MEG Matters

MIT’s New Magnetoencephalography Lab Delivers Results
A new brain scanner at the McGovern Institute is revealing insights into visual perception, attention and the neural basis of autism.

Somewhere nearby, most likely, sits a coffee mug. Give it a glance. An image of that mug travels from desktop to retina and into the brain, where it is processed, categorized and recognized, within a fraction of a second. All this feels effortless to us, but programming a computer to do the same reveals just how complex that process is. Computers can handle simple objects in expected positions, such as an upright mug. But tilt that cup on its side? “That messes up a lot of standard computer vision algorithms,” says Leyla Isik, a graduate student in Tomaso Poggio’s lab at the McGovern Institute.

MEG works in a way that is fundamentally different from the more familiar MRI scanner. Unlike MRI, it involves no external magnetic field. Instead, it uses an array of extraordinarily sensitive detectors, chilled to near absolute zero by liquid helium, to measure the tiny magnetic fields that are naturally produced by our brains and whose rapid fluctuations, recorded at the surface of the head, can reveal profound insights into what’s happening inside.

MEG scanners are not cheap, but with the help of several generous donors we were able to acquire a state-of-art system in 2011, and I am happy to report that our investment is starting to bear rich fruit. I have been using MEG in my own research on attention, and it is also used by many other groups within and beyond MIT, to study questions ranging from vision to autism. We can’t predict what they will discover next, but I am confident that when we put powerful technology within reach of an unparalleled community of brain researchers, exciting science is sure to emerge.

Bob Desimone, Director
Doris and Don Berkey Professor of Neuroscience

On the cover:
The combination of magnetoencephalography and MRI can reveal timing and localization of brain function with unprecedented precision.

Image: Dimitrios Pantazis
MIT’s new magnetoencephalography lab is starting to deliver results

For her thesis research, Isik is working to build better computer vision models, inspired by how human brains recognize objects. But to track this process, she needed an imaging tool that could keep up with the brain’s astonishing speed.

In 2011, soon after Isik arrived at MIT, the McGovern Institute opened its magnetoencephalography (MEG) lab, one of only a few dozen in the entire country. MEG operates on the same time-scale as the human brain. Now, with easy access to a MEG facility dedicated to brain research, neuroscientists at McGovern and across MIT—even those like Isik who had never scanned human subjects—are delving into human neural processing in ways never possible before.

The Making of...

MEG was developed at MIT in the early 1970s by physicist David Cohen. He was searching for the tiny magnetic fields that were predicted to arise within electrically active tissues such as the brain. Magnetic fields can travel unimpeded through the skull, so Cohen hoped it might be possible to detect them noninvasively. Because the signals are so small—a billion times weaker than the magnetic field of the Earth—Cohen experimented with a newly invented device called a SQUID (short for superconducting quantum interference device), a highly sensitive magnetometer. In 1972, he succeeded in recording alpha waves, brain rhythms that occur when the eyes close. The recording, scratched out on yellow graph paper with notes scrawled in the margins, led to a seminal paper that launched a new field. Cohen’s prototype has now evolved into a sophisticated machine with an array of 306 SQUID detectors contained within a helmet that sits over the subject’s head like a giant hair dryer.

As MEG technology advanced, neuroscientists watched with growing interest. Animal studies were revealing the importance of high-frequency electrical oscillations such as gamma waves, which appear to have
“An engineer might have picked a different site, but we cannot overstate the importance of having MEG right here, next to the MRI scanners and easily accessible for our researchers.”

To run the new lab, Desimone recruited Dimitrios Pantazis, an expert in MEG signal processing from the University of Southern California. Pantazis knew a lot about MEG data analysis, but he had never actually scanned human subjects himself. In March 2011, he watched in anticipation as Elekta engineers uncrated the new system. Within a few months, he had the lab up and running.

**Computer Vision Quest**

When the MEG lab opened, Isik attended a training session. Like Pantazis, she had no previous experience scanning human subjects, but MEG seemed an ideal tool for teasing out the complexities of human object recognition.

She recorded the brain activity of volunteers as they viewed images of objects in various orientations. She also asked them to track the color of a cross on each image, partly to keep their eyes on the screen and partly to keep them alert. “It’s a dark and quiet room and a comfy chair,” she says. “You have to give them something to do to keep them awake.”

To process the data, Isik used a computational tool called a machine learning classifier, which learns to recognize patterns of brain activity evoked by different stimuli. By comparing responses to different types of objects, or similar objects from different viewpoints (such as a cup lying on its side), she was able to show that the human visual system processes objects in stages, starting with the specific view and then generalizing to features that are independent of the size and position of the object.

Isik is now working to develop a computer model that simulates this step-wise processing. “Having this data to work with helps ground my models,” she says. Meanwhile, Pantazis was impressed by the power of machine learning classifiers to make sense of the huge quantities of data produced by MEG studies.

With support from the National Science Foundation he is working to incorporate them into a software analysis package that is widely used by the MEG community.

**Mixology**

Because fMRI and MEG provide complementary information, it was natural that researchers would want to combine them. This is a computationally challenging task, but MIT research scientist Aude Oliva and postdoc Radoslaw Cichy, in collaboration with Pantazis, have developed a new way to do so. They presented 92 images to volunteers subjects, once in the MEG scanner, and then again in the MRI scanner across the hall. For each data set, they looked for patterns of similarity between responses to different stimuli. Then, by aligning the two ‘similarity maps,’ they could determine which MEG signals correspond to which fMRI signals, providing information about the location and timing of brain activity that could not be revealed by either method in isolation. “We could see how visual information flows from the rear of the brain to the more anterior regions where objects are recognized and categorized,” says Pantazis. “It all happens within a few hundred milliseconds. You could not see this level of detail without the combination of fMRI and MEG.”
Another study combining fMRI and MEG data focused on attention, a longstanding research interest for Desimone. Daniel Baldauf, a postdoc in Desimone’s lab, shares that fascination. “Our visual experience is amazingly rich,” says Baldauf. “Most mysteries about how we deal with all this information boil down to attention.”

Baldauf set out to study how the brain switches attention between two well-studied object categories, faces and houses. These stimuli are known to be processed by different brain areas, and Baldauf wanted to understand how signals might be routed to one area or the other during shifts of attention. By scanning subjects with MEG and fMRI, Baldauf identified a brain region, the inferior frontal junction (IFJ), that synchronizes its gamma oscillations with either the face or house areas depending on which stimulus the subject was attending to—akin to tuning a radio to a particular station.

Having found a way to trace attention within the brain, Desimone and his colleagues are now testing whether MEG can be used to improve attention. Together with Baldauf and two visiting students, Yasaman Bagherzadeh and Ben Lu, he has rigged the scanner so that subjects can be given feedback on their own activity on a screen in real time as it is being recorded. “By concentrating on a task, participants can learn to steer their own brain activity,” says Baldauf, who hopes to determine whether these exercises can help people perform better on everyday tasks that require attention.

Postdoc Daniel Baldauf and visiting student Yasaman Bagherzadeh are using MEG to study attention.

In addition to exploring basic questions about brain function, MEG is also a valuable tool for studying brain disorders such as autism. Margaret Kjelgaard, a clinical researcher at Massachusetts General Hospital, is collaborating with MIT faculty member Pawan Sinha to understand why people with autism often have trouble tolerating sounds, smells and lights. This is difficult to study using fMRI, because subjects are often unable to tolerate the noise of the scanner, whereas they find MEG much more comfortable.

In the scanner, subjects listened to brief repetitive sounds as their brain responses were recorded. In healthy controls, the responses became weaker with repetition as the subjects adapted to the sounds. Those with autism, however, did not adapt. The results are still preliminary and as-yet unpublished, but Kjelgaard hopes that the work will lead to a biomarker for autism, and perhaps eventually for other disorders.

In 2012, the McGovern Institute organized a symposium to mark the opening of the new lab. Cohen, who had invented MEG forty years earlier, spoke at the event and made a prediction: “Big things are probably going to happen here.” Two years on, researchers have pioneered new MEG data analysis techniques, invented novel ways to combine MEG and fMRI, and begun to explore the neural underpinnings of autism. Odds are, there are more big things to come.
Mark Harnett to Join McGovern Faculty

We are pleased to announce that Mark Harnett will join the McGovern faculty, starting in 2015. Harnett is currently a postdoctoral researcher at the Howard Hughes Medical Institute, where he studies the electrophysiological properties of individual neurons, and specifically the biophysical mechanisms that allow dendrites to integrate complex patterns of synaptic input. In recent work, which he plans to continue at MIT, Harnett has begun to examine these issues in awake behaving mice, in order to link biophysical mechanisms to the properties of neural circuits and to the control of behavior.

“Brain Matters” on WBUR

This summer, Boston’s National Public Radio station, 90.9 WBUR, aired a special series on the brain called “Brain Matters.” The weekly program featured interviews with Bob Desimone and Ed Boyden on the future of neuroscience and John Gabrieli’s brain imaging research on dyslexia. The program website also includes cutting-edge brain imagery produced by McGovern scientists, and video profiles of 11 young MIT neuroscientists, including three from the McGovern Institute. For more information visit http://wbur.org/series/brain-matters/

McGovern to Host Symposium on Brain Connectivity

On September 11–13, the McGovern Institute will co-host the Fourth Biennial Conference on Resting State / Brain Connectivity. The conference will take place at MIT’s Kresge Auditorium and will feature talks and poster sessions on technical advances in brain connectivity and applications to neurological and psychiatric diseases.

For more information visit http://martinos.org/brainconnectivity/

State Secretary of Education Visits McGovern Institute

Massachusetts Secretary of Education Matthew Malone visited the McGovern Institute in July to learn more about John Gabrieli’s research on dyslexia. Gabrieli’s team recently discovered differences in brain activity that may help identify dyslexia in children before they start learning to read.

MIT Presents Symposium on Art, Science & Technology

The MIT Center for Art, Science & Technology (CAST) is hosting “Seeing/ Sounding/ Sensing,” a 2-day event with Lore Harp McGovern serving as Honorary Chair. The symposium invites creative artists to join with philosophers, neuroscientists, anthropologists, historians, and other scholars for an intellectual and cultural exchange.

McGovern Investigator Tomaso Poggio will provide commentary to a keynote address by Bruno Latour, a noted philosopher and anthropologist from The Institut d’études politiques de Paris.

According to CAST, “The goal of the symposium is to challenge each domain’s conventional certainty about ‘what is known,’ ‘how we know it,’ or ‘how we can know more,’ and to stimulate new issues for possible cross-disciplinary scholarship in the future.”

The two-day event (September 26–27) is open to the public but registration is required. For more information visit http://arts.mit.edu/cast-symposium/

Secretary Malone (center) with (left to right) Elizabeth Norton, Sara Beach, John Gabrieli, Nadine Gaab, Nancy Duggan and Ola Ozronov-Palchik.
McGovern engineers led by Ed Boyden have developed an optogenetic molecule sensitive enough that neurons can be silenced even by the low level of light that can penetrate the skull. The protein, known as Jaws, makes it possible to do long-term studies noninvasively, without the need for a surgically implanted light source. This approach could pave the way to eventual therapies for epilepsy and other neurological disorders, Boyden says, although much more testing and development is needed.

Researchers in Boyden’s lab and the University of Vienna have created an imaging system that reveals neural activity throughout the brains of living animals. This technique, which can generate 3-D movies of entire brains at the millisecond timescale, could help scientists discover how neuronal networks process information and control behavior.

About 40% of children diagnosed with ADHD will eventually outgrow the diagnosis. By comparing brain activity in adults who recovered from childhood ADHD and those who did not, John Gabrieli’s lab has identified differences between the two groups. These different patterns of activity, seen within a brain system known as the default network, may eventually allow doctors to predict which therapy is likely to work for a given patient.

A separate study from the Gabrieli lab suggests an explanation for why adults find it hard to learn a new language. Unlike children, who naturally learn language habits, adults are impeded by their own efforts to master the complex rules of language.

Researchers in Emilio Bizzi’s lab have shown for the first time that muscle movements can be controlled by applying optogenetics to the spinal cords of animals that are awake and alert.

Feng Zhang has been named a winner of the 2014 Gabbay Award in Biotechnology and Medicine from Brandeis University. Feng will share the award with Jennifer Doudna of the University of California, Berkeley and Emmanuelle Charpentier of Umeå University.

The researchers are being honored for their work on the CRISPR/cas system, a genome editing technology that is expected to transform many areas of biomedical research and may ultimately form the basis of new treatments for human genetic disease.

Michale Fee has been appointed the Glen V. and Phyllis F. Dorflinger Professor in the Department of Brain and Cognitive Sciences.

Ed Boyden, who has been an associate professor in the MIT Media Lab, with joint appointments in the Departments of Brain and Cognitive Sciences and Biological Engineering, was promoted to the rank of full professor on July 1.
MIT Neuroscientists Unite for Summer Retreat

On June 2–3, McGovern researchers joined colleagues from the Picower Institute for Learning and Memory and the Department of Brain and Cognitive Sciences for a joint retreat, held in Falmouth, Cape Cod. The event featured 15 talks and 42 posters and was attended by over 300 researchers.

The McGovern Institute for Brain Research at MIT is led by a team of world-renowned neuroscientists committed to meeting two great challenges of modern science: understanding how the brain works and discovering new ways to prevent or treat brain disorders. The McGovern Institute was established in 2000 by Patrick J. McGovern and Lore Harp McGovern, with the goal of improving human welfare, communication and understanding through their support for neuroscience research. The director is Robert Desimone, who is the Doris and Don Berkey Professor of Neuroscience at MIT and former head of intramural research at the National Institute of Mental Health.

Further information is available at: http://mcgovern.mit.edu