Exploring the Possibilities of Combining EEG and MRI

The Project: To examine the safety of a research technique that could advance investigations of brain activity.

The Solution: Use software to assess the integration of electroencephalography with magnetic resonance imaging.

Researchers have been working to integrate MRI and EEG in order to combine the spatial resolution available with MRI and the temporal resolution offered by EEG. Leonardo M. Angelone is a doctorate student in the biomedical engineering department at Tufts University, Medford, MA. He received a master's degree in electrical engineering from Rome's La Sapienza University. He is conducting research on simultaneous EEG and high-field MRI recordings under the supervision of Dr. Giorgio Bonmassar at the Athinoula A. Martinos Center for Biomedical Imaging, Massachusetts General Hospital, Charlestown, MA. He can be reached at angelone@nmr.mgh.harvard.edu. Dr. Giorgio Bonmassar is an instructor in radiology at the Athinoula A. Martinos Center. He received a master's degree in electrical engineering from La Sapienza University and a doctorate in biomedical engineering from Boston University. He can be reached at giorgio@nmr.mgh.harvard.edu. David Carpenter is commercial director of Remcom Inc., 315 S. Allen St., Suite 222, State College, PA 16801. He received a doctorate from the University of Bath, UK, specializing in electromagnetic systems, measurements, and simulation from static fields to microwave frequencies. More information on electromagnetic simulation software is available by contacting Carpenter at 814-861-1299 or info@remcom.com.

By Leonardo M. Angelone, Dr. Giorgio Bonmassar, and David Carpenter
Electromagnetic simulation software is being used to investigate the safety of an important research technique that integrates electroencephalography (EEG) with magnetic resonance imaging (MRI). The integration of these two analysis methods has the potential to improve investigations of brain activity because EEG offers high temporal resolution while MRI offers high spatial resolution. However, there are concerns about temperature increases in sensitive brain tissues that could be caused by current induced in EEG electrodes by the radio frequency (RF) power generated by MRI.

Research at the Athinoula A. Martinos Center for Biomedical Imaging at Massachusetts General Hospital has simulated the RF power dissipated in the human head in an integrated MRI-EEG software simulation. The results *(Angelone et al., 2004)* showed that in particular cases, such as high magnetic MRI fields and use of metallic EEG leads, the specific absorption rate (SAR), which measures tissue exposure to RF, is four to seven times higher than in MRI alone, indicating that power levels need to be reduced in integrated experiments.

One of the most important challenges in brain imaging is to model the sources of brain activity during different visual, auditory, or motor tasks. Brain mapping with MRI has the highest spatial resolution of current non-invasive imaging techniques. The spatial resolution of MRI is typically millimeters in the case of human subjects. However, because MRI measures primarily a hemodynamic response with a time constant on the order of seconds, the precise mechanics of information exchange within the brain, which occur on a millisecond scale, remain hidden. EEG, on the other hand, can provide temporal accuracy in the required millisecond range, but the spatial accuracy is only on the order of centimeters. Researchers have been working to integrate MRI and EEG in order to combine the spatial resolution available with MRI and the temporal resolution offered by EEG.

Safety Concerns

However, this emerging research technology raises rare but real safety issues. The use of electrodes in an MRI environment is in many respects similar to the presence of metallic implants in an MRI environment, which has already been addressed in several studies. These studies have shown that heating of tissues in the area of the implant is a function of the dimensions, orientation, shape, and location of the implant in the patient. Furthermore, in the case of metallic wire, which is particularly relevant to the integrated EEG-MRI case, the location of heating in the tissue is usually concentrated in a small volumetric area near the tip of the wire. These results highlight the importance of specific studies involving EEG electrodes in the presence of an RF field.

At the Athinoula A. Martinos Center for Biomedical Imaging, electromagnetic simulation was used to measure the RF energy absorbed by the human head in an integrated EEG-MRI experiment. The software selected was XFDTD Version 6.1 from Remcom Inc., State College, PA, which incorporates a full-wave, three-dimensional solver based on the finite-difference-time-domain (FDTD) method. According to the Federal Communications Commission as stated in OET Bulletin 65, *Evaluating Compliance with FCC Guidelines for Human Exposure to RF Electromagnetic Fields, Supplement C*: "Currently, the FDTD algorithm is the most widely accepted computational method for SAR modeling." Furthermore, in FCC Part 95, Section 603(f), it is stated: "Applications for equipment authorization of devices operating under this section must contain a FDTD computational modeling report showing compliance with these provisions for fundamental emissions." Remcom provided FDTD heterogeneous head and body models, together with software that allowed repositions of limbs. In addition, it supplied the specific anthropomorphic mannequin (SAM) head as a CAD file, which can be oriented and meshed at any desired resolution within XFDTD to aid users in complying with FCC limits on SAR.

MRI-EEG Modeling

Due to the particular spatial resolution needed for the research, high-resolution head models were developed by meshing the anatomical MRI data of two adult male subjects. The brain was segmented into cerebrospinal fluid, gray matter, and white matter, using a hybrid method combining watershed algorithms and deformable surface techniques.

Using the XFDTD Geometric Modeler, an FDTD model was constructed of a birdcage coil composed of 16 300-mm perfect electrical conductor rods, closed by two 260-mm-diameter, 1-mm-thick loops at each end. They were placed symmetrically around the head. Using the standard features available in XFDTD, a circular excitation was simulated, driving the current generators placed on the centers of the rods with 1-A peak-to-peak amplitude and a 22.58-degree phase-shift between any two adjacent generators. The surface coil used was a circular perfect electrical conductor, oriented in the XZ plane with a diameter of 140 mm and thickness of 1 mm. The current source, a sinusoidal generator of 1-A peak-to-peak amplitude with internal resistance of 50 ohms, was placed on the lowest point of the ring.

SAR is the variable typically used to quantify the effects on tissue exposure to RF signals. SAR is defined as the time derivative of the incremental energy absorbed by an incremental mass contained in a volume of given density *(NCRP, 1981)*. Again using standard post-processing features in the bio-pro module, XFDTD was used to compute the electric and magnetic fields and the SAR. Simulations were performed with surface and birdcage MRI coils; 16, 31, 62, and 124 electrodes; and at 128 and 300 MHz. An Athlon PC was used for the calculations.

Higher SAR Values

The results confirmed an average of up to seven times the original value in averaged SAR on the skin as well as an increase in the tissues adjacent to the electrodes. The difference in SAR between the condition with electrodes and the condition without electrodes was greater with the birdcage coil than with the surface coil. The peak 1-g averaged SAR values were highest at 124 electrodes, increasing to as much as two orders of magnitude at 300 MHz compared to the original value. At 300 MHz, there was a four-fold increase of SAR averaged over the bone marrow and a seven-fold increase in the skin. The study shows that the presence of non-magnetic, high-conductive, metallic EEG electrodes can increase the peak SAR on the subject by as much as 172 times.

The simulation also showed that with the electrodes and leads, because of the RF-induced currents along the leads, the electric field increases near the electrodes. Thus, the electrodes increase the electric field on the skin and on the surrounding tissues. This generates an increase of peak SAR values for both surface and birdcage coils, relative to that produced by the RF of the coil only.

A growing number of laboratories are performing EEG recordings during MRI. The research described here indicates the pulsed RF fields that are used to elicit MRI signals from tissue may pose a safety hazard by inducing currents in the EEG electrodes/leads.

Safety issues, a relatively minor problem at 1.5 Tesla *(Mirsattari et al., 2004)* may be present at higher fields when using purely metallic EEG electrodes/leads. The electromagnetic simulations performed at the Athinoula A. Martinos Center for Biomedical Imaging quantified the resulting SAR for different RF coil types, numbers of electrodes, and frequencies. The results, computed by using the FDTD technique available in the simulation software, confirmed an increase of up to seven times the averaged SAR on the skin and as much as 172 times for peak 1-g averaged SAR compared to MRI performed without metallic EEG electrodes.

The FDA guidelines *(FDA, 2003)* for MRI environments recommend SAR levels lower than 3 W/kg averaged over the head for 10 minutes and 8 W/kg in any gram of tissue in the head for five minutes. The conclusions to draw from this study are that in order to comply with the FDA recommendation, the maximum input power used for an MRI sequence needs to be reduced when using metallic EEG electrodes/leads.

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