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Study Reveals Primates, and Their Neurons, in the Act of Reasoning

Every day humans make thousands of decisions, small and large, based on the information at hand and their assessment of the potential outcome of those choices.

Now, in a pioneering study of rhesus macaque monkeys, a team of researchers from the Howard Hughes Medical Institute (HHMI) at the University of Washington has caught primates in the act of probabilistic reasoning. They have measured the electrical activity at play in brain cells as the animals make a choice based on their interpretation of a set of visual cues and the potential for reward.

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— **Michael N. Shadlen**

Writing June 3, 2007 in an advance online publication of the journal *Nature*, a team of researchers led by HHMI investigator Michael N. Shadlen at the University of Washington describes experiments in which monkeys learned to base their decisions on the combined probabilities for reward of a random sequence of shapes presented on a video screen. In the process, Shadlen and colleague Tianming Yang, also of the University of Washington, measured the response of neurons in a region of the brain associated with vision, motor planning and attention.

It's amazing the monkeys can do this, said Shadlen, and it's pretty incredible you can find neurons in the brain that are doing these calculations.

The new findings are important because they lend insight into how the brain calculates the odds of an outcome from a set of symbols and combines the information over time to arrive at a decision. Thus, Shadlen and Yang conclude, We have demonstrated a crude capacity for probabilistic inference in monkeys — a capacity that might underlie cognitive reasoning in humans.

Teasing out these big secrets of the brain, Shadlen said, may one day help guide therapies for a host of neurological disorders, including schizophrenia,

dementias, and neurodegenerative diseases.

We don't know how the brain actually works, Shadlen explained. This gives us some insight into what the underlying neural computations are.

Humans routinely make judgments based on information that can influence, but does not assure, a desired outcome. Our brains, however, have the capacity to reason about alternatives and opt for a course of action most likely to pay dividends.

Decisions do involve taking information at moments in time and combining them to make the best choices, said Shadlen. Shadlen and his colleagues sought to test the idea that a part of the brain known as the parietal cortex — which gathers sensory information for decision-making — also performs calculations that underlie probabilistic reasoning. To approach this question, they trained two monkeys to perform a probabilistic categorization task adapted from a technique used to study human learning and memory.

When presented with a random series of four shapes at half-second intervals, the monkeys were trained to move their eyes to either a red or green target to receive a liquid reward. The different shapes were weighted and the sum of the four weights associated with the shapes established the odds of reward. The four shapes that come up are drawn from a set of 10. There are ton of potential hands, to use a poker analogy, that can come up, said Shadlen. Monkeys can only perform the task by combining evidence from shapes instead of memorizing all possible hands.

At the same time the monkeys were making their choices, Shadlen and Yang recorded the electrical activity of cells in the parietal cortex. The sampled neurons, according to Shadlen, are translating sensory information as a quantity that is encoding probability or a degree of belief. They're adding up numbers.

Shadlen likened the process to the technique famed mathematician and code breaker Alan Turing used to break the German Enigma code in World War II. Deconstructing that cipher depended on an algorithm Turing devised to identify the settings of the rotors used in the German encryption machines. Turing accumulated evidence in support of a rotor configuration by aligning letters from two intercepted messages and looking for matches in the sequence of letter pairs. He kept a running sum of evidence in the form of logarithms of probabilities.

Our brains turn out to do the same thing, said Shadlen. As neurons gather sensory input, in this case visual information, the information is added up and the sum, ultimately, dictates a choice. It allows us to take pieces of information and weigh them, to compare apples and oranges, said Shadlen. You have to consult different sources of evidence about the relative probability of things that occur in the world. The neurons in our study were not only able to hold on to information from one shape or another, but were able to combine this information with the information from another shape, and they weigh the information appropriately, just as a human reasoner gives

more or less weight to evidence that is more or less predictive of an outcome.

In the new study, the monkeys learned to combine probabilistic information from the shape combinations to make their choice. This phenomenon, argued Shadlen, can be a window to activity in the brain critical to its core functions: Decision-making can be a model for many kinds of higher functions, we think. I think what we're really studying here is cognitive function. That's the essence of understanding how the human brain works, he said.