

Mapping Brain Terrain

Adapted from a Presentation by Rodolfo R. Llinás

Department of Sociology and Biophysics, New York University Medical Center,
550 First Avenue, New York, New York 10016

The brain has revealed many of its secrets during the decade dedicated to its honor. Many of the exquisite techniques used in quite ingenious ways to uncover the workings of the brain involve microanalysis of the chemistry and biophysics of the brain's complex and varied cellular structure.

But, most revelations that can be readily appreciated by a general audience come from the giant leaps made in brain imaging. In this field we can see the human brain in action. We can see the brain registering a sound, a sight, or a touch. We can capture the neural origins of the movement of a finger or toe or the complex movement involved in uttering a word. We can image a thought process.

Skilled investigators are dissecting the inner workings of the mind, seeing behavior in the functioning brain in startling and compelling ways. Herein are described the tools that have revealed much. Investigators such as Marcus Raichle, Richard Frackowiak, and John Mazziotta have pioneered work that is inherently interesting and has a solid application in clinical settings for diagnosis and treatment.

The new advances that allow imaging of the brain are driven by the biology of the brain and its control of its own blood flow, complex physical principles, and computer technology. These several advances of modern technology have enabled us to understand the structure and function of the mind. With the newest technologies we can actually see a thought formulate in the mind. Among these are magnetic encephalography, functional magnetic resonance imaging, and positron emission tomography.

Most of these approaches have become rather well known to the world-at-large. Human brain imaging began in the early seventies with X-ray computed tomography (CT or CAT), which shows only coarse structure. The real underlying advance was the ability to generate, using computers, maps of the brain taken from signals being generated and recorded.

Magnetic resonance imaging (MRI) has since shown us the brain in almost exquisite detail. The technique uses harmless changes in a magnetic field to image the brain. It works in this way: The brain has varied amounts of water depending on the region. Since water is polar, i.e., it is not uniformly charged, the image is generated because, in simple terms, the signal from an area with a higher concentration of water (or other polar molecules) is different from signals from adjacent areas. With increasing magnetic field strength, finer and finer detail has been resolved. Functional MRI (see below) has taken the approach an important step further.

Pioneer studies showing the functioning brain came from people such as Seymour Kety and Louis Sokoloff. They started measuring glucose uptake, oxygen consumption and blood flow in different regions of the brain. Both blood flow and oxygen use increase in a region of the brain that is active. This laid the foundation for an *in vivo* autoradiographic technique, positron emission tomography (PET), which brought function to the center stage of human brain imaging.

To formulate a thought, process a sensation, or perform any other action, the brain needs extra energy. Blood flow increases in the area being employed. PET relies on "excited oxygen" being given to the subject. An array of detectors shows where this oxygen is being used, i.e., where the brain is more active.

More recently, the advent of functional magnetic resonance imaging (fMRI) has given us the capability of learning yet even more about the function of the human brain more readily. The change in blood flow causes the image of the brain detected to change, and this change is highlighted (by showing the active region in, for example, red). Functional magnetic resonance images can be obtained with standard MRI machines; however, in this case, the machine is programmed to detect the changes in the signal while performing a task as compared with the original resting condition.

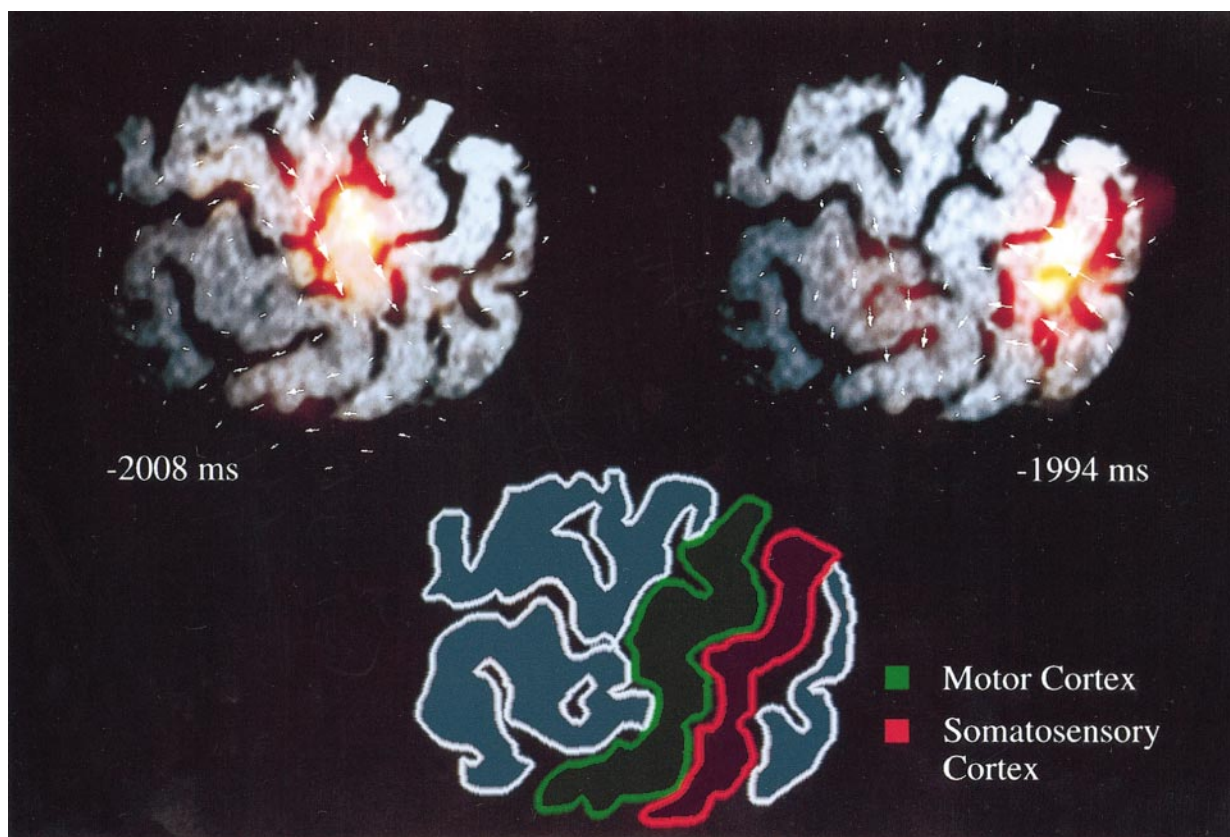


FIG. 1. Magnetoencephalographic images (MEGs) using multiple magnetometer coils. Images show temporospatial electrical activation pattern of the sensory and motor regions of the cerebral cortex as the subject makes voluntary hand movements. The two images on the top row shows activation in both the somatomotor (left) and somatosensory (right) and the time interval between them (12 msec); arrows indicate the direction of current flow. The diagram below indicates the areas of the cortex illustrated above. The MEG images are superimposed on MRIs of the subject's cortex. Yellow indicates area of greatest activity; blue indicates regions of lowest activity. From Lado, Ribary and Llinás (unpublished observation).

Finally, a newcomer in the neuroimaging field is magnetoencephalography (MEG). This new technique produces functional imaging of neuronal electrical activity per se, rather than through changes in blood flow. From that point of view, it must be considered a perfect complement to PET and MRI, which have been so decisive in the description of the morphological aspects of the living brain. Magnetoencephalography measures the small magnetic fields (10^{-14} Tesla) produced by the electrical activity of neurons using pickup coils that are made superconductive by immersion in liquid helium at close to absolute zero degrees. Thus, rather than mapping the anatomy of blood flow, the image

gives the actual message that the neuronal system supports. The time resolution (4000 images per second) is close to 1000 times faster than what may be imaged using fMRI. Indeed, these three systems combined represent the ultimate future in human brain research using noninvasive means.

An example of the type of imaging that can be obtained using MEG is shown in Fig. 1. The electrical organization of the motor and sensory cortices are displayed at 2- to 7-ms intervals, as the subject being imaged waves his hand back and forth. The images show the sequential activation of the motor and somatosensory cortex at different times during movement execution.