Cracking the Perception Code

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The brain may interpret the information it receives from sensory neurons using a code more complicated than scientists previously thought, according to new research from the National Autonomous University of Mexico and Cold Spring Harbor Laboratory. By studying how monkeys perceive a vibrating object when it touches the skin, scientists found that changes in an animal's attention over time influence how a sensory signal is interpreted.

Howard Hughes Medical Institute (HHMI) international research scholar Ranulfo Romo of the Institute of Cellular Physiology at the National Autonomous University of Mexico and his colleagues—Rogelio Luna and Adrián Hernández, also of the National Autonomous University of Mexico, and Carlos D. Brody of Cold Spring Harbor Laboratory in New York—report their results in the September 2005 issue of the journal Nature Neuroscience, published online July 31, 2005.

Neuroscientists already knew that touching the skin with a vibrating object causes specialized sensory neurons in the brain to fire, and that firing of these neurons, which are found in a region of the brain known as the primary somatosensory cortex, is directly related to monkeys' ability to tell how fast something is vibrating, Romo said. But the neurons' firing patterns are complex, and it's been tricky to tease out "which component of the neuronal activity was more likely associated with behavioral performance," he explained.

Theoretically, there are many ways in which neurons could relay information about stimulus frequency, Romo said. Frequency information might be encoded in the time between consecutive neuronal firings, the overall rate of firing, or the number of times a neuron fires.

To distinguish among these possibilities, Romo and his colleagues designed an experiment in which they touched the monkeys' fingertips with a vibrating but painless probe for varying lengths of time. The monkeys were first taught to respond to varying vibration frequencies; in a training session, the scientists touched the monkeys twice in a row, with the probe vibrating at a different frequency each time. The monkeys signaled to the experimenters which stimulus was vibrating faster, and, when they were correct, they were rewarded with a treat.

The standard stimulus that the scientists trained the monkeys to respond to lasted 500 milliseconds (half a second). They found that when they used a stimulus that lasted 750 milliseconds instead, the monkeys consistently thought the probe was vibrating with a higher frequency than it actually was. The same thing happened in reverse; if a stimulus was given for only 250 milliseconds, the monkeys thought it was vibrating at a lower frequency. The effect was stronger for the shortened stimulus than for the lengthened stimulus, Romo noted.

Based on this experiment, it seemed most likely that the monkeys were determining the vibration frequency by the number of times the neurons fired, Romo said, since the firing rate and time between firings wouldn't change just because the stimulus duration changed.

The scientists knew they hadn't quite cracked the neural code, though, because the magnitude effects weren't right; the monkeys thought that a stimulus that was 50 percent shorter was vibrating at just a slightly lower frequency than it was—not 50 percent lower.

To find the cause of this discrepancy, they recorded electrical activity in single neurons of the primary somatosensory cortex.

Since the shortened stimulus had produced a greater effect than the lengthened stimulus, the researchers wondered if the first part of the response might be more significant in determining vibration frequency.

They explored two possible mechanisms of action: the neural firing response could adapt to the stimulus over time, making the neurons more sensitive at the beginning than at the end, or a perceptual process after neuronal firing could give more subjective weight to the beginning of the response.

Looking at the electrical responses from single neurons, Romo and his colleagues determined that, if all the neuronal firings were treated equally, these responses could not explain the monkeys' perception of the signal. If the researchers assumed that the monkeys paid more attention to the beginning of the response, however, the neural activity perfectly explained the monkeys' errors when judging different durations of stimuli.

Romo suggested that the best explanation for the behavioral data was to assume that the monkeys pay the most attention to the first 250 milliseconds of neural firing, and that their attention falls off exponentially from there. The longer the stimulus, the less important additional neuronal firings become to the monkeys' perception of how fast the stimulus is vibrating, even though they continue to pay some attention throughout.

Figuring out how the brain codes sensory information into neuronal firing and how the firing patterns are interpreted by perceptual areas of the brain is a huge challenge in neurophysiology, one that's often overlooked, said Romo.

“The neuronal correlates reported in most of the neurophysiological studies in the different sensory modalities simply do not pay attention to this," he noted. "They assume that variation in firing rate is enough as a measure."

Source: Howard Hughes Medical Institute