Aalto-yliopisto
Perustieteiden
korkeakoulu

Mutual information between BOLD fMRI and corresponding MEG signals

Oliver Kostamo

24.04.2025

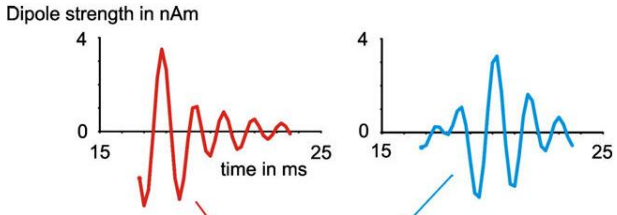
Advisor: M.Sc. Silvia Cotroneo

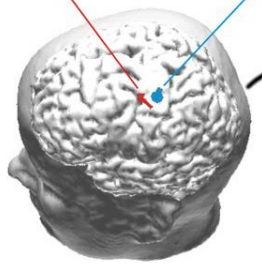
Supervisor: Prof. Nuutti Hyvönen

Aalto-yliopisto
Perustieteiden
korkeakoulu

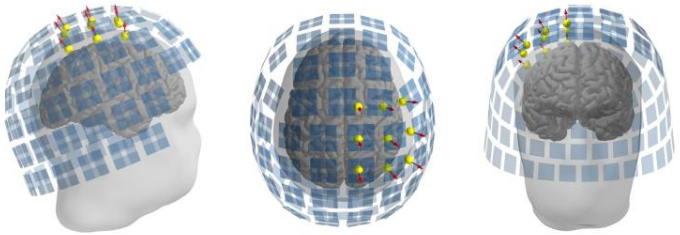
[1] [2] [3] [4]

Brain source

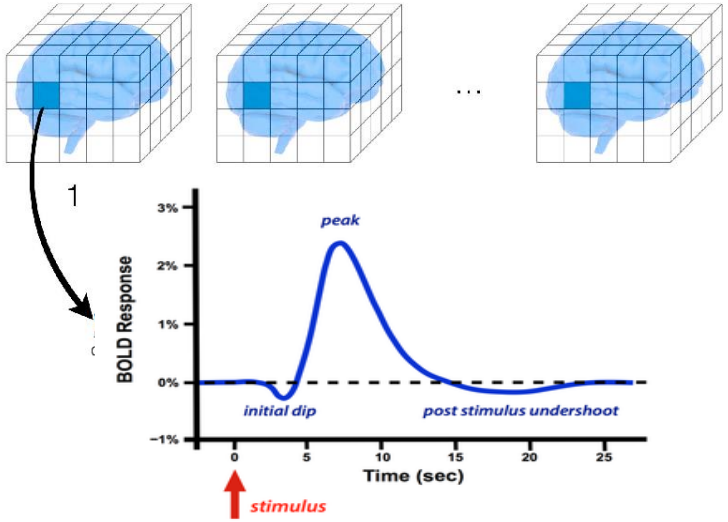


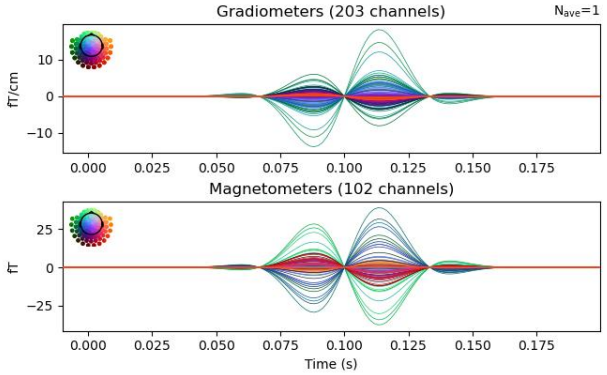


MEG



fMRI



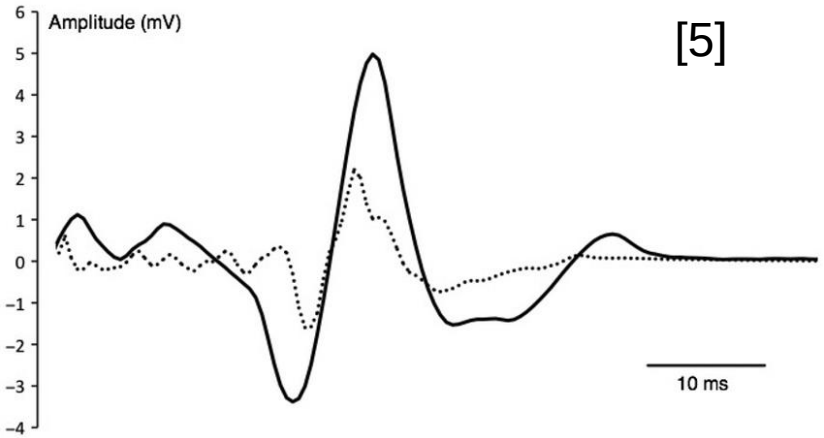


[1] Sidén, Per: Scalable Bayesian spatial analysis with Gaussian Markov random fields (2020)
[2] https://mriquestions.com/does-boldbrain-activity.html
[3] Zetter, R., Iivanainen, J. & Parkkonen, L.: Optical Co-registration of MRI and On-scalp MEG.
[4] Haueisen, Jens et al.: Identifying mutual information transfer in the brain with differential-algebraic modeling: Evidence for fast oscillatory coupling between cortical somatosensory areas 3b and 1 (2007)

Aalto-yliopisto
Perustieteiden korkeakoulu

Brain activation due to tasks

- Brain activation due to tasks or stimulus can be measured with many different methods
- Existing methods have their respective strengths and weaknesses
- We limit our focus to MEG and fMRI



[5]

[5] Roger Nelson: Evoked Potentials and GCP Event Data (2020)

Magnetoencephalography (MEG)

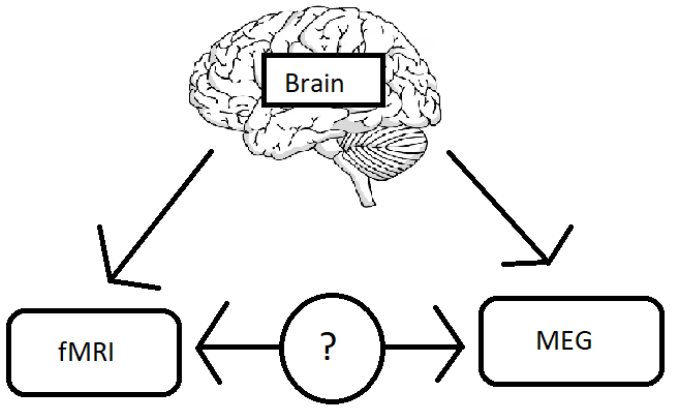
- Measures magnetic fields generated by electric currents in the brain
- High temporal resolution (~1 ms)
- Spatial resolution (multiple mm range) not as good as with MRI

Functional Magnetic Resonance Imaging (fMRI)

- Detects changes in blood oxygenation and flow
- Good spatial resolution (~1 mm), limited temporal resolution (~1-3 s) compared to MEG

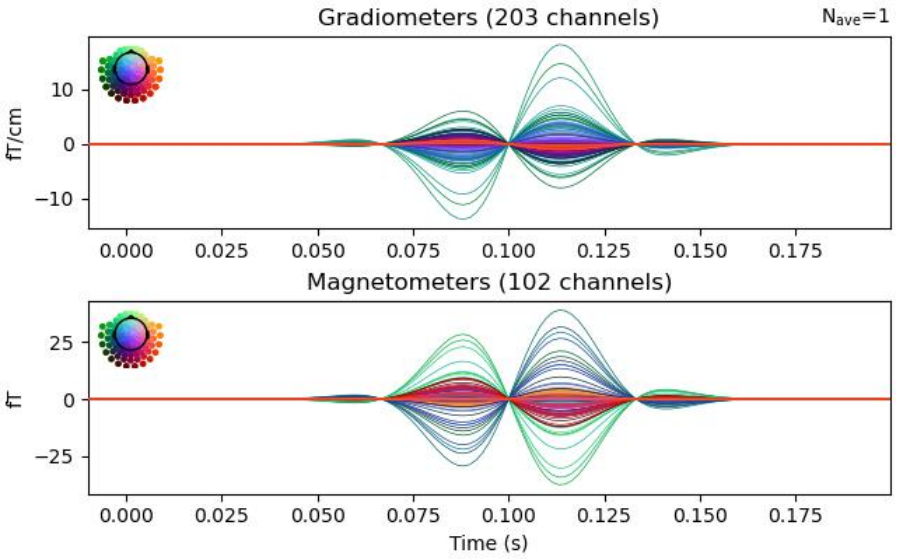
Multimodal studies

- The goal is to take advantage of differences in imaging modalities
- High temporal resolution in MEG, high spatial resolution in fMRI



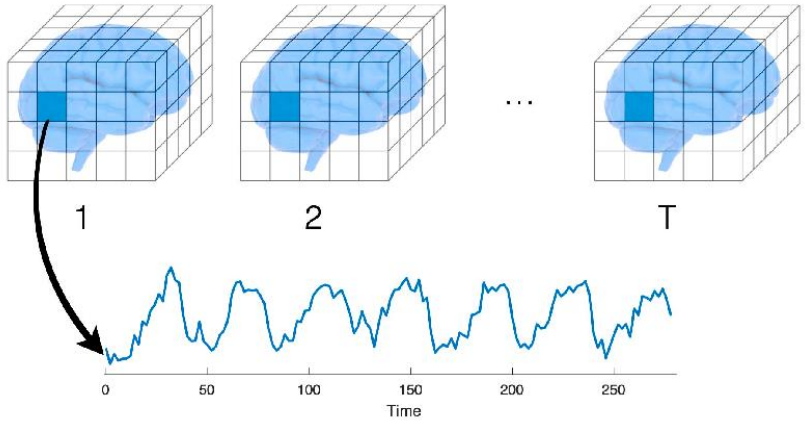
MEG source space

- First establish a forward model of potential sources
  - Can be derived from e.g. structural MRI scan
- Source space either surface-based or volume-based
  - In both cases, discrete set of points onto which the activity is mapped
- These are normally used when solving the inverse problem
- The MEG signal can now be simulated using the forward model



fMRI source space

- 3D grid of voxels (i.e. volumetric pixels)
- Usually defined using a structural MRI scan
- The fMRI data is mapped to these voxels
- Unlike in MEG, there is no inverse problem to be solved
- The time course can be simulated from the source signal

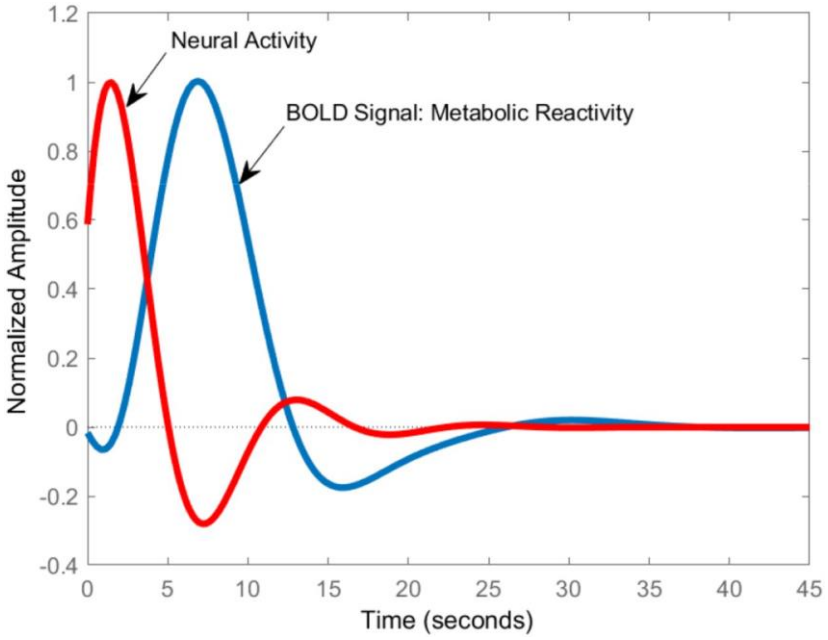


[1]

[1] Sidén, Per: Scalable Bayesian spatial analysis with Gaussian Markov random fields (2020)

BOLD fMRI

- Peak is delayed (~5 s from onset of activity)
- Temporal resolution in the range of seconds (~1-3 s)
- Response is related to neural activity, but other factors also influence the measure
- Can be estimated by convolving neural activity/stimulus with a haemodynamic response function



[6]

[6] Charles D. Schaper: Analytic Model of fMRI BOLD Signals for Separable Metrics of Neural and Metabolic Activity (2019)

Mutual Information (MI)

- Pairwise measure of statistical dependence
- Unlike e.g. Pearson's correlation, MI also reflects non-linear relationships
- Related to Shannon's entropy
- Inexpensive to calculate with binning-based estimator

$$I(X;Y) := \int f(x,y) \log \frac{f(x,y)}{f(x)f(y)} dxdy$$

$$I(X;Y) = H(X) - H(X|Y)$$

$$= H(Y) - H(Y|X)$$

$$\mathrm{H}(X) = -\int_{\mathbb{X}} f(x) \log f(x)\, \mathrm{d}x.$$

$$\mathrm{H}(X|Y) = -\int_{\mathcal{X},\mathcal{Y}} f(x,y) \log f(x|y)\, dxdy$$

Goal

- Use a realistic, simulated brain source to estimate corresponding MEG and BOLD fMRI signals
- Compare the two signals with Mutual Information
- Assess the effects of temporal and spatial signal sampling strategies on the mutual information estimates of the signals

Timetable

- Topic presentation: 22.04.
- Main results by mid-May
- Writing the thesis: March-June
- Results and thesis ready by end of June

Literature and references

- Baillet, S.: Magnetoencephalography for brain electrophysiology and imaging (2017)
- Nikos K. Logothetis: What we can do and what we cannot do with fMRI (2008)
- Nikos K. Logothetis, Brian A. Wandell: Interpreting the BOLD signal

Figures

- [1] Sidén, Per: Scalable Bayesian spatial analysis with Gaussian Markov random fields (2020)
- [2] https://mriquestions.com/does-boldbrain-activity.html
- [3] Zetter, R., Iivanainen, J. & Parkkonen, L.: Optical Co-registration of MRI and On-scalp MEG.
- [4] Haueisen, Jens et al.: Identifying mutual information transfer in the brain with differential-algebraic modeling: Evidence for fast oscillatory coupling between cortical somatosensory areas 3b and 1 (2007)
- [5] Roger Nelson: Evoked Potentials and GCP Event Data (2020)
- [6] Charles D. Schaper: Analytic Model of fMRI BOLD Signals for Separable Metrics of Neural and Metabolic Activity (2019)