Fully Complex Magnetoencephalography

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MEG — Magnetoencephalography

- Non-invasive, Passive, Silent
- Simultaneous Whole Head recordings
  160 magnetic sensors (3 reference)
- Exquisitely Sensitive
  ~ 100 fT ($10^{-13}$ Tesla)
  ~ $10^4$ neurons
- Temporal Resolution
  ~ 1 ms
  (c.f. fMRI: ~1 s)
Neural Activity = Neural Current
Non-invasive Direct electrophysiological measurement (not hemodynamic)
MEG Response

Isofield Contour Map

L  R

Time = 98.00[msec]
Frequency Response

Stimulus Modulated at Single Frequency \(\Rightarrow\) Steady State Response (SSR)

32 Hz Modulation
400 Hz tone carrier
100 trials @ 1 s (concatenated)

Extremely Precise Phase-Locking: 0.01 Hz
No trial-to-trial jitter
Whole Head Steady State Response

32 Hz
Whole Head Transfer Function

16 Hz

32 Hz

48 Hz

64 Hz
Phase Conventions

Cartesian

Compass

Cartesian

Compass
Current–Equivalent Dipoles

Raw Data

Current Dipoles Complex Too!

Two Dipole Fit

Left Dipole

Right Dipole

32 Hz
Complex Equivalent–Current Dipoles

\[ \mathbf{V} = \mathbf{V}_{\text{Re}} + i \mathbf{V}_{\text{Im}} \]

\[ \mathbf{V}(\theta) = \mathbf{V}_{\text{Re}} \cos(\theta) + \mathbf{V}_{\text{Im}} \sin(\theta) \]

\[ \theta_{\text{Max}} \]

Two Dipole Fit

\[ \mathbf{V}_{\text{Max}}, \mathbf{V}_{\text{Min}} \]

Orientations

\[ \eta = \frac{|V_{\text{Min}}|}{|V_{\text{Max}}|} \]

0 < \eta < 1

Physiologically Simple Current Sources: \( \eta = 0 \)

“Strength”

“Sharpness”
Simulated Sharpness

Compound/Effective Current Sources

\[ \eta_L = 0 \]
\[ \eta_R = 0 \]

\[ \eta_L = 0 \]
\[ \eta_R = 0.5 \]

\[ \eta_L = 0 \]
\[ \eta_R = 0.25 \]

\[ \eta_L = 0 \]
\[ \eta_R = 1 \]
Summary

- Fully Complex MEG necessary
  - Complex Magnetic Flux
  - Generated by Complex Neural Currents

- Complex Neural Current Sources
  - Six Degrees of Freedom:
    - Orientation (2), Strength, Phase, Sharpness, Minor orientation (1)
  - Sharpness ➞ Compound Neural Source

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Thank You
Functional Imaging

Non-invasive recording from human brain (Functional brain imaging)

- Positron emission tomography PET
  - Excellent spatial resolution (~ 1-2 mm)
  - Poor temporal resolution (~ 1 s)

- Functional magnetic resonance imaging fMRI
  - PET, EEG require across-subject averaging
  - fMRI and MEG can capture effects in single subjects

- Electroencephalography EEG
  - Poor spatial resolution (~ 1 cm)
  - Excellent temporal resolution (~ 1 ms)

- Magnetoencephalography MEG

Hemodynamic techniques

Electromagnetic techniques
Magnetic Flux Detectors

Superconductivity →
Magnetic flux quantization →
Josephson Effect →
SQUID = Superconducting Quantum Interference Device

\[ \Phi = n \frac{h}{2e} = n \Phi_0 \]

\[ \Phi_0 = \frac{h}{2e} = 2.07 \times 10^{-15} \text{ Wb} \]
Sensor Configurations

**SQUID Magnetometer**

**SQUID Gradiometer**

Noise reduction from Differential measurement

Planar type

50 mm base line

Axial type
Time Course of MEG Responses

Evoked Responses
MEG Events Time-Locked to Stimulus Event

Pure Tone

Broadband Noise
Neural Modulation Transfer Function

Amplitude (nAm x 10^-5)

Frequency (Hz)

Phase (degrees)

Right Hemisphere Dipole

c.f. Ross et al. (2000)