NEUROSCIENCE

Magnetic Brain Imaging Traces A Stairway to Memory

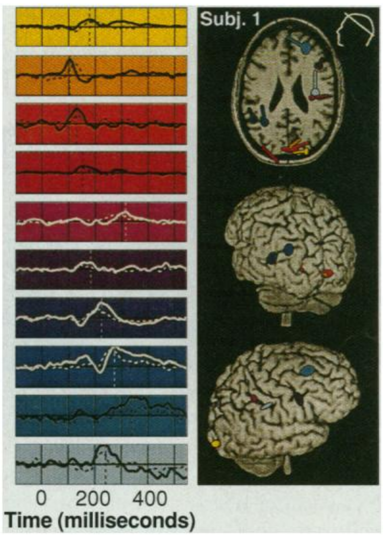
LOS ANGELES—"And we forget because we must/And not because we will," declared the poet Matthew Arnold. We are all familiar with the dimming—sometimes gradual, sometimes almost instantaneous—of visual memories. But poetic insight could not have revealed what Samuel Williamson of New York University (NYU) and his colleagues found when they used a novel brain-imaging technique to trace in real time how the human brain processes and stores a visual stimulus. The team discovered that visual memories—some vanishingly brief and some longer lasting—form in many different places along the processing pathway.

By monitoring the subtle magnetic fields that sprout from the skull, Williamson and his colleagues Mikko A. Uusitalo and Mika T. Seppä of the Brain Research Unit at the Helsinki University of Technology in Finland were able to watch how neuronal firing marched along the entire visual pathway—the first time that's been done for the human brain. The result was a motion picture of the neural processing of a visual stimulus—and an unexpected discovery. "In every location where you have a response to a [visual] stimulus, it establishes a memory," said Williamson when he presented the work at a meeting of the American Physical Society here 2 weeks ago. The data imply, says Williamson, that each site has a distinct "forgetting time," ranging from tenths of a second in the primary visual cortex—the first stage of raw processing—to as long as 30 seconds farther downstream.

"I think it's a plausible hypothesis," says Susan Courtney of the Laboratory of Brain and Cognition at the National Institute of Mental Health in Bethesda, Maryland. What's more, because the forgetting times Williamson has clocked become increasingly long, some researchers suggest that he may even have uncovered a stairway into long-term memory—a progression leading to the storage of more permanent representations. "It's the beginning of a very interesting study of the transition from signals into symbols in the brain," says Jack Cowan, a mathematician and brain researcher at the University of Chicago.

Earlier work, some of it by Courtney, had already implicated some of the regions with the longer persistence times in "working memory," the short-term storage that holds information for immediate use (*Science*, 27 February, p. 1347). Courtney had mapped these memory areas with a technique called functional magnetic resonance imaging, or fMRI, which traces surges in blood flow to working parts of the brain. But although fMRI can make accurate spatial maps of widespread brain activity, its time resolution—generally a few seconds—means it can't capture fast changes in isolated patches, which is what researchers need to do if they want a more detailed picture of how the brain is working.

The technique Williamson used—variously called magnetic source imaging (MSI) and magnetoencephalography (MEG)—handily picks up these rapid activity changes (*Science*, 27 June 1997, p. 1974). In MSI, the subject's head is surrounded by an array of hypersensitive magnetic detectors called SQUIDs, for superconducting quantum interference devices. SQUIDs consist of tiny loops of superconductor interrupted by an insulating gap. They can pick up the minute magnetic fields generated by neurons firing in the brain, because magnetic fields change the rate at which electrons "tunnel" across the gap, altering the current. "These SQUIDs are the most sensitive detectors for magnetic fields ever made," says J. A. Scott Kelso of Florida Atlantic University in Boca Raton. In brain studies, he says, the SQUIDs pick up changing fields a billionth as strong as Earth's magnetic field.



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Moving picture. Magnetic signals show that the visual cortex (yellow and red) is the first brain region to respond to a checkerboard pattern, followed by higher order processing regions (blue).

Working with three subjects, Williamson's team put this sensitivity to work in monitoring the cascade of firing set off when each subject glimpsed a checkerboard pattern for about a tenth of a second. In quick succession, over less than half a second, about a dozen patches lighted up like pinball bumpers, starting with the primary visual cortex in the occipital lobe at the back of the brain. The excitation darted up both sides of the brain, touching other cortical areas, such as the right prefrontal cortex and the left parieto-occipito-temporal junction. "The cortex is processing information, and that processed information goes back down into the thalamus"—a routing switchboard deep in the brain—"and comes popping back up to another place," says Williamson, who is in the Department of Physics and the Center for Neural Science at NYU.

The team members then did another round of tests in which they showed the checkerboard twice, with a varying time interval between the displays, to see whether the first stimulus had left any kind of impression along the way. For very brief intervals—10ths of a second—only the areas of initial processing in the back of the brain fired on the second flash, while the others were silent. Williamson interprets this response pattern to mean that the primary visual cortex had already shunted the information off and "forgotten" it, while areas further downstream still "remembered." But as the interval was increased to 10, 20, or even 30 seconds, the downstream areas began firing on the second flash, with a strength finally approaching that of the initial pop. The memories decayed with the simplicity of a capacitor discharging electricity—exponentially with time—and the later an area's place in the processing queue, the longer its memory time was.

"That's an interesting clue as to the nature of the higher order processing" of visual information, says Cowan. "It's an important result," adds Eric Halgren, a neurophysiologist at the University of Utah in Salt Lake City, who is especially impressed with the remarkably simple falloff of the memories within the complicated network of the brain. He nevertheless counsels "some caution," because it can be difficult to trace an MSI signal to a specific site in the brain. Williamson says these ambiguities are most troublesome for widespread activity deep in the brain, not the shallow patches he monitored in the visual system.

Kelso, whose own MEG studies of magnetic activity synchronized with motor tasks will be published soon, adds that the technique's spatial ambiguities are worth wrestling with for the sake of the timing information, which is critical for unraveling the workings of the brain. "If you tell me where the game is, that's useful information," says Kelso. "But if you want to know the rules of the game, you need to look at the time-dependent dynamics. Williamson in this particular task is looking at those kinds of things, and I think that's what's very exciting here."

–**James Glanz**