Basic Principles of Electroencephalography & Magnetoencephalography

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Brain, Body, & Mind

Mentality

Structure

Function
Presurgical Mapping of Vital Areas in the Brain

fMRI + MEG/EEG

Introduction

Tumor

Epileptic foci
Visualization & Modulation of Human Brain Information Processing

Introduction
Integrated Brain Research Unit (IBRU)

- MEG/EEG source localization
- Structure MRI
- Functional MRI
- Brain computer interface (BCI)
- MEG/EEG rhythm analysis
- Clinical studies

Introduction
Basics of electroencephalography
In 1875, Richard Caton discovered the EEG from the exposed brains of rabbits and monkeys.
In 1925, Hans Berger measured human brain’s electrical activity on the scalp.
Neuroelectric potentials

- Electroencephalogram (EEG)
- Evoked potential (EP)
- Event-related potential (ERP)

Recording site: scalp
cortex
within the depth of the brain

By courtesy of Prof. Yong-Yang Lin
Overview of signaling between neurons

- Post-synaptic (dendritic) potentials vs. axonal action potentials.

By courtesy of Prof. Yong-Yang Lin
Neural electrical activity

- **Currents of the action potential**
- **Postsynaptic cellular currents**
Action potential

- Resting potential
- Na+ influx
- K+ efflux
- Overshoot

By courtesy of Prof. Yong-Yang Lin
Postsynaptic cellular current

By courtesy of Prof. Yong-Yang Lin
Current dipole

By courtesy of Prof. Yong-Yang Lin
Action potential vs Postsynaptic current

Action Potential

"Quadrupole"

Postsynaptic Potential

"Dipole"

action potential

[100 mV]

1 ms

postsynaptic potential

[10 mV]

10 ms

By courtesy of Prof. Yong-Yang Lin
The dipoles make the major contribution to the scalp potential.

When neurons are activated, local currents are produced.

EEG measures the currents that flow during the excitations of the dendrites of many pyramidal neurons in the cerebral cortex.

Potential differences are caused by summed postsynaptic potentials from pyramidal cells that create dipoles between soma and apical dendrites.
Necessary conditions:

Aligned neurons and synchronous activity

- Neurons which are radially symmetric, randomly oriented or asynchronously activated do not produce externally observable electric or magnetic fields.

- Neurons which are non-radially symmetric, spatially aligned and synchronously activated add up to produce externally observable electric or magnetic fields.

By courtesy of Prof. Yong-Yang Lin
By courtesy of Prof. Yong-Yang Lin
Radial equivalent dipole

By courtesy of Prof. Yong-Yang Lin
Tangential equivalent dipole

By courtesy of Prof. Yong-Yang Lin
By courtesy of Prof. Yong-Yang Lin
Figure 44.1. A sample digital EEG laboratory using a network server to transfer and store EEG files.
International 10-20 system

By courtesy of Prof. Yong-Yang Lin
Fig. 3.1. Differential amplification of simple signals, applied to input 1 (top input at the triangular amplifier symbol) and input 2 (bottom input) with respect to an electrical zero level at the ground connection (middle input). Electrical changes at scalp electrodes are indicated by fields on the head diagram; a change towards negative in an electrode is indicated by an upward deflection of the signal above or below the electrode lead; a change towards positive is indicated by a downward deflection. The same polarity convention is used for the signals at the amplifier output which represent pen deflections. – a. A negative signal at input 1 causes an upward pen deflection; – b. A positive signal at input 2 is inverted at the ground level and also causes an upward pen deflection; – c. Two signals of equal size but opposite polarity appearing simultaneously at both inputs are added to each other and cause a pen deflection twice the size of that caused by each potential alone; – d. Two signals of equal size and the same polarity applied simultaneously to both inputs are subtracted from each other and cause no pen deflection.
Fig. 3.2. Differential amplification of signals of different amplitude (a and b) and timing (c and d). Symbols are the same as in Fig. 3.1. — a. Simultaneous appearance of a negative potential at input 1 and of a negative potential of half its size at input 2 causes an upgoing pen deflection half the size of that produced by the potential at input 1 alone; — b. Simultaneous appearance of a negative signal at input 1 and of a positive signal of half its size at input 2 causes an upgoing pen deflection of an amplitude one and a half times that produced by the signal at input 1 alone. — c. Appearance of a negative signal at input 1 followed by appearance of a positive signal of the same size at input 2 causes a sustained upgoing pen deflection; — d. Appearance of a negative signal at input 1 followed by a negative signal of the same size at input 2 causes a diphasic pen deflection of a longer total duration and of a faster falling phase than that caused by either signal alone.
Fig. 4.1. Bipolar montages. a. and b.: Localization of electrical potentials on the scalp by phase reversal; c. and d.: Possible pitfalls of this method.
Fig. 4.2. Referential montages. a, b and c: Localization of electrical potentials by amplitude of pen deflections; d, e and f: Possible pitfalls of this method.
EEG analysis

- Visual analysis of spontaneous waveforms
  - Epilepsy, infectious diseases, metabolic disorders, stroke, degenerative diseases
- Spectral analysis
- Topographic mapping, dipole modeling
- AEP, VEP, SEP
- ERD, ERS
- P300
- Polysomnography

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Research and clinical applications of the EEG

- The greatest advantage of EEG is speed. EEG can determine the relative strengths and positions of electrical activity in different brain regions.
  - Monitor alertness, coma and brain death
  - Locate areas of damage following head injury, stroke, tumor, etc.
  - Test afferent pathways (by evoked potentials)
  - Monitor cognitive engagement
  - Produce biofeedback situations
  - Control anesthesia depth
  - Investigate epilepsy and locate seizure origin
  - Test epilepsy drug effects
  - Assist in experimental cortical excision of epileptic focus
  - Monitor human and animal brain development
  - Test drugs for convulsive effects
  - Investigate sleep disorder and physiology
Basics of magnetoencephalography
Basics of magnetoencephalography

By courtesy of Prof. Yong-Yang Lin
“MEG” is short for...
Magnetoencephalography

MEG Stands for...
- Magnetoencephalography
  - Magneto = magnetic
  - Encephalo = brain
  - Graphy = writing
- MEG = the magnetic signals from the brain

By courtesy of Prof. Yong-Yang Lin
Neuromagnetic fields

Magnetoencephalogram (MEG)
Evoked fields (EF)
Event-related fields (ERF)

By courtesy of Prof. Yong-Yang Lin
Overview

• Part 1: Introduction to MEG
  – What it measures
  – How it works
  – MEG recording procedure
  – Ways to interpret

• Part 2: Clinical and research applications
Part 1

• What MEG measures
  – Neuroscience
  – Physics behind MEG

• How does MEG work?
  – S.Q.U.I.D. technology
  – Shielded room

• MEG recording procedure

• Ways to interpret MEG
  – Dipole models
  – Distributed models
  – Other techniques

By courtesy of Prof. Yong-Yang Lin
Your body and brain are full of nerves which transmit and receive information electrically, producing “magnetic fields” that provide a window into their function.

By courtesy of Prof. Yong-Yang Lin
The axon has bidirectional currents and therefore two opposing dipoles whose magnetic fields effectively cancel each other.

The post-synapse has unidirectional current and therefore only has one dipole. The magnetic field is not canceled in this case.

By courtesy of Prof. Yong-Yang Lin
What MEG measures... 

● Theory:
  – MEG measures groups of post-synaptic currents of layer 5 cortical neurons firing synchronously

● Practical:
  – MEG provides maps of where and when groups of certain types of neurons fire
  – This is a FUNCTIONAL measurement

By courtesy of Prof. Yong-Yang Lin
What MEG measures: Neuroscience

Structure and function

Planning ahead, prediction, speech (lower mostly left), motor (thin strip in front of central sulcus)

Receives nerve impulses for pain, temperature, touch, and pressure: primary sensory area.

CEREBRAL CORTEX

Frontal Lobe

Parietal Lobe

Temporal Lobe

Occipital Lobe

Hearing, memory processing, may be involved in integration of multiple sensory functions i.e. hearing, and touch.

CEREBELLUM

BRAIN STEM

Visual information

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By courtesy of Prof. Yong-Yang Lin
A current dipole can be thought of as a battery that has a positive and a negative pole. Electrical current flows from positive to negative. Because there are two poles, we call dipole. It sets up...

- Electric field
- Magnetic field

By courtesy of Prof. Yong-Yang Lin
Electrical currents generate magnetic fields.

The magnetic field lines make a ring around the direction of the current flow.

Magnetic field and right hand rule:

Point right thumb in direction of current, and fingers curl around direction of magnetic field.

By courtesy of Prof. Yong-Yang Lin.
Image your head was a sphere.
Put a dipole in it.
The dipole can be:

- Radial
- Tangential
- Partly radial Partly tangential

MEG will see the tangential dipoles in the brain. But not the radial ones

By courtesy of Prof. Yong-Yang Lin
Tangential dipoles are tangential to the SKULL; NOT necessarily to the brain.

Thus dipoles which are radial to brain surface can be seen if they are tangential to skull.

What MEG measures: Physics

**MEG is blind to...**

By courtesy of Prof. Yong-Yang Lin
MEG v.s. EEG in signal detection

- The scalp and skull, which distort the electric potentials, are transparent for magnetic fields. Thus, MEG can pick up neuronal activities ‘directly through the skull’.

- MEG is mainly sensitive to tangential sources, whereas EEG reflects all intracranial currents.

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What MEG measures: Physics

Magnetic fields

- Earth’s Field
- Urban Noise
- Car at 50 m
- Screwdriver at 5 m
- Transistor, IC chip at 2 m

B (Teslas)

- $10^{-4}$
- $10^{-5}$
- $10^{-6}$
- $10^{-7}$
- $10^{-8}$
- $10^{-9}$
- $10^{-10}$
- $10^{-11}$
- $10^{-12}$
- $10^{-13}$
- $10^{-14}$
- $10^{-15}$

- Human heart
- Skeletal muscles
- Fetal heart
- Human eye
- Human Brain (alpha)
- Human Brain (evoked response)
- SQUID System
- Noise level

By courtesy of Prof. Yong-Yang Lin
How does MEG work?

Two key technologies:
- S.Q.U.I.D. Sensors
- Shielded Room

Kamerlingh Onnes

By courtesy of Prof. Yong-Yang Lin
Faraday’s Law

- Make a loop of wire
- Pass magnetic field through this loop
- A current will be induced
  - This is a magnetic flux to current converter

The voltage on the loop changes as a function of the magnetic flux passing through it.

By courtesy of Prof. Yong-Yang Lin
Superconductors? Why?

- To boost sensitivity
- Brain signal < 10^-12 Tesla – VERY SMALL
- Superconductors require extreme cold – Use liquid helium (-270°C)

How does MEG work: SQUID

By courtesy of Prof. Yong-Yang Lin
How does MEG work: Shielded Room

**Shielded room**

- Remove extraneous magnetic fields
- Of interest:
  - Brain Response $< 10^{-12}$ Tesla
  - VERY SMALL
- Extraneous:
  - Earth’s Magnetic Field $\approx 5*10^{-5}$ Tesla
  - TOO BIG
Properties of MEG

By courtesy of Prof. Yong-Yang Lin
MEG recording procedure

**3D digitizer**

- Place 4 coils and EOG electrodes
- Landmark: Nasion, RPA and LPA

By courtesy of Prof. Yong-Yang Lin
MEG recording procedure

**MEG Recording**

- Whole-scalp 306 channel neuromagnetometer (Vectorview™, Elekta Neuromag, Helsinki, Finland)
- Continuous and transient real-time data acquisition
- Optional 64 EEG channels
- 8 trigger lines
- 4 order low-pass filter: 30…1000 Hz
- High-pass filter: down to DC
- Head Position Indicator (Polhemus Isotrak II)

By courtesy of Prof. Yong-Yang Lin
Ways to interpret MEG

– Dipole models
– Distributed models
– Other techniques
Ways to interpret MEG: Dipole models

Dipole models

Forward problem (well-posed)
\[ Y = K(J) + E \]

Inverse problem (ill-posed)

Data \( Y \)  
Current density \( J \)

Basic Source Model
- Columnar organization of cortex and spatial functional specialization on cortical surface lead to current dipole model to represent local regions of activation.

Source Estimation Problem: find one or more current dipoles representing current sources in cortex (with orientation normal to the surface)

Forward Models
- Use quasistatic EM model to map from current source to measured fields
- Interested in “primary” rather than “volume” currents
- Spherical head: closed form
- Real head shape & conductivity from MR: use BEM or FEM

By courtesy of Prof. Yong-Yang Lin
Ways to interpret MEG: Dipole models

Auditory neuromagnetic responses

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Ways to interpret MEG: Dipole models

MEG-MRI Coordination

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Ways to interpret MEG: Dipole models

Source modeling

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Ways to interpret MEG: Dipole models

2 Dipoles model

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Ways to interpret MEG: Dipole models

Fitting result

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Noise problems

Ways to interpret MEG: Dipole models

External magnetic disturbances which have fairly uniform distribution but varying amplitudes can be suppressed by the signal space projection (SSP) technique. The measured signals span a signal space whose dimension equals the number of channels $n$ being measured.

By courtesy of Prof. Yong-Yang Lin
Part 2

Clinical and research applications of MEG
Clinical applications

- **Epilepsy**
  - Enhanced identification of spike activity
  - Localization of spike focus and functional areas
  - Evaluation of epileptic pathogenesis
  - Functional evaluation before and after treatment intervention
  - Making a thorough evaluation possible for epilepsy patients (spike localization; relation to functional cortices; evaluation of sensorimotor, auditory, visual, and cognitive functions)

- Functional mapping in patients with brain tumor
- Language lateralization
- Functional evaluation in various neurological diseases

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