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Noisy Brain May Help Learning

While most people need peace and quiet to cram for a test, the brain itself may need noise to learn, a recent study suggests. In experiments with monkeys, the researchers found that neural activities in the brain gradually change, even when nothing new is being learned. Challenging the monkeys to adjust their task triggered systematic changes in their neural activities on top of this background “noise.”

The researchers said their findings suggest a new theory of how the brain learns. Traditional views held that learning occurs by rewiring neural circuitry that is normally stable. In contrast, the new theory proposes that neural circuitry is continually being rewired, even during behavior that does not change. According to the theory, this neural rewiring normally remains invisible at the behavioral level because the brain's motor cortex is redundant; many wiring configurations can accomplish the same behavior.

“What surprised us most was that the neural representation of movement seems to change even when behavior doesn't seem to change at all,” said Howard Hughes Medical Institute investigator Sebastian Seung, who led the mathematical analysis and modeling components of the study. “This was a surprising degree of instability in the brain's representation of the world.”

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The new theory suggests that motor cortex drifts between behaviorally equivalent wiring configurations because of an ongoing noisy learning process. The noise component changes connections between neurons randomly, while the learning component corrects the connections in order to maintain the behavior. When a new task needs to be learned, the learning component makes the appropriate changes in the connections while the noise

component adds random changes. As a result, neural activities show task related changes on top of random background changes.

Seung and Emilio Bizzi, both at the Massachusetts Institute of Technology, led the study, which was published in the May 24, 2007, issue of the journal *Neuron*. Bizzi's lab conducted the experimental portion of the study. The lead author on the study was Uri Rokni in the Seung laboratory.

The researchers were motivated to develop their theory by findings that Bizzi and colleagues published in 2004. In experiments with macaque monkeys, Bizzi's students, Andrew Richardson and Camillo Padoa-Schioppa, measured neural activities in the motor cortex while the animals manipulated a handle to move a cursor to targets on a screen. In control experiments, the monkeys had to move the cursor to targets in the same way they had been trained. In learning experiments, the monkeys had to adapt their movements to compensate for novel forces applied to the handle.

Bizzi and his colleagues found that even when the monkeys were performing the familiar control task, their neural activities gradually changed over the course of the session.

To explore the significance of these background changes, Rokni analyzed the data from the learning component of Bizzi's experiments. He found he could distinguish learning-related neural changes from the background changes that occurred during the control experiments. From this analysis, Rokni developed a working theory that combined the concepts of a redundant neural network and that of a “noisy” brain.

“A good analogy to redundant circuitry, which accomplishes the same behavior by different wiring configurations, would be a piece of text, in which you can say the same thing with different words,” Rokni explained. “Our theory holds that the learning brain has the equivalent of a ‘teacher’ and a ‘tinkerer’—a learning signal and noise in the learning process, respectively. In producing a specific piece of text, the tinkerer just randomly changes the words, while the teacher continually corrects the text to make it have the right meaning. The teacher only cares about the meaning and not the precise wording. When the teacher and tinkerer work together, the text keeps changing but the meaning remains the same. For example, the tinkerer may change the sentence “John is married” to “John is single,” and the teacher may correct it to “John is not single.” In the same way, learning in the brain has two components--error-correction and noise--so that even though the neural representation keeps changing, the behavior remains fixed. We think the tinkerer, that is the noise, is not merely a nuisance to the teacher, but is actually helping the teacher explore new possibilities it wouldn't have considered otherwise.”

To test this idea, Rokni constructed a mathematical model of a redundant cortical network which controls movement, and used it to simulate the

learning experiment with the monkeys. In this model, learning of the connections between neurons was assumed to be a considerably noisy process. "When we ran the simulation long enough, the performance became good, but the neural representation kept changing, very similar to the experiments," Rokni said.

According to Rokni, the concepts of redundant networks and "noisy learning" have important implications for neurobiology. "I don't think this concept of redundancy—that the brain can say the same thing in different ways—has really been fully appreciated until now," he said. "Also, investigators did not anticipate that the neural representation is constantly changing, even when there is no learning going on. And even though the idea that noise is necessary for learning is not new, our findings present important evidence to support that concept.

"More practically, people who are constructing devices that translate brain signals to operate such external devices as neural prostheses will have to take such constantly changing neural representations into account," said Rokni.

The researchers plan to explore further how the brain searches for neural activity patterns that are appropriate for a given task. It is difficult to study this question with conventional animal experiments, because the relationship between neural activities and muscle activation is not fully known. For this reason, the researchers plan to work with colleagues who are developing brain-machine interfaces, in which implanted electrodes decipher brain signals that correspond to specific motor behaviors. Using such interfaces, the researchers hope to learn more about how the brain changes its neural activities to improve behavior, said Rokni.