based decisions," McGinty said. "These weak results were surprising, because other studies (e.g., using lesions of OFC) clearly show that OFC is somehow involved in value-based choices. But without identifying the link between OFC activity in behavior, it will be impossible to understand what exact role it plays."

To overcome challenges encountered in previous studies, the researchers drew inspiration from a third line of research that examines the coding of information in the brain at the level of neuron populations.

"The idea of population coding is that the brain represents information over a distributed ensemble of many neurons that are active simultaneously," McGinty said. "This means that if you want to understand the information represented in a particular part of the brain, measuring individual neurons one-at-a-time is not sufficient. Instead, you need to measure the activity of many neurons simultaneously, and you need an analysis approach that decodes that information based on all the neurons that you're measuring at once."

The key objective of the study was to understand the contribution of neurons in the OFC to simple value-based decision, but looking at the activity of populations of neurons recorded simultaneously, rather than looking at individual neurons. To do this, they recorded the activity of neuron populations in the OFC of macaque monkeys as they completed a value-based decision-making task.

"We trained macaque monkeys to play a simple decision-making game where in every trial we ask them to choose between two objects on a visual display," McGinty said. "Each object was associated with a juice reward of 1, 2, 3, 4 or 5 drops, which was delivered to the monkey when chosen. Importantly, we frequently offered the monkey two objects that were physically distinct but worth the same amount of juice. These were the most important decisions for our study: because the two options were equally valuable, we expected the monkeys' choices to be variable from one trial to the next; our goal was to explain this variability as a function of neural activity."

As monkeys played this simple game, the researchers monitored activity in their OFC using a neural recording technique that measures the activity of dozens of neurons simultaneously. They then analyzed these recordings in conjunction with the decisions that the monkeys made during the game.

"We wished to predict the variability in the monkeys' decisions on the equal-value trials as a function of variability in the ensemble of OFC neurons," McGinty said. "To do this we used a decoding method that identified the multi-neuron patterns of activity that represented the values of the options that were offered to the monkey on each trial."

Essentially, McGinty and Lupkin assigned a weight to every neuron they recorded, which corresponded to the neuron's sensitivity to value. They then computed the weighted sum of the activity of the recorded neurons during each trial.

"This approach summarizes the activity of all the simultaneously recorded neurons and distills that activity down to a single number," McGinty said. "You can think of this number (i.e., the weighted sum of neural activity) as a neurally derived estimate of the value representation encoded by all the recorded neurons on that trial. We then measured how well the variability in the monkeys' decision behavior on the equal-value trials could be explained by variability in this neurally derived estimate of the population representation of value."

The findings of this study are aligned with those of previous works, as it found weak associations between individual OFC neurons and the choices of monkeys during value-based decision-making tasks.

"Finding a link between ensemble-level OFC value signals and behavior resolves a mystery about the function of the primate orbitofrontal cortex," McGinty said. "Based upon the previous evidence from single neurons, it was unclear whether the value-coding neurons were contributing to decision-making.

"But using these ensemble-level decoding methods we can show very clearly the relationship between variability in value representation and variability in choice. This is one of the key building blocks necessary to establish that the neurons of the orbitofrontal cortex are responsible for creating the sense of subjective value that ultimately dictates our actions."

McGinty and Lupkin also performed follow-up analysis, isolating the multi-neuron activity patterns corresponding to the monkeys' choice, independently from patterns that represented their values. Notably, they found that the neural activity patterns associated with the choice and with value encoding overlapped, but they were not precisely the same.

"This means is that some of the choice-related activity patterns in the orbitofrontal cortex can be attributed to the value manipulation that we performed in this study," McGinty said. "But the OFC also has other choice-related activity patterns that are not related to value, or at least not related to the reward magnitude manipulation that we used here.

"This is an intriguing finding because it suggests that orbitofrontal cortex could potentially represent multiple behaviorally relevant variables (e.g., the probability of a given reward) that could align with the choice-related activity patterns in this area."

The recent study by this team of researchers highlights the link between the value-based decisions of primates and the activity of neuron populations in their OFC, which could be explored further in future experiments. Ultimately, the results it gathered shed new light on the neural basis of healthy everyday decision-making, which could offer insight into how these mechanisms can change in those suffering from various mental illnesses.

"In value-based decision making, we know that value isn't just related to the magnitude of an upcoming reward, but also to other factors such as probability, effort, delay, and the physical properties of the outcome itself (e.g., ice cream vs. potato chips)," McGinty added.

"One of the things we want to understand in the future is how these other variables are represented in the orbitofrontal cortex, and how the multi-neuron patterns related to these variables are related to the choice-related patterns that we've been able to identify. Another important high-level question is how these patterns adapt and change over the course of learning or in different contexts."

More information: Vincent B. McGinty et al, Behavioral read-out from population value signals in primate orbitofrontal cortex, *Nature Neuroscience* (2023). DOI: 10.1038/s41593-023-01473-7