Echo-Planar MRI: Learning to Read Minds

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Magnetic resonance imaging (MRI) is a prized weapon in the armamentarium of basic researchers and clinicians, used for everything from studying changes in the brains of schizophrenic patients to diagnosing torn knee ligaments in professional athletes. Yet speed has not been the technique's strong point. Far from it. In fact, because it is slow, during its 20-year history MRI has largely been used for studying static biological structure rather than fast-moving function.

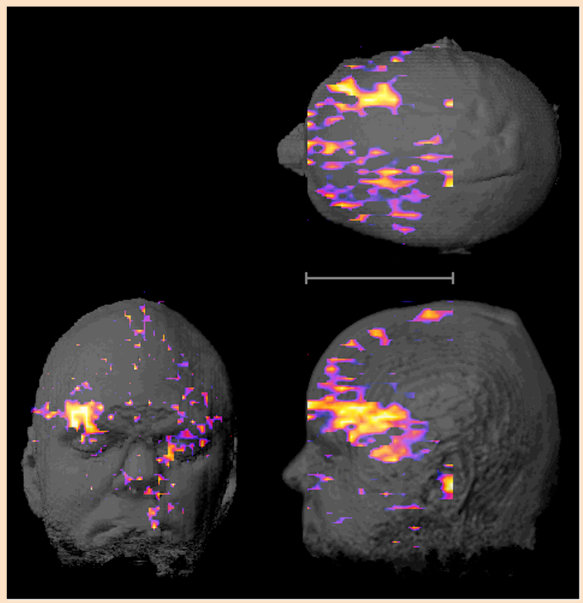
But MRI is no longer the slow kid on the block, thanks to high-performance data acquisition techniques that speed up the time needed to provide complete MR images from several minutes to as little as 30 milliseconds. As a result, echo-planar MRI (EPI)—the collective name for the new techniques—is providing high-resolution images of functional activity in brain, heart, liver, and other tissues. "We've broken the speed barrier (of MRI), and the implications for both basic research and diagnostics is tremendous," says Robert Turner of the National Institutes of Health's (NIH) Laboratory of Cardiac Energetics.

In all MR imaging, a radio pulse perturbs hydrogen nuclei aligned in a magnetic field. The excited protons emit detectable radio signals as they "relax" from the excited state. These signals are brief, a few hundred milliseconds at most. With conventional MRI hardware this is just long enough to acquire one line of an image that typically requires several hundred lines. Obtaining data for the next line requires another radiofrequency pulse, but before that can happen the nuclei must return to magnetic equilibrium, a process that may take several seconds. As a result, acquiring a conventional clinical MR image may take 15 minutes.

EPI, developed by Sir Peter Mansfield, a physicist at the University of Nottingham, United Kingdom, solves this problem by collecting several hundred lines of data in one fell swoop using high-powered, rapidly oscillating magnetic field gradients, high-speed acquisition hardware, and modified image-processing software. Mansfield proposed the theory in 1977, but it was only in the past few years that his group, along with collaborators at Siemens AG, Advanced NMR Systems (ANMR), NIH, the University of California, San Francisco, and elsewhere solved the technical problems and implemented EPI. Upgrading a conventional MR scanner to one capable of echo-planar performance costs $500,000, and both Siemens and ANMR, in collaboration with General Electric, have developed commercial EPI scanners that are now coming on the market.

Already, researchers and clinicians alike are clamoring for the new instruments. From a utilitarian point of view, the new devices should reduce the overall cost of MRI because patient throughput will be greater. But beyond that, demand for EPI is fueled by the fact that the method eliminates the motion artifacts that plague its conventional counterpart. Conventional MRI is so slow that even images of the brain are blurred as the brain shifts with the cardiac and respiratory cycles. The heart obviously moves much more, and, as a result, cardiac imaging has been virtually impossible.

Now, says Turner, it is possible to evaluate cardiac function in real time using EPI. For example, Mansfield and Michael K. Stehling, a physicist at Boston's Beth Israel Hospital, have measured laminar and turbulent flow in the heart and through heart valves. They have also been able to diagnose valvular heart disease by detecting blood flow through leaky or stenosed valves.



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Madness in his method. Echo-planar MRI images reveal the reaction of a patient with obsessive-compulsive disorder to "an envelope soiled with illicit drugs."

Mark S. Cohen and his colleagues at Massachusetts General Hospital (MGH) have used EPI to study muscle activity as it occurs. "We've been able to see muscle recruitment patterns during complex exercise. This has clear implications for both basic science research and clinical use," said Cohen, director of MGH's High-Speed Imaging Laboratory.

Perhaps most exciting, says Cohen, is the possibility of using EPI to study real-time functioning of the brain. And, indeed, using EPI, Kenneth Kwong at the MGH Nuclear Magnetic Resonance Center, building on research done by Turner and Seiji Ogawa at AT&T Bell Laboratories, has developed a technique that offers what some neuroscientists say are revolutionary maps of the brain in action. In 1990, Ogawa noted that blood vessels in the brain became more visible in MR images as blood oxygen content falls, and he attributed this change to the fact that the two forms of hemoglobin—oxyhemoglobin and deoxyhemoglobin—behave differently in a magnetic field. Turner then showed, using EPI, that it was possible to observe the time course of deoxygenation in animals breathing nitrogen. Kwong noted similar changes in human subjects holding their breath.

One day in 1992, Kwong used Turner, who was visiting Kwong's lab, as a test subject in MGH's EPI machine. While showing Turner a flashing checkerboard pattern (a standard visual stimulation in imaging experiments), Kwong noticed that the MR signal rose whenever the flashes occurred, returning to normal when the flashes stopped. With further study, Kwong correlated those signal changes with the real-time deoxygenation and reoxygenation of hemoglobin. Kwong, Turner, and their collaborators at MGH and Harvard Medical School then used this observation to create the first dynamic images of the brain's visual cortex in action without using contrast agents or radioactive labels. "Basically, deoxyhemoglobin is the body's own contrast agent," said Turner.

Cohen said he has "absolutely no doubt that echo-planar MRI will make a major impact as a clinical tool, simply through imaging speed." But, he added, "what we're tying to do here is optimize the system so we can use it as a neuroscience research tool. In effect, we're trying to develop a mind-reader."

–J.A.