Auditory Neuroscience with Magnetoencephalography:
New Quantitative Approaches

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Outline

- Auditory Magnetoencephalography
  - MEG Fundamentals
  - Neural Source Localization
- “Newish” Quantitative Approaches
- MEG in the Fourier Domain
- Signal Separation & Denoising
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Origin of MEG Neural Signal

Dendritic currents
not
Axonal currents
Magnetoencephalography

- Non-invasive, Passive, Silent Neural Recordings
- Simultaneous Whole-Head Recording (~200 sensors)
- Sensitivity
  - high: \(~100 \text{ fT} (10^{-13} \text{ Tesla})\)
  - low: \(~10^4 – 10^6\) neurons
- Temporal Resolution: \(~1 \text{ ms}\)
- Spatial Resolution
  - coarse: \(~1 \text{ cm}\)
  - ambiguous
Functional Brain Imaging

= Non-invasive recording from human brain

Hemodynamic techniques

Excellent Spatial Resolution (~1 mm)

Poor Temporal Resolution (~1 s)

Electromagnetic techniques

Poor Spatial Resolution (~1 cm)

Excellent Temporal Resolution (~1 ms)

fMRI
functional magnetic resonance imaging

PET
positron emission tomography

fMRI & MEG can capture effects in single subjects

EEG
electroencephalography

MEG
magnetoencephalography
Magnetic Field Strengths

Intensity of magnetic signal (T)

- Earth field
- Urban noise
- Contamination at lung
- Heart QRS
- Fetal heart
- Muscle
- Spontaneous signal (α-wave)
- Signal from retina
- Evoked signal ~ 10^4 neurons
- Intrinsic noise of SQUID

Biomagnetism

- EYE (retina): Steady activity, Evoked activity
- LUNGS: Magnetic contamination
- LIVER: Iron stores
- HEART: Cardiogram (muscle), Timing signals (His Purkinje system)
- GI TRACK: Stimulus response, Magnetic contaminations
- BRAIN (neurons): Spontaneous activity, Evoked by sensory stimulation
- SPINAL COLUMN (neurons): Evoked by sensory stimulation
- MUSCLE: Under tension
MEG Magnetic Signal

- Direct electrophysiological measurement
- Not hemodynamic
- Real-time
- No unique solution for distributed source
MEG Auditory Field

Flattened Isofield Contour Map

Instantaneous Magnetic Field

Sink Source

40 fT/step

$t = 98$ ms
MEG Auditory Field

3-D Isofield Contour Map

Chait, Poeppel and Simon, Cerebral Cortex (2006)
Time Course of MEG Responses

- Auditory Evoked Responses
  - MEG Response Patterns Time-Locked to Stimulus Events
  - Robust
  - Strongly Lateralized

- Auditory Induced Responses
  - MEG Response Patterns not Time-Locked to Stimulus Events
  - Not Addressed Today
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Neural Source Localization

- No Unique Solution from Magnetic Field to Neural Current Distribution ("Inverse Problem")

- Several Plausibly Physiological Solutions
  - Equivalent-Current Dipoles
  - Minimum Norm Estimation & variants
  - Beamforming & variants
  - Others
Neural Source Troubles

- Equivalent-Current Dipoles
  - How Many?
  - Non-intuitive side effects
- Minimum Norm Estimation vs. Beamforming
  - Each side can produce datasets that show misleading results from other method
- Excellent Tutorial
  - Lütkenhöner & Mosher in “Auditory Evoked Potentials” by Burkard et al.
Neural Source Solutions?

- All of the major methods are good
  - Can give physiologically plausible result
  - Can give “correct/true” result
- Any of the major methods might get you into trouble
  - Each has weaknesses
- The best method to use may be the one which is used by people whose results you trust
  - Knowing an expert always helps
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MEG STRF from Speech

- **Stimulus**: 2 minutes of monaural speech
- **Speech Spectrogram → MEG Response**
- **Method**: Boosting with cross validation
- **Accuracy comparable to individual AI neuron**

Ding & Simon, Submitted
Separation of Dichotic Speech

- **Stimulus**: 2 minutes of dichotic speech
- **STRF** robust against spatial masking of speech
- **Strong attentional modulation** of neural representation (STRF)

**Monaural Speech**

**Attended Speech**

**Unattended Speech**

Ding & Simon, Submitted
Information Content in MEG Signal

- Cross-correlation of speech envelope & MEG response **diagonal** for long segments
- **Stimulus Decoding:**
  strongest correlation  
  = best stimulus guess
- Predictions worsen when too many small-duration segments
- Conservative estimate (linear)
- **Stimulus decoding accuracy:**
  - 4 bit/s in right hemisphere
  - 1 bit/s, in left hemisphere
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MEG Frequency Response

Stimulus:
Amplitude Modulation at 32 Hz

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

Amplitude + Phase...
Whole Head Steady State Response

Phasor Isofield Contour Map

$f = 32$ Hz

Example: Auditory Streaming

- Stream Segregation with Competing Foregrounds
- Attentional Modulation of Neural Representation

Whole Head Transfer Function

- 16 Hz
- 32 Hz
- 48 Hz
- 64 Hz
Complex Magnetic Field

with / without generated contours
Current-Equivalent Dipoles

Raw Magnetic Field Data

Two Dipole Fit

Left Hemisphere Current Equivalent Dipole

Right Hemisphere Current Equivalent Dipole
Complex Neural Current Sources

Two Dipole Fit

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

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

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

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Data driven spatial filtering: many available methods—ICA, PCA, DSS

Generate spatial filters & their outputs ("components")


DSS components ordered by reproducibility
  1st component "maximally reproducible" = most stimulus driven
DSS Example

- Most reproducible filter & component
- Optimally filters out trial-to-trial-variable signal = neural noise
- Filter can be applied to other signals, e.g. single trials

DSS Example: Spectral

Frequency Spectrum before DSS

Frequency Spectrum after DSS

Ding & Simon, J. Neurophysiol (2009)
DSS Examples: Phase

Phasor Spread before DSS

Phasor Spread after DSS

Ding & Simon, J. Neurophysiol (2009)
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Past Undergraduates

Computational Sensorimotor Systems Laboratory
The Department of Biology at the University of Maryland, College Park, invites applications for an Assistant Professor in sensory neurobiology. We seek an outstanding candidate taking experimental and/or theoretical approaches to major questions in sensory neurobiology at the molecular, cellular, and/or organismal levels. Applicants must have a doctorate degree and should have developed, or demonstrate the potential to develop, an outstanding research program and a record of extramural funding. Applicants should also exhibit a commitment to excellence in teaching. Postdoctoral experience is preferred.

Applicants should apply electronically to https://jobs.umd.edu, specifying Sensory Neurobiology, Dr Catherine Carr, Search Committee Chair (position #116926). Applications should consist of a single PDF file containing (1) a letter of application, (2) a curriculum vita, (3) a statement of research interests and plans, (4) a statement of teaching experience and interests. PDFs of selected publications can be submitted as supplementary information if desired. Please arrange for three recommendation letters to be submitted directly to https://jobs.umd.edu, specifying the same information as above. For best consideration, applications should be complete by Dec. 30, 2010.

The University of Maryland is an equal opportunity/affirmative action employer. Applications from minorities and women are encouraged.
Single Orientation Current Sources
Auditory Streaming I

- Stream Segregation & MEG
- Foreground vs. Background
- Attentional Modulation of Neural Representation
- Neural Correlate of Behavioral Buildup

Interaction between attention and bottom-up saliency mediates the representation of foreground and background in an auditory scene. Elhilali, Xiang, Shamma & Simon (2009) PLoS Biology
Neural Correlates of Therapy for

- Combine MRI with MEG
- Competing Neural Source Localization Algorithms not Unique
- Campus MRI system on track for summer 2011