Multivariate connectivity methods in the MNE-Python toolbox

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SUMMARY

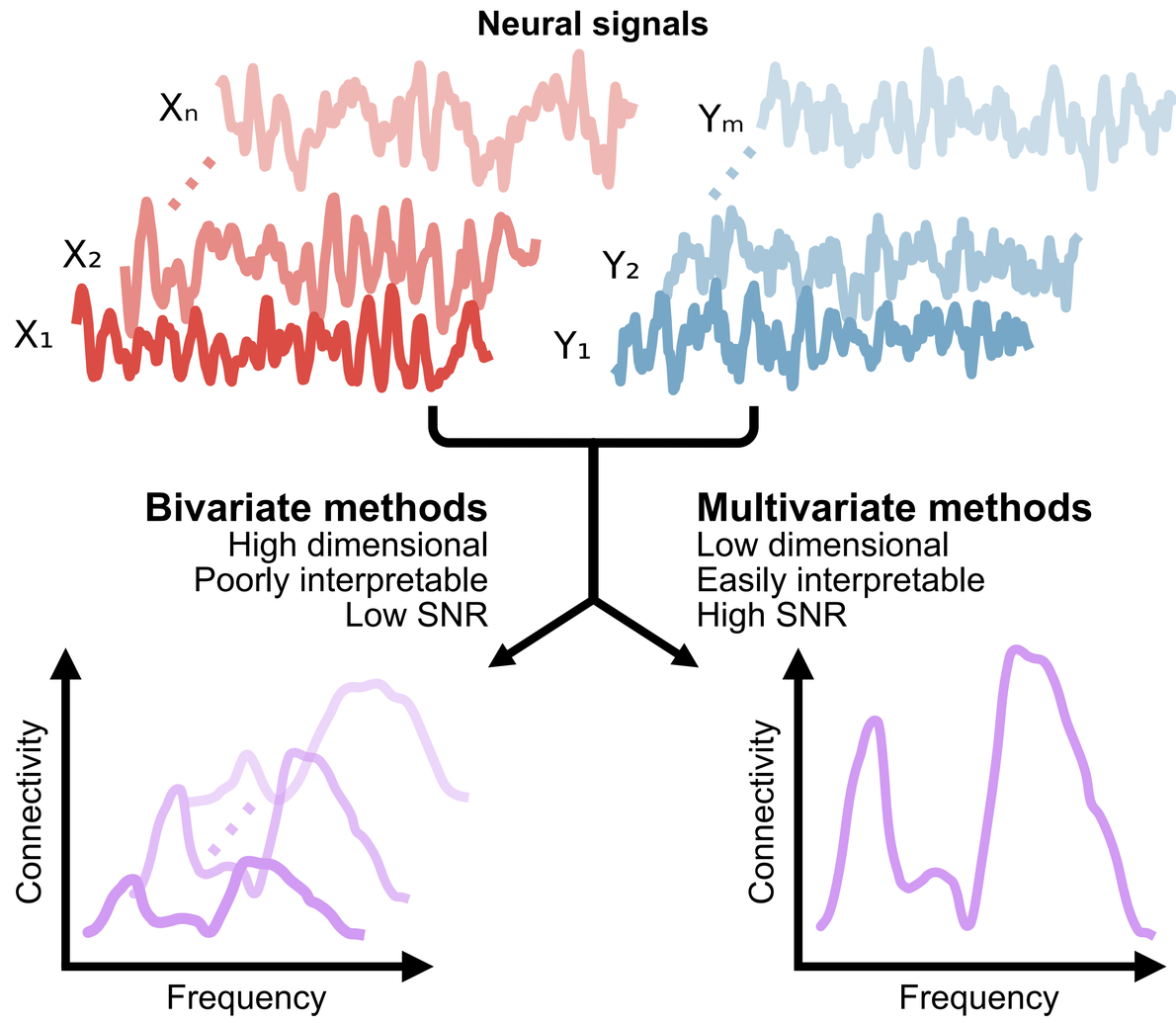
- Connectivity analyses in multichannel recordings with bivariate methods produce high-dimensional, difficult to interpret results.
- Averaging connections to reduce the dimensionality lowers SNR if signals sit outside oscillatory sources.
- In contrast, multivariate methods produce interpretable, low-dimensional results with high SNR.
- MNE-Python is a popular signal processing toolbox for Python [1].
- MNE-Connectivity builds on the MNE-Python API to offer connectivity estimation tools.
- We have implemented advanced, multivariate connectivity estimation methods in MNE-Connectivity (available as of v0.6).

UNDIRECTED CONNECTIVITY: Coherency-based methods

- Correlation in the frequency domain.
- **Bivariate:** coherency; coherence; imaginary part of coherency [2].
- **Multivariate:** canonical coherency [3]; maximised imaginary part of coherency [4]; multivariate interaction measure [4].
  - Uses eigendecomposition-based spatial filters to optimise connectivity; provides corresponding spatial maps of connectivity [5].

DIRECTED CONNECTIVITY: Granger causality

- Degree to which one signal predicts another [6].
- **Bivariate:** Granger causality [7].
- **Multivariate:** State-space Granger causality [8].
  - Uses state-space transformation of autoregressive model; compatible with time-reversal-correction for spurious connectivity artefacts [9].



Check out MNE-Connectivity:
mne.tools/mne-connectivity/

Support for:

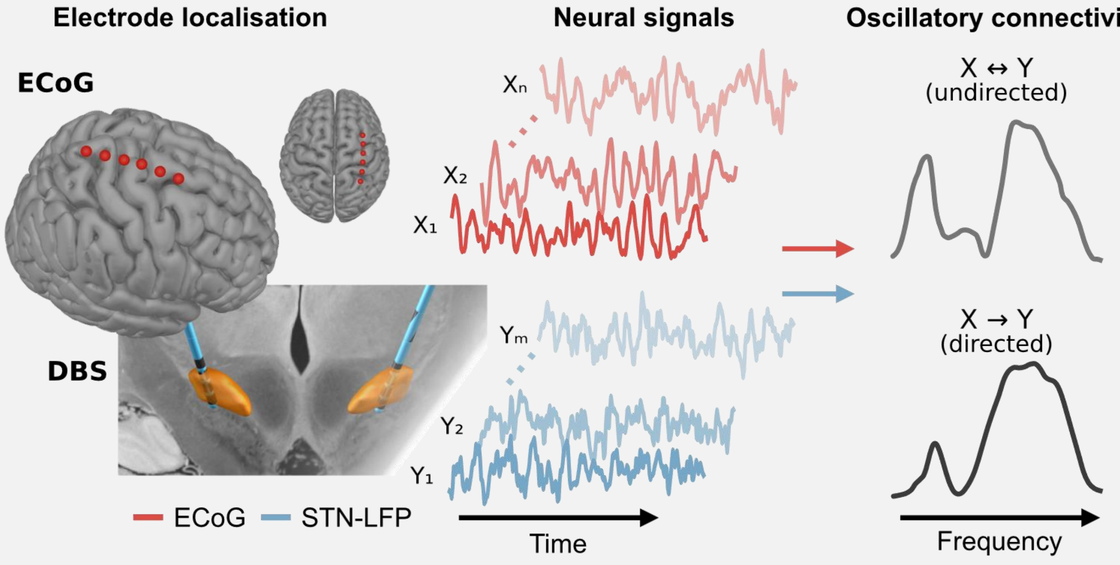
Maximised imaginary part of coherency
Multivariate interaction measure
State-space Granger causality
Canonical coherency

MEG + EEG ANALYSIS & VISUALIZATION

References: [1] Gramfort *et al.* (2013). *Frontiers in Neuroscience*. DOI: 10.3389/fnins.2013.00267; [2] Nolte *et al.* (2004). *Clinical Neurophysiology*. DOI: 10.1016/j.clinph.2004.04.029; [3] Vidaurre *et al.* (2019). *NeuroImage*. DOI: 10.1016/j.neuroimage.2019.116009; [4] Ewald *et al.* (2012). *NeuroImage*. DOI: 10.1016/j.neuroimage.2011.11.084; [5] Haufe *et al.* (2014). *NeuroImage*. DOI: 10.1016/j.neuroimage.2013.10.067; [6] Granger (1969). *Econometrica*. DOI: 10.2307/1912791; [7] Geweke (1982). *Journal of the American Statistical Association*. DOI: 10.2307/2287238; [8] Barnett & Seth (2015). *Physical Review E*. DOI: 10.1103/PhysRevE.91.040101; [9] Winkler *et al.* (2016). *IEEE Transactions on Signal Processing*. DOI: 10.1109/TSP.2016.2531628.

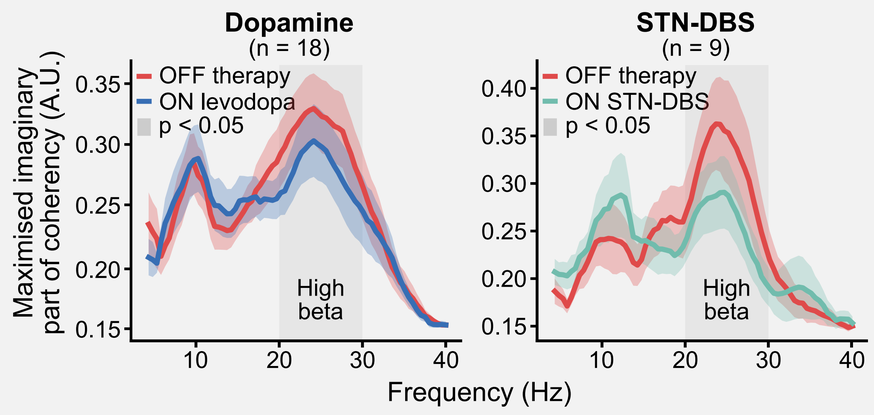
METHODS IN ACTION: Analysis of cortex – basal ganglia connectivity in Parkinson's disease patients

- Electrocorticography (ECoG) strips targeting motor cortex and deep brain stimulation (DBS) leads targeting subthalamic nucleus (STN) implanted in Parkinson's disease patients.
- Resting-state recordings of cortex and STN activity taken: in absence of therapy (OFF therapy); with dopaminergic medication (ON levodopa); and with STN DBS (ON STN-DBS).
- Analysis of undirected connectivity (maximised imaginary part of coherency) and directed connectivity (time-reversed, state-space Granger causality) between cortex and STN.



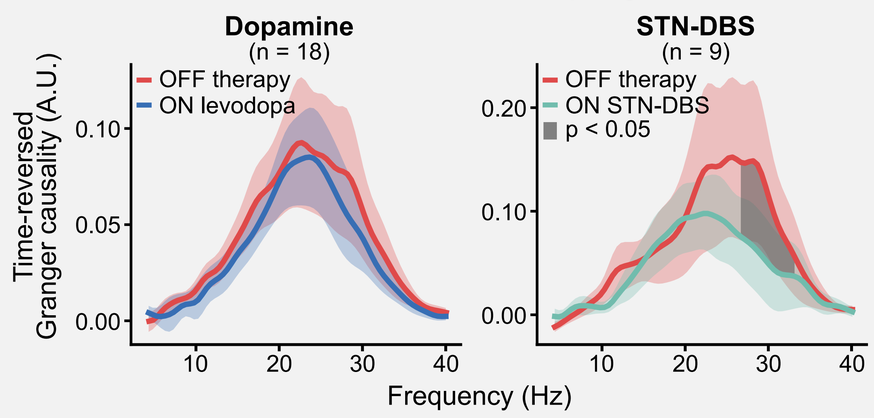
Undirected connectivity: Cortex ↔ STN

Therapeutic suppression of cortico-subthalamic coupling



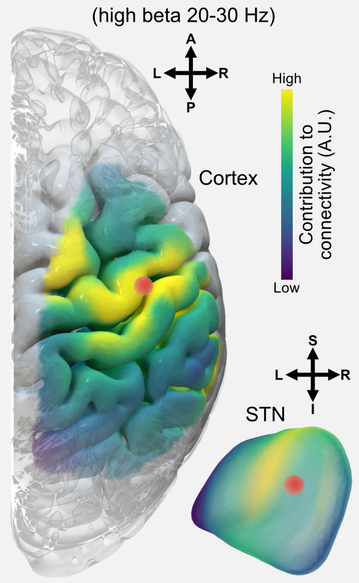
Directed connectivity: Cortex → STN

Cortex drives cortico-subthalamic coupling



Spatial maps of connectivity

(high beta 20-30 Hz)



Results in more detail:

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