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MEG sharpens focus on human vision
While magnetoencephalography (MEG) progresses clinically in such areas as localization of epilepsy and pre-surgical functional mapping before a tumor resection, basic MEG research is underway in such areas as the diagnosis of traumatic brain injury and to explore how the brain interacts with the senses to impart meaning about the world.

Investigators at the Massachusetts Institute of Technology’s (MIT) MEG lab are unraveling the elemental mechanics of the human visual system, the “what” and “when” of vision once visual information passes from the retina to the brain. Human vision, MIT researchers are finding, is a highly complex process involving low- and high-level neural computations, yet it’s also incredibly fast – much faster than a typical 300 ms eye-blink – and one that requires no conscious effort.

“We produced a first-of-its-kind movie that illustrates how information travels in the human visual cortex in a resolution of milliseconds and millimeters,” says Dimitrios Pantazis, PhD, Director of the MEG Lab at MIT’s McGovern Institute for Brain Research. “Such fidelity opens up tremendous possibilities. For example, even the most advanced machine vision algorithms are hopeless compared to the human visual system. The human brain can teach us how to radically redesign machine vision by replicating human brain function. Additionally, our efforts to understand brain disorders – with our current emphasis on autism spectrum disorders (ASD) – can characterize the nature of hypersensitivities to stimuli, and lead to improved interventions at younger ages.”

With their Elekta Neuromag® TRIUX™ MEG system, MIT researchers are exploring various aspects of the human visual system. MEG can detect the very weak magnetic fields arising from electrical activity in the brain, enabling investigators to monitor the timing of brain activity with millisecond precision. Imaging modalities such as fMRI complement MEG by adding spatial data.

Invariant object recognition

For many computer algorithms for vision, when does a cup cease to be a cup? Answer: when the perspective is shifted to above the cup, radically transforming its appearance. Object transformations frustrate computer algorithms, while human vision solves these “puzzles” effortlessly and unconsciously.

MIT Prof. Tomaso Poggio and doctoral student Leyla Isik are using MEG to study this phenomenon,
known as invariant object recognition. Invariance is a measure of how well the human visual system or computer algorithm recognizes objects despite transformations in their appearance (e.g., size, viewing angle).

To test invariant object recognition in human subjects, Isik presents different objects (e.g., faces, inanimate objects, letters, scenes) while the subject receives a MEG scan. Vision happens automatically, so subjects view the objects without being asked to perform a task. To analyze the MEG data, Isik uses a machine learning algorithm that associates a pattern of MEG activity with the image the subject was shown.

“We found we could very accurately determine which image a subject was viewing just based on the MEG data,” she observes. “In addition, because MEG provides very high temporal resolution, I can see how the neural signals evolve in response to the images.” (Figure 1)

Object recognition in space and time

Investigators Aude Oliva, PhD, Radek Cichy, PhD and Dr. Pantazis, are using MEG and fMRI to study how the visual processing of objects in the human brain evolves in time and space within the first few hundred milliseconds of neural processing.

“We still lack fundamental knowledge on the ‘where’ and ‘when’ of these processes,” Dr. Cichy says. “We’re looking for analogies for how this processing works from a mechanistic viewpoint.”

Subjects are presented with 92 different object images at 1.5- to 2-second intervals while receiving MEG and fMRI scans. The images represent six categories: human and non-human faces and bodies, and natural and artificial objects.

A machine learning algorithm is employed to determine when individual objects are decoded (i.e., “recognized”) based on MEG signals in the brain’s ventral visual pathway. The timing of assignment of objects to their membership in a category (e.g., human v. non-human) also is examined. To obtain spatial information, the MEG results are compared to fMRI responses to the objects.

“Individual images are decoded as early as 60 ms in the primary visual area, whereas the object’s membership in a category is decoded later – ranging from 120 to 170 ms – with further processing in the inferior temporal cortex,” explains Dr. Cichy. “These studies provide an integrated space- and time-resolved view of human object categorization during the first stages of vision. Importantly, this research provides a quantitative link between human visual dynamics and results from studies of the visual system of primate models.” (Figure 2)

Neural basis of attention

Attention to certain visual characteristics of an object is actually guided by widely distributed neural networks in the brain. These networks receive information from early visual areas and relay signals back to improve the integration of this visual information into a concept of the object or its characteristics. Research by Prof. Robert Desimone and Daniel Baldauf, PhD, is helping identify the higher order brain networks responsible for attention and the mechanisms by which they coordinate the refinement of object recognition.

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Figure 2. a) Observers saw 92 different images of everyday objects while their brain activity was measured with MEG and fMRI. b) Combining MEG and fMRI data with representational similarity analysis, MIT researchers showed which part of the brain is active shortly after an image appeared. At about 60ms, only the early visual cortex in the back of the brain was active, a brain region known for early visual analysis. Subsequently, activity spread to brain regions involved in later visual processing, until the inferior temporal cortex was activated, a brain region that represents complex shapes and categories of objects.
An example of how this bottom-up and top-down communication system works might be a scenario in which one is looking for a friend at the airport who is wearing a red sweater. “Knowing your friend is wearing red allows you to selectively concentrate on that color,” Dr. Baldauf explains. “A brain network called the inferior frontal junction [IFJ] would encode the target color red and then selectively engage the areas in the visual cortex that process red. Accordingly, this boosts that visual information over, for instance, green or blue items.”

The use of MEG, fMRI and diffusion tensor imaging (DTI) have helped Dr. Baldauf better understand this process. Experimental subjects are presented with short movies containing images of either houses or faces and – importantly – shown in a specific rhythm to enable frequency tagging and reveal if certain brain areas are coupled.

“If we present something in a 2 Hz rhythm on the screen, we will find some neural networks that also oscillate at 2 Hz,” he says. “We found evidence that the IFJ guides the attentional process. If you attend to a face stimulus, the IFJ becomes functionally coupled with the fusiform face area, and if you attend to a house stimulus, the IFJ connects stronger to an inferior temporal area, the parahippocampal place area, which is more attuned to houses.”

**Visual habituation in autism**

MEG’s ability to measure the brain’s response to repeated stimuli is helping researchers understand Autism Spectrum Disorders (ASD). Profs. Pawan Sinha and Margaret Kjeigaard, and MEG Lab Director Dr. Pantazis, recently completed a study exploring ASD subjects’ and control subjects’ habituation to auditory stimuli. This study showed that ASD subjects demonstrate increasing MEG signal strengthening to periodic auditory stimuli, consistent with a lack of habituation that contrasts with the diminishing MEG signals in the brains of normal control subjects.

“The hypothesis is that kids with ASD cannot properly habituate to stimuli – everything seems new to them and so they tend to avoid stimuli and withdraw into their own world,” researchers Kleovoulos Tsourides and Tapan Gandhi conducting the study, explain. “We’re now moving from testing auditory stimuli to testing visual stimuli to corroborate this sensory hypersensitivity.”

In the visual modality, several experiments are underway. So far, the results have correlated well for the control subjects. “We don’t have results yet for the ASD subjects, but we predict similar behavior as observed with the auditory stimuli,” Dr. Pantazis says. “This would confirm our hypothesis that autistic individuals lack habituation across domains. Such findings could lead to habituation as a biomarker for diagnosing ASD very early in child development.”

**On the horizon**

Dr. Pantazis believes there is a great deal yet to learn in their explorations of the human visual system with MEG.

“We have only scratched the surface,” he says. “I am thrilled with the progress we have made during the three years of our MEG Lab operation. These projects are unique, yet at the same time they complement each other toward a comprehensive understanding of vision. I promise more will come in the near future.”