Magnetoencephalography (MEG)

Neuromagnetism Lab at Henry Ford Hospital

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Outline

- Magnetoencephalography (MEG)
- Clinical Applications
- A multi-source technique for understanding the underlying biophysics: Multi-Resolution FOCUSS (MR-FOCUSS)
- Research Investigations
A technique for localizing sources of electrical activity within the human brain by non-invasively measuring the magnetic fields arising from such activity.
148 MEG Coil Channel Locations
Localization of neuronal activity
A Neuromagnetism Lab
Human Brain

- Frontal lobe
- Central sulcus
- Parietal lobe
- Gyri
- Sulci
- Longitudinal Fissure
- Occipital Lobe
- Precentral gyrus
- Postcentral gyrus
- Frontal lobe
- Parietal Lobe
- Lateral Fissure
- Temporal lobe
- Cerebellum

Cells lined up in the cortical surface
Active neurons oriented such that current flows are tangential to scalp, i.e. in sulci or fissures.

Magnetic fields can be detected outside the skull.

Active neurons on gyral surfaces produce little or no measurable external magnetic field.

Magnetic fields are not affected by intervening tissues.
Neurons consist of 3 parts:

- The cell body contains the nucleus where metabolism occurs.
- The dendrites receive messages from other nerve cells.
- These signals travel down the axon to other nerve cells.
Magnetic Field Generation
Source Model: Equivalent Current Dipole

Biot-Savart’s law: \( dB = \frac{\mu_0}{4\pi} \frac{I \: \Delta l \times \vec{r}}{r^2} \)

\( \vec{q} = \overrightarrow{1} \Delta l \)

Electrical Insulation

Current Source

Current Sink

4D-Neuroimaging
Detection Device

- Dewar
- Liquid Helium
- SQUID
- Detector Coil
- Magnetic Field Lines
- To Electronics

4D-Neuroimaging
Strengths of Biological and Environmental Magnetic Fields

Magnetic Field Strength (femtoTesla)

- 10,000,000,000,000,000 - MRI
- 1,000,000,000,000,000
- 100,000,000,000,000
- 10,000,000,000,000
- 1,000,000,000,000
- 100,000,000,000
- 10,000,000
- 1,000,000
- 100,000
- 10,000
- 1,000
- 100
- 10

- Earth steady field (.2 Gauss)
- Urban Noise
- Heart (QRS)
- Epileptic Spike
- Sensory Evoked Response
- SQUID Noise
Clinical Applications of MEG

- Epileptiform brain activity
- Auditory cortex
- Somatosensory cortex
- Visual cortex
- Motor cortex
- Language centers

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Epilepsy presurgical mapping
ECD localization onto MRI

- Seizure
- Interictal Spikes

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Somatosensory localization: left little finger
Visual Evoked Magnetic Fields

Right Hemifield

Left Hemifield (abnormal due to tumor)

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Analytical Techniques

Current Density Mapping

Single Equivalent Current Dipole Localization
Epileptic Spike Localization

Epileptic spikes localized by ECD and 2DII

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Two Dimensional Inverse Imaging (2DII)

- A non-linear current density imaging technique.
  (Moran & Tepley: Brain Topography 12:201-217)
- Images extended and compact sources of neuronal activity.
- The 2DII technique transforms random initial amplitudes of a 3000 point cortical structure into source structure corresponding to the magnetic field data utilizing an iterative algorithm. For robustness 20 solutions are used to create the images.
- MR-FOCUS utilizes the 2DII source structure and a least squares solution, which replaces the minimum norm technique in the FOCUSS iterative algorithm. This technique is superior to 2DII for imaging low amplitude sources in the presence of concurrent high amplitude activity in other cortical areas.
Two Dimensional Inverse Imaging (2DII)

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Localization of Language Areas

A clinical technique to non-invasively measure language comprehension (Wernicke’s and Broca’s area) utilizing a multisource analysis of MEG data.
Methods

- 148-Channel MEG
  (4-D Neuroimaging WH2500)

- 10 patients with epilepsy & 20 control subjects
  (complex partial seizures)

- Two Language tasks
Language Tasks

Picture Naming

Verb Generation

airplane
Data Collection

- MEG: 508 Hz bandpass: 0.1 to 100 Hz
- Raw data is averaged 60-80 trials
- Data forward and backward filtered 1-50 Hz
- MEG data visually inspected for peak activity at
  - ~100ms visual response
  - ~230ms Wernicke’s area
  - ~400ms Broca’s area
- The entire waveform from time of stimulus onset (t=0) to 650ms was analyzed by MR-FOCUSS
Cortical Model

- Created from Volumetric MRI Data
- 2734 cortical locations
- Distribution matches cortical gray matter
Imaging Technique: MR-FOCUSS

- Utilizes a multi-resolution source structure basis of the cortical model
- Incorporates a FOCUSS iterative solution that iteratively modifies initial source amplitudes
- $x$, $y$, and $z$ cortical amplitudes initialized with random amplitudes
- For statistical robustness, ~20 solutions averaged to create images
148 MEG Channels
Picture Naming
Verb Generation

Wernicke’s activation at 255 ms after onset of visual stimuli.

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Picture Naming

Broca’s activation at 320 ms after onset of visual stimuli.

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Basal Temporal Language Area

BTLA’s activation at 180 ms after onset of visual stimuli during Verb Generation.
Results

- Activation was seen in the superior temporal and angular gyrus during both tasks.
- Wernicke’s activation was stronger during the verb generation task.
- Cortical activation was also seen in the inferior prefrontal cortex in both tasks.
- Broca’s activation was stronger during the picture naming task.
- Average latencies for STG ~ 235 ms; PFC ~ 411 ms
- Amplitude of the cortical generators for Verb Generation: ~ 450 pAm
  Picture Naming: ~ 369 pAm
Time Evolution of Language Processing

Normal Reading Subject during: Picture Naming
Applications for Dyslexia

Picture Naming

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Applications for Dyslexia
Picture Naming

Subject with Dyslexia
Verb Generation

Figure 10 SPM maps of the Verb Generation task. A) Three-plane glass brain along (Fixed effect analysis corrected p<.001) with, B) axial overlay shown of selected images, z score scale shown in color bar.
Picture Naming

Figure 8. SPM maps of the Picture Naming task. A) Three-plane glass brain along (Fixed effect analysis corrected <.001) with, B) axial overlay shown of selected images, z score scale shown in color bar.
Morphing Digitized Points to MRI
Auditory Cortex Localization
Multiple subjects one MRI

- Red - Spherical Solutions
- Green - Dense Solutions
- Blue - Sparse Solutions
Research Investigations

- Analytical Techniques
- Epilepsy
- Dyslexia
- Auditory Plasticity
- Migraine
- Sleep
- Stroke
- Parkinson’s Disease
Strengths of MEG

- Measures neural activity
- Non invasive
- ms temporal resolution
- mm spatial resolution
- Correlates function and anatomy
Summary

• MEG is a safe and non-invasive technique to image neural function

• MR-FOCUSS provides an extended view of the neuronal activation involved and the neuronal pathways connecting cortical processing areas.
The Future
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Spatial and Temporal Resolutions for Various Functional Imaging Modalities

- EEG
- MRS
- MEG
- ECoG
- fMRI
- PET
- SPECT
Two Dimensional Inverse Imaging (2DII) & MR-FOCUSS

- Current density imaging techniques
- Incorporate a wavelet basis to obtain a multi-resolution description of the cortical source structure
- Performs focal changes of source structure amplitudes for enhances imaging of multiple simultaneously active compact sources
- Relatively insensitive to noise
- Useful for studying the sequence of interhemispheric neuronal activity
- Can study time evolution of sources
- Available at: http://rambutan.phy.oakland.edu/~meg