Currents in axons and dendrites

- Postsynaptic currents:
  - > 10 ms: better chances for temporal summation
  - dipolar currents
  - the main source of MEG & EEG!

- Action potentials:
  - ~ 1–3 ms: no/little temporal summation
  - Cancellation: fields diminish rapidly
Parallel dendrites

Pyramidal cells: parallel orientation => spatial summation
Sensor-level responses: Auditory

Magnetometers, axial gradiometers

Planar gradiometers

Sensor type essential knowledge for correct interpretation of sensor-level MEG data!

100 ms
MEG responses – the feature space

- **Stimulus-locked evoked responses**
  - Spatial and temporal pattern

- **Induced responses: Changes in...**
  - Power of oscillatory activity
  - Interareal coherence
  - Interareal phase-locking

- **Tagged responses**
  - Using temporally structured stimuli (e.g. frequency tagging) and following the corresponding activation by their spectral fingerprints
fMRI-BOLD vs. MEG/EEG responses
Evoked responses: Viewing and imitating lip forms

Nishitani & Hari 2002
Lip Forms: Cortical Activation Sequence

Nishitani & Hari, Neuron 2002
Modulation of oscillatory power:
Action viewing

Resting

Acting

Viewing
Action viewing: 20-Hz activity

Hari et al. PNAS 1998
Phase-locking value (PLV)

\[ \phi_2(1, t) - \phi_1(1, t) \]

Trial 1

Ch1

\[ \phi_1(1, t) \]

Ch2

\[ \phi_2(1, t) \]

Trial N

Ch1

\[ \phi_1(N, t) \]

Ch2

\[ \phi_2(N, t) \]

Not phase-locked

0

Strongly phase-locked

1

\{(\ldots)\}

PLV

(Lachaux et al., 1999)

Simoes et al. PNAS 2003
Time-frequency representation of PLVs

Left SI Vs. Right SII

\[ p < 0.05 \]

Simoes et al. PNAS 2003
Tagging: Bistable visual percepts

- Do the tag-related signals modulate with the percept?
- MEG experiment:
  - fixate between the “noses”
  - report the percept behaviorally
  - 10-min recording

Parkkonen et al. PNAS 2008
Dynamics of the tag signals

Behav. signal

MEG signals

Instantaneous amplitude by Morlet wavelets

Averaging across percept switches ($n = 34 \ldots 104$)

Parkkonen et al. PNAS 2008
MEG decoding – issues and opportunities

♦ Signal-to-noise ratio
  – Response averaging typically employed
  – Single-trial responses detectable? Often yes!

♦ Spatial resolution when multiple conditions present
  – Are the associated spatial patterns sufficiently distinct?
  – Tailoring the stimuli for maximal separability of the responses

♦ Exploiting the spatio-temporal dynamics
  – Looking for a trajectory instead of a snapshot of activity?

♦ Real-time decoding: Detection latency (excl. pure computation time)
  – How long temporal windows required?
  – Frequency vs. time resolution in detecting oscillatory components
MEG decoding – refs

Mellinger, et al. (2007)
An MEG-based brain–computer interface (BCI).
*NeuroImage*, 581–593.

Bradberry, et al. (2009)
Decoding center–out hand velocity from MEG signals during visuomotor adaptation.
*NeuroImage*, 1691–1700.

Waldert et al. (2008)
Hand movement direction decoded from MEG and EEG.
*J Neurosci*, 1000–1008.

Georgopoulos et al. (2005)
MEG signals predict movement trajectory in space.
Rieger et al. (2008)
Predicting the recognition of natural scenes from single trial MEG recordings of brain activity
_NeuroImage_, 1056–1068.
Source modelling

- Given the current distribution $J(r)$, the corresponding electric and magnetic signals can be calculated uniquely (forward problem)

- On the contrary, mapping from the electric and magnetic measurements to the current distribution $J(r)$ is not unique (inverse problem)
  - for example, assuming a spherical conductor, radial currents can be added without changing MEG and current loops can be added without changing EEG

- Thus, additional constraints are required to estimate the primary currents $J_p(r) = \text{sources} \approx \text{active areas}$
Dipole models

- Equivalent current dipole (ECD)
  - infinitesimally short current "line"
  - has orientation and strength
  - models the activity of ~ 1 cm² of cortex
  - fitted to the measured data in the least-squares sense
  - the most common MEG/EEG source model
Multidipole modelling

MEG data with electric Median nerve stimulation
Activation of the first and second somatosensory cortices as modelled with equivalent current dipoles (ECDs)

Location, orientation and timing of the sources

Image courtesy of M. Hämäläinen
Minimum Norm Estimates (MNE)

- Model MEG data
  - By a current distribution confined within the brain
  - Without prior assumptions on the number, location or strength of the sources
MNE: Source points

Uniform source point grid

Cortically-constrained source point set with orientation normal to the cortical surface

7-mm spacing along the grey matter sheet: ~ 6 000 points / brain = ~18 000 dipoles / brain
MNE: Finding the source amplitudes

- Underdetermined problem: more unknown variables (dipole moments) than measurements (MEG channels)
- Constraints required to solve the problem
  - Minimize the sum of the dipole moments across all voxels
    - sufficient constraint to yield a unique solution, i.e, an estimate of the dipole moments in each voxel.
    - different ways to calculate the sum => different minimum norm estimates.
MNE: More mathematically...

- Dipole moment ~ primary current in a voxel
- Brain/cortex divided into $N$ voxels. Three orthogonal primary current directions within each voxel can represent any direction of the current.
- Source vector $\mathbf{j} = (j_1, j_2, j_3, j_4, j_5, j_6, \ldots j_{3N})$ contains the primary current strengths of all $N$ voxels, in all three directions.
- Forward operator $\mathbf{L}$ gives the MEG signals associated with primary currents in the voxels. For primary currents $\mathbf{j}$, the measured signals $\mathbf{b} = \mathbf{L} \mathbf{j} + \mathbf{n}$
MNE: Minimization

- Search for the minimum $j'$ that still explains the measurements $b$
- minimize $\| W_D (b - L j') \|^p + a \| W_M j' \|^p$

  data term: estimate must explain the measurements
  model term: estimate must be “small”

- the parameter $p$ defines the norm
- the parameter $a$ controls the amount of regularization
- the weighting matrices $W_D$ and $W_M$ can be used to assign additional properties to the estimates
MNE: The effect of the norm

\[ p = 2 \]

Gaussian priors
(l2 norm, MNE)

\[ \int_G ||J||^2 dG \rightarrow \text{min} \]

Diffuse solution

\[ p = 1 \]

Exponential priors
(l1 norm, MCE)

\[ \int_G ||J|| dG \rightarrow \text{min} \]

Focal solution

Image courtesy of M. Hämäläinen