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Brain Communicates In Analog And Digital Modes Simultaneously

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Summary: Contrary to popular belief, brain cells use a mix of analog and digital coding at the same time to communicate efficiently, according to a study by Yale School of Medicine researchers published this week in Nature.

FULL STORY

Contrary to popular belief, brain cells use a mix of analog and digital coding at the same time to communicate efficiently, according to a study by Yale School of Medicine researchers published this week in Nature.

This finding partially overturns a longstanding belief that each of the brain's 100 billion neurons communicate strictly by a digital code. Analog systems represent signals continuously, while digital systems represent signals in the timing of pulses. Traditionally, many human-designed circuits operate exclusively in analog or in digital modes.

"This study reveals that the brain is very sophisticated in its operation, using a code that is more efficient than previously appreciated," said David McCormick, professor in the Department of Neurobiology and senior author of the study. "This has widespread implications, not only for our basic understanding of how the brain operates, but also in our understanding of neuronal dysfunction."

"It's as if everyone thought communication in the brain was like a telegraph, but actually it turned out to be more similar to a telephone," he said.

Neurons receive input from other cells largely through synaptic contacts on their dendrites and cell bodies. The release of neurotransmitters at these synapses causes the voltage inside the cell receiving the transmitters to fluctuate continuously. Once this voltage passes a threshold, an action potential is generated. The action potential is a specialized waveform known to be able to travel down the axon, or output portion of the cell.

Due to its length and thinness, the nerve axon has been believed to be impassable to the smaller analog voltage deflections that gave rise to action potential. As this action potential reaches the synaptic terminals of the axon, it causes the release of a transmitter onto the next neurons in the chain. So, although signals in the cell body are represented in an analog fashion, they were thought to be transmitted between cells solely through the rate and timing of the action potentials that propagated down the axon, that is, in a digital fashion.

McCormick's group demonstrated that the analog signal present in the cell body also propagates down the axon and influences synaptic transmission onto other neurons. As the voltage on the sending cell becomes more positive, the amplitude of the subsequent transmission to the receiving cell, mediated by an action potential, is enhanced. This means that the waveform generated in the receiving neuron is not just determined by the digital pattern of action potentials generated, but also by the analog waveform occurring in the sending neuron.

For example, McCormick said, epileptic seizures and the aura of migraine headache both involve large changes in the voltage inside neurons. He said this study indicates that these abnormal patterns of activity may be directly communicated to nearby neurons, even in the absence of the generation of the digital code of action potential activity.

McCormick said future investigations and models of neuronal operation in the brain will need to take into account the mixed analog-digital nature of communication. Only with a thorough understanding of this mixed mode of signal transmission will a truly in depth understanding of the brain and its disorders be achieved, he said.

The first author is Yousheng Shu of Yale. Co-authors are Andrea Hasenstaub, Alvaro Duque and Yuguo Yu of Yale.

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