MRC Cognition and Brain Sciences Unit

UNIVERSITY OF CAMBRIDGE

EEG/MEG 3:

Advanced Functional Connectivity Analysis

Olaf Hauk

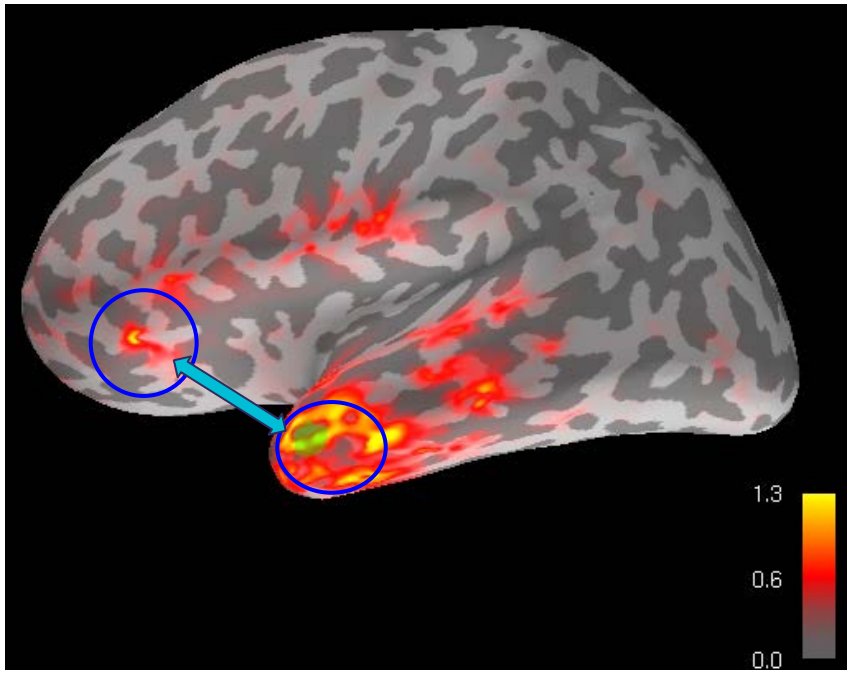
olaf.hauk@mrc-cbu.cam.ac.uk

COGNESTIC 2022

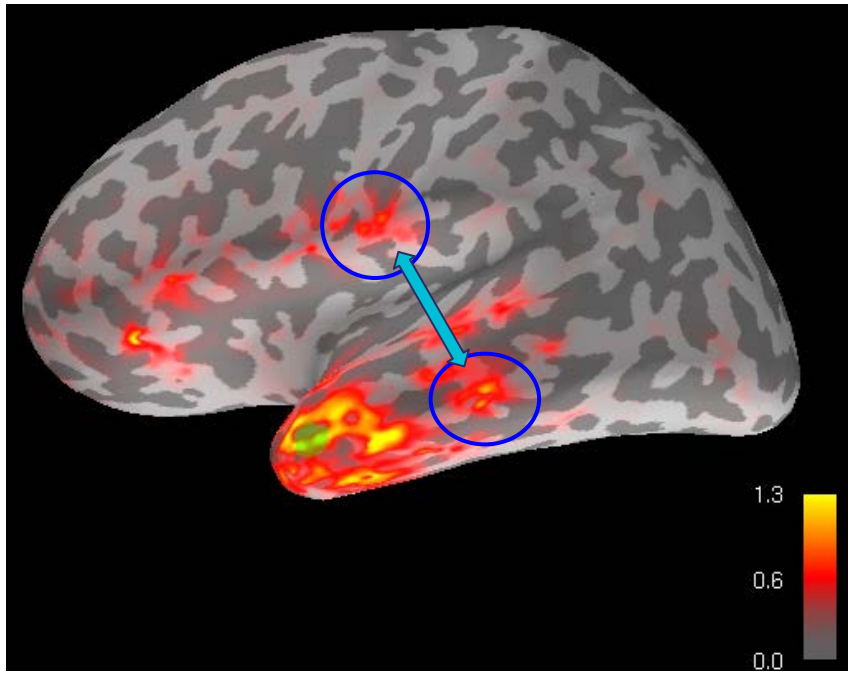
Spatial Resolution And Leakage Can Confound Connectivity Measures

Field Spread / Point Spread

Connectivity between two regions may reflect cross-talk from one of the regions



Connectivity between two regions may reflect cross-talk from a third region

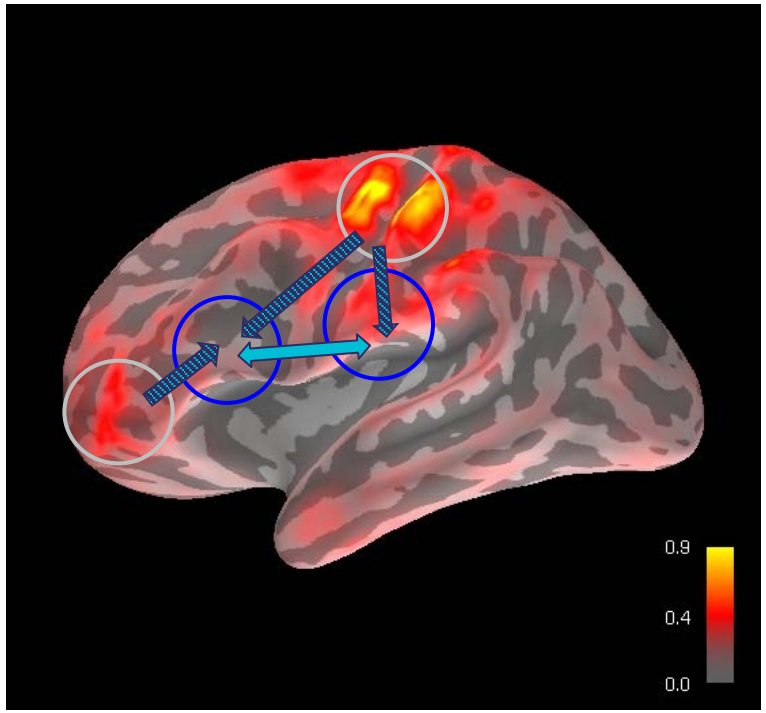


Some connectivity measures can rule out “zero-lag” connectivity

(but they are then also insensitive to real zero-lag connectivity)

Field Spread / Point Spread

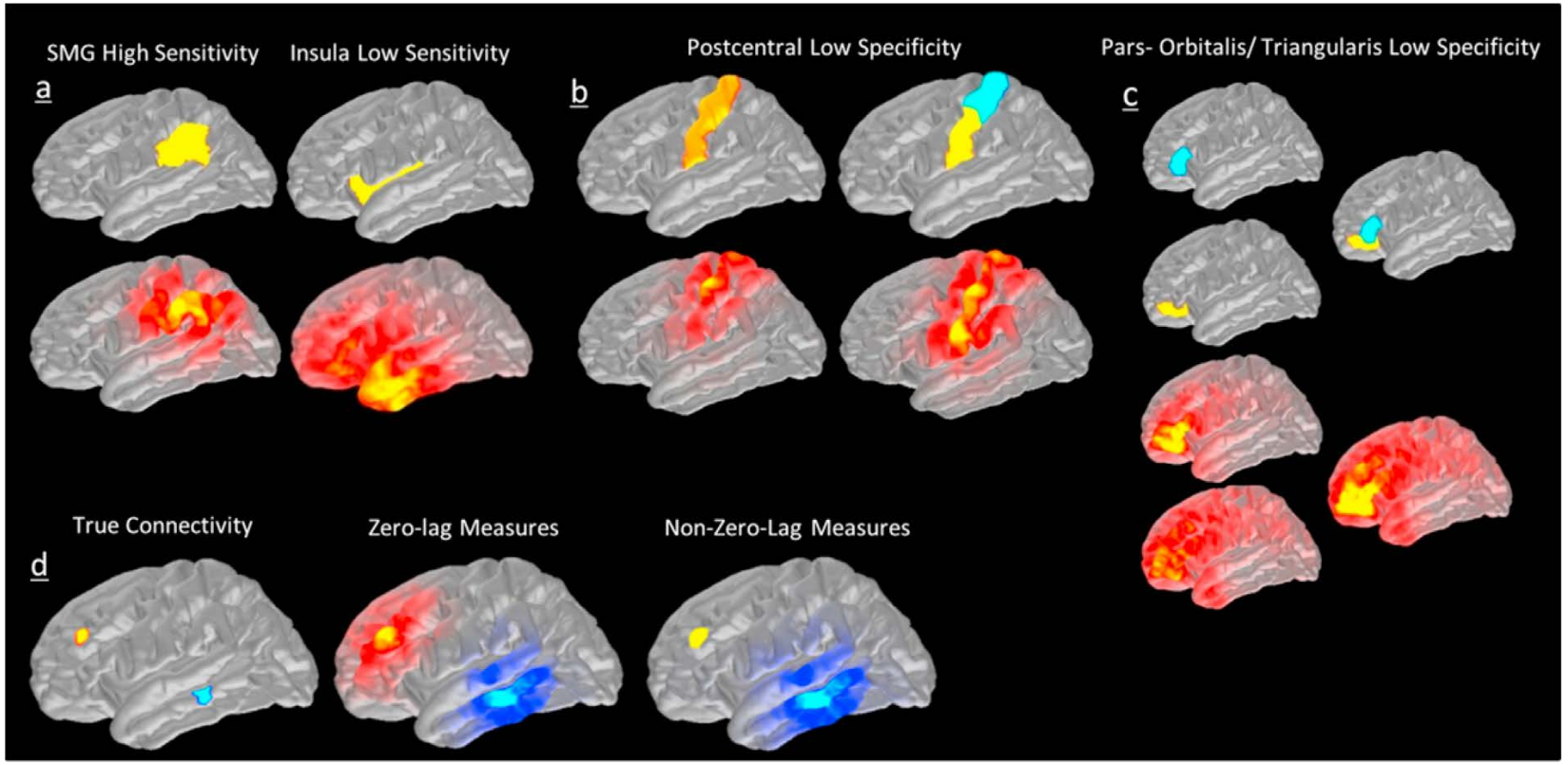
Connectivity between two regions
may reflect cross-talk from
several other regions



This is bad, and there is not much you can do –
except getting your model right in the first place, or use whole-brain analysis.

Leakage Can Produce Spurious Connectivity

(also at zero-lag)

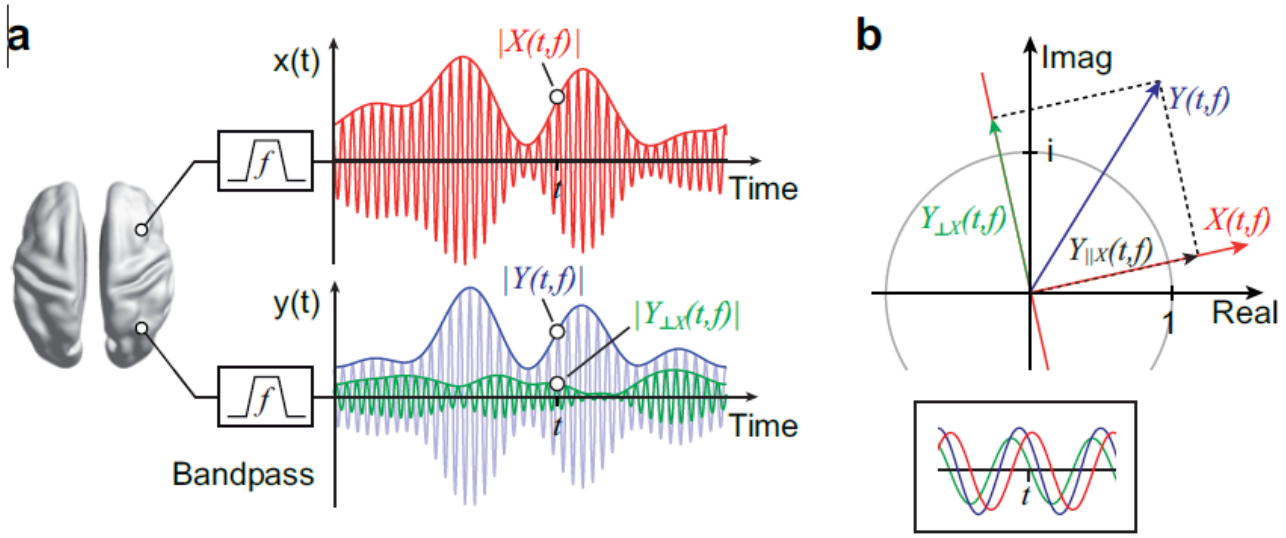


Farahibozorg, Henson, Hauk, NI 2018, https://pubmed.ncbi.nlm.nih.gov/28893608/
See also:
Palva et al., NI 2018, https://pubmed.ncbi.nlm.nih.gov/29477441/
Colclough et al. NI 2015, https://pubmed.ncbi.nlm.nih.gov/25862259/

One Possibility: Remove Zero-Lag Connectivity

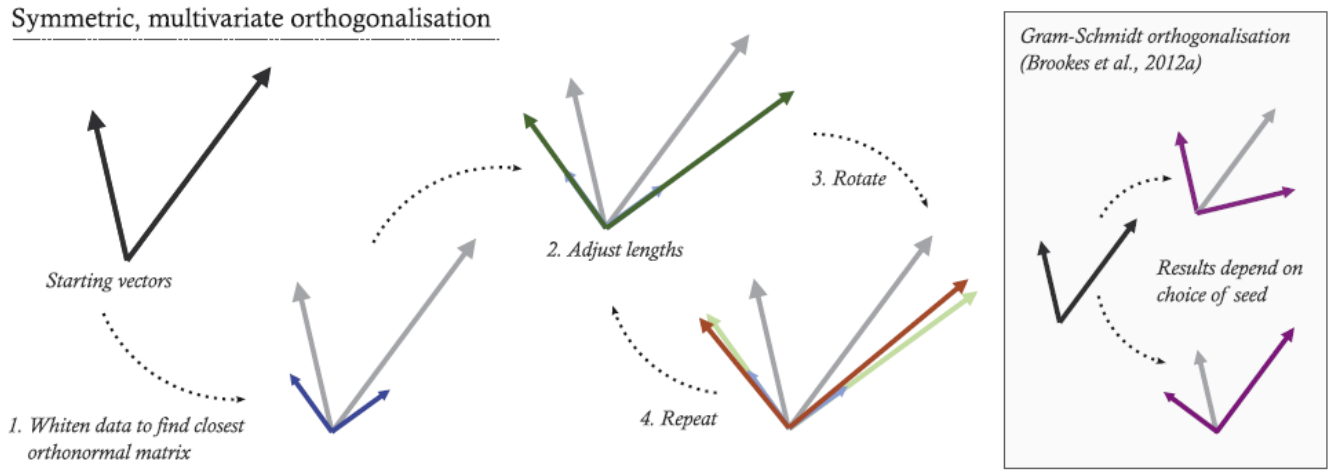
Orthogonalisation of time courses, Partial regression

Bivariate:



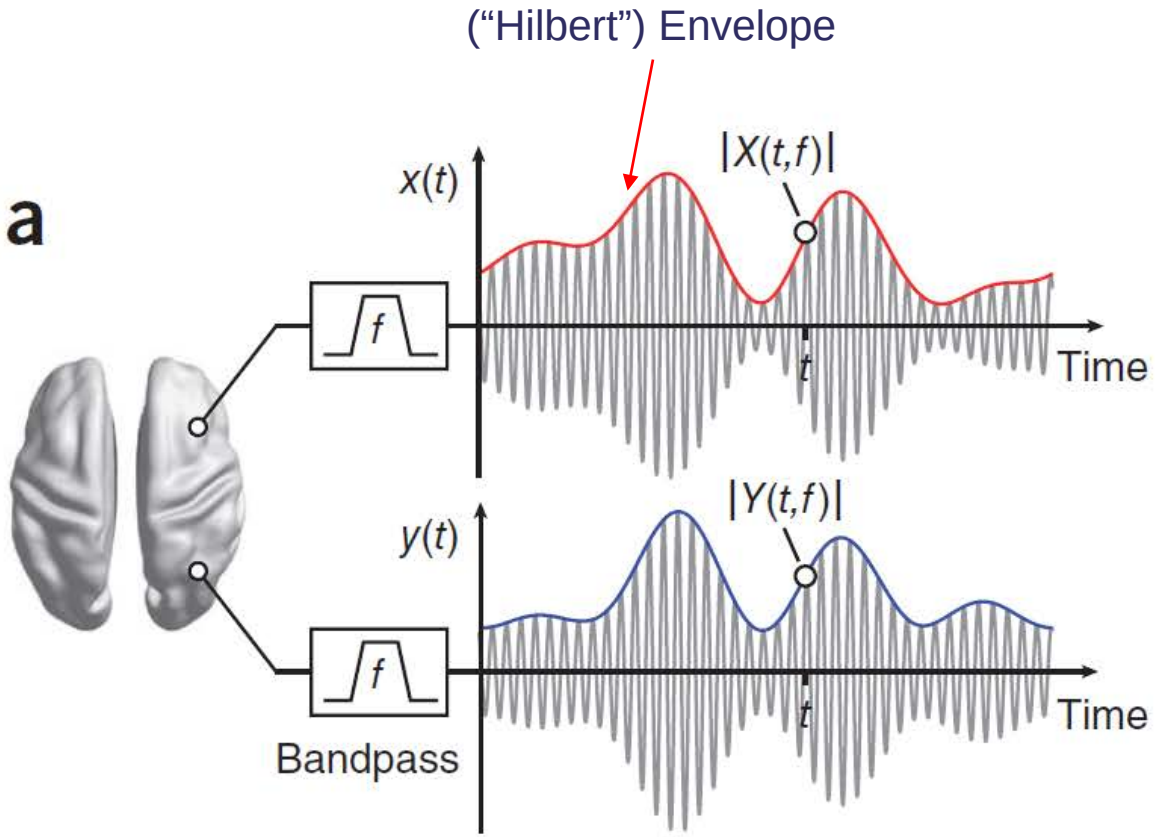
Hipp et al., Nat Nsc 2012, https://www.nature.com/articles/nn.3101

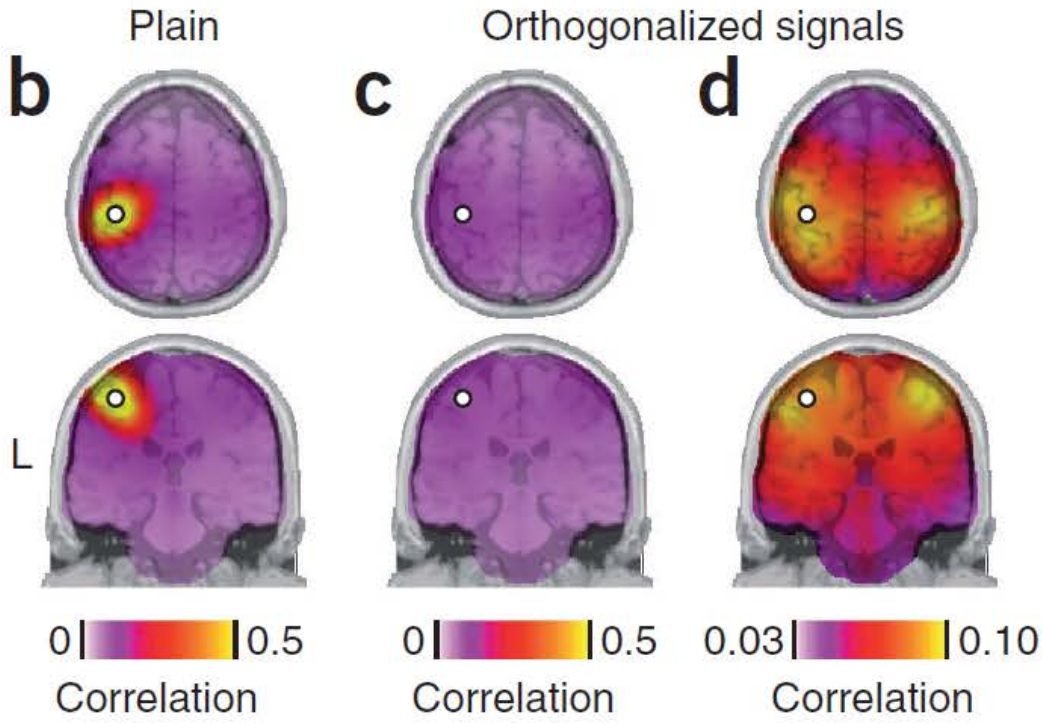
Multivariate:



Colclough et al., NI 2015, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4528074/

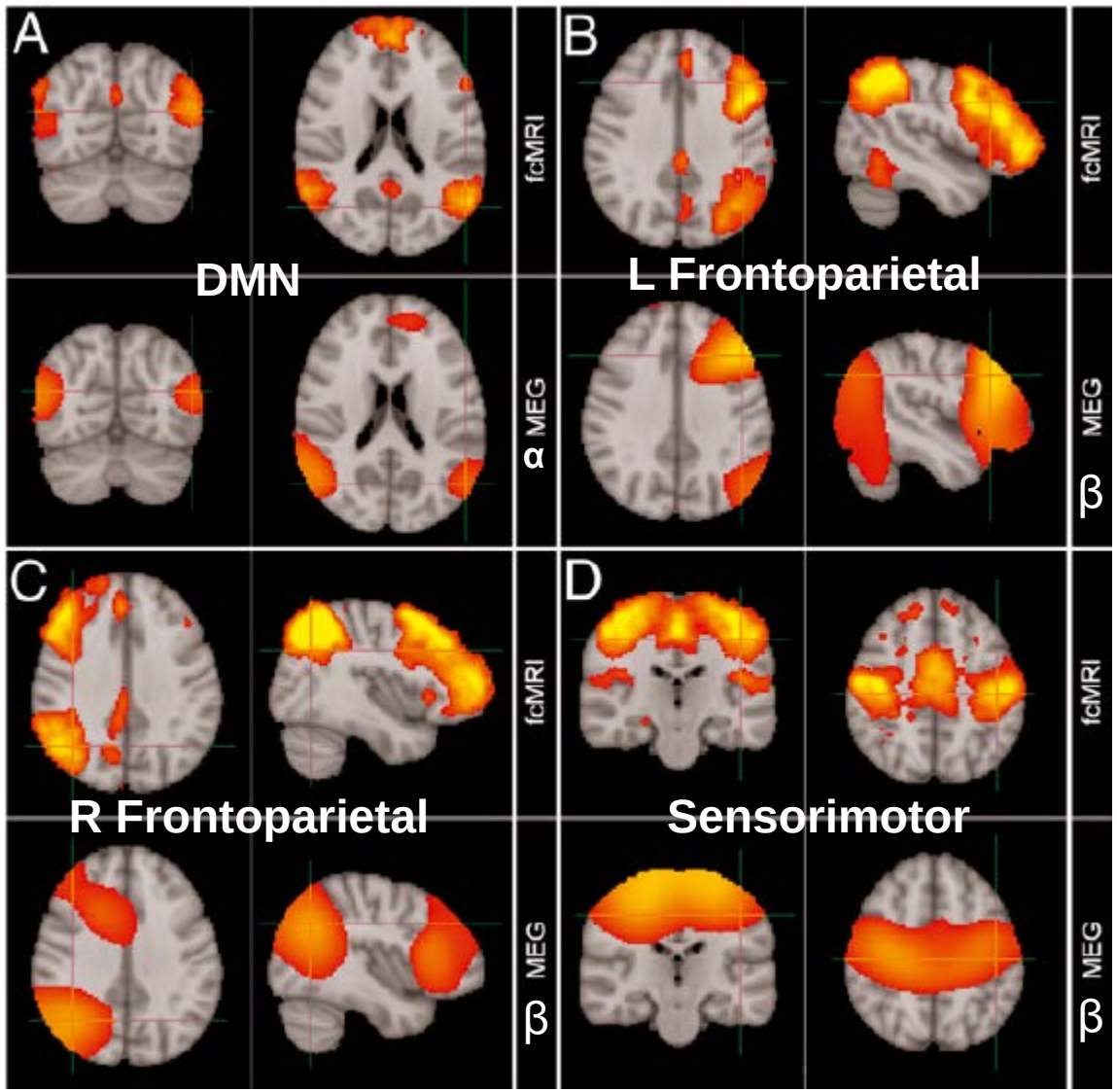
Functional Connectivity of Resting State Activity

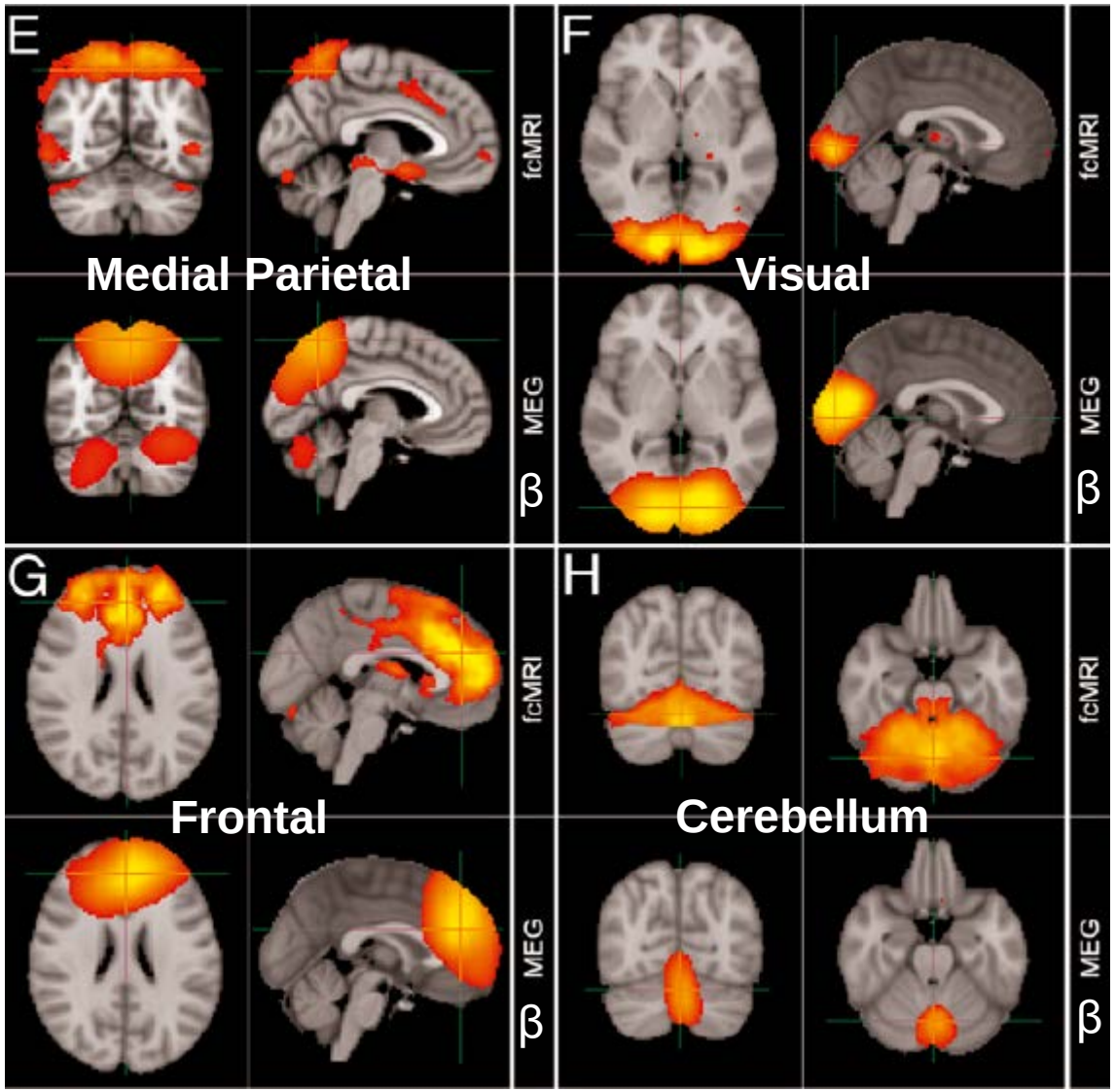




Hipp et al., Nat Nsc 2012, https://www.nature.com/articles/nn.3101

Functional Connectivity of Resting State Activity





Brooks et al., PNAS 2011, https://www.pnas.org/doi/10.1073/pnas.1112685108

One Possibility: Remove “Zero-Lag” Connectivity

Imaginary Part of Coherency

In spectral connectivity measures like Coherence, only use the imaginary part of the signal, which is unaffected by zero-lag connectivity (phase differences of zero are only represented in the real part).

Ewald et al., NI 2012, https://pubmed.ncbi.nlm.nih.gov/22178298/

Pascqual-Marqui, arXiv 2007a and 2007b, https://arxiv.org/abs/0706.1776, https://arxiv.org/abs/0711.1455

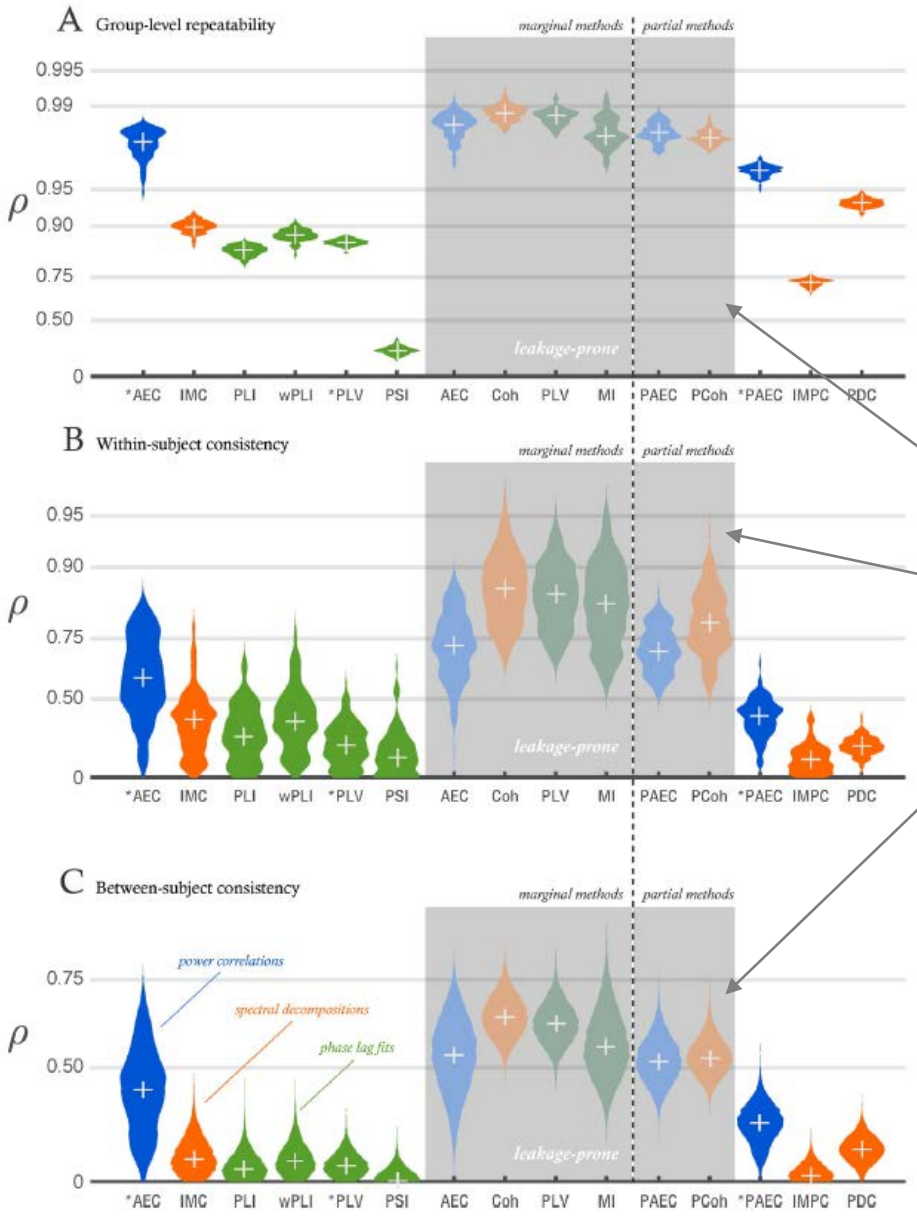
Note: “Non-zero-lag methods” may also ignore true zero-lag connectivity, e.g. for bilateral sources – one may through out the child with the bath water.

Leakage and Reliability of Functional Connectivity Methods

Group-level repeatability

Within-subject consistency

Between-subject consistency



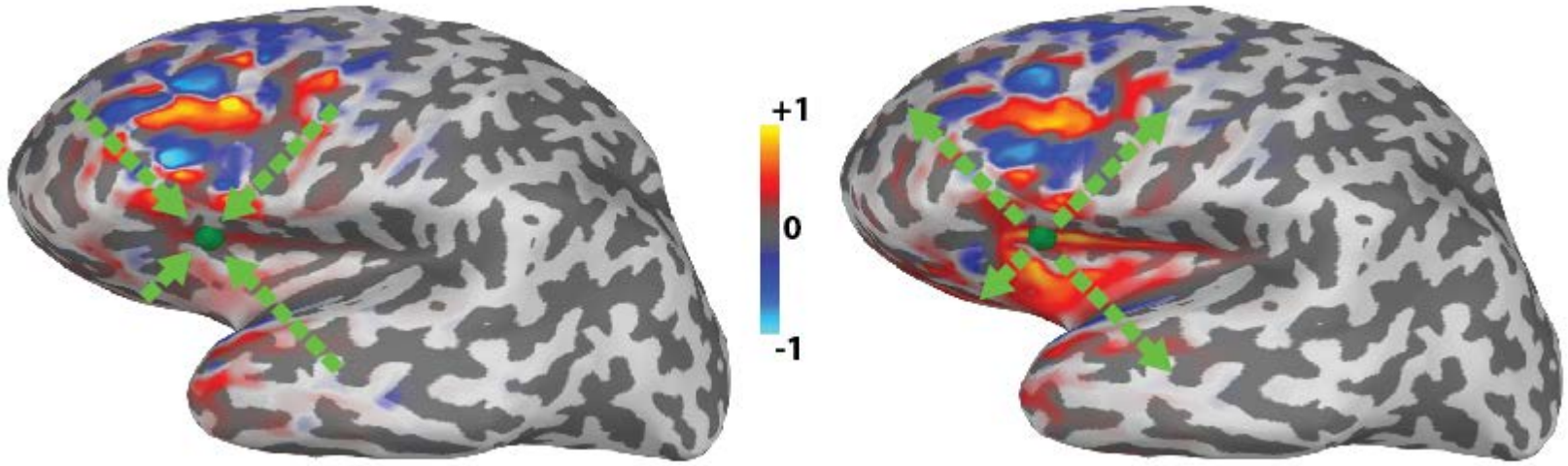
leakage-prone

Colclough et al., Neuroimage, 2016
https://pubmed.ncbi.nlm.nih.gov/27262239/

Spatial Resolution / Leakage:

Point-Spread and Cross-Talk

Cross-Talk Function
(CTF)



How other sources may affect the estimate for this source

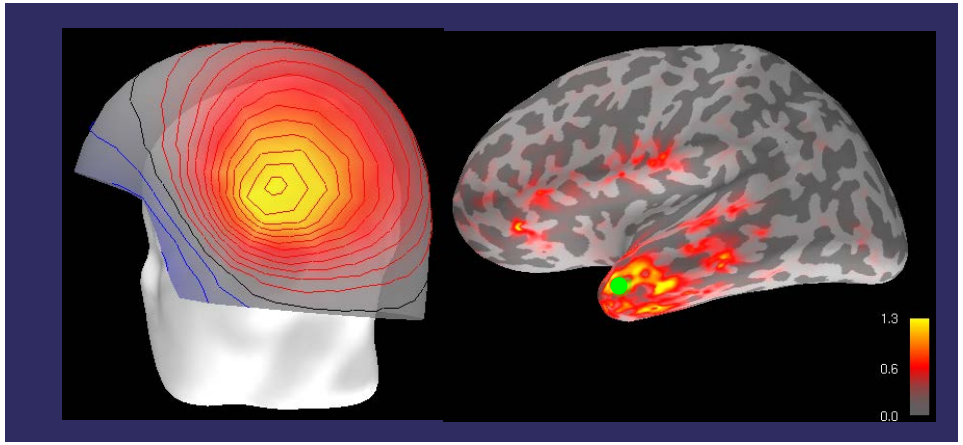
Point-Spread Function
(PSF)

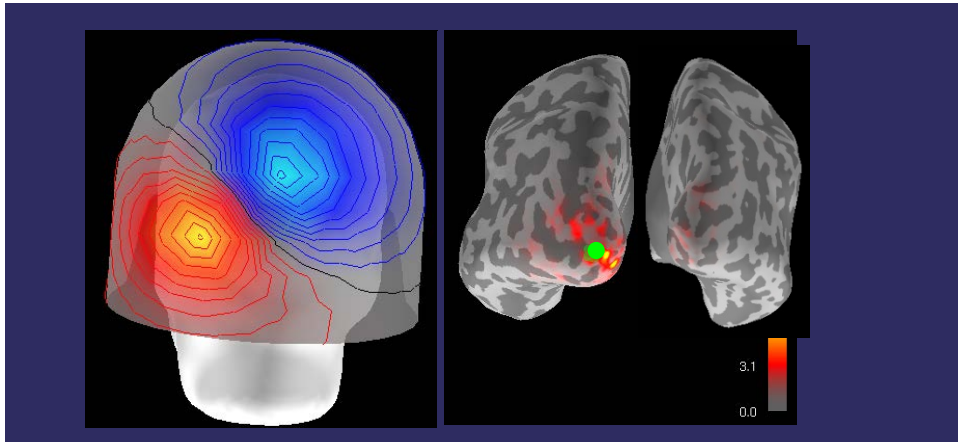
How this source affects estimates for other sources

Hauk, Stenroos, Treder, Neuroimage 2022
https://www.sciencedirect.com/science/article/pii/S1053811922002993

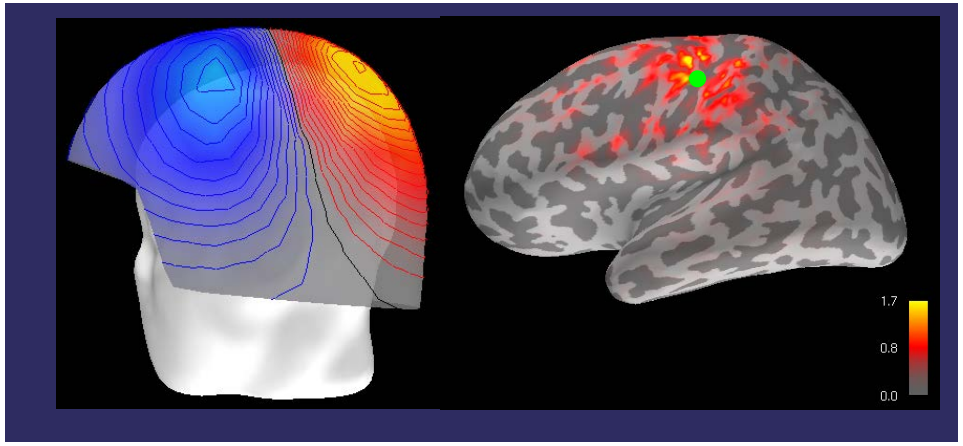
PSFs and CTFs for Some ROIs

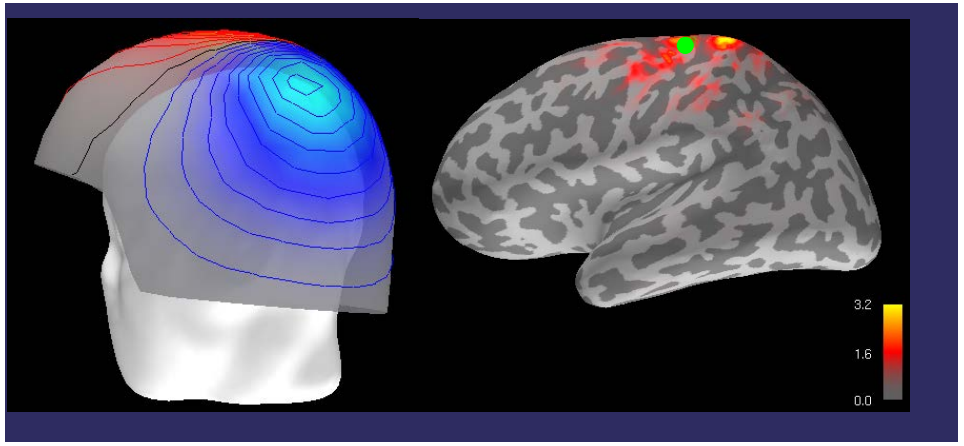
For MNE, PSFs and CTFs turn out to be the same





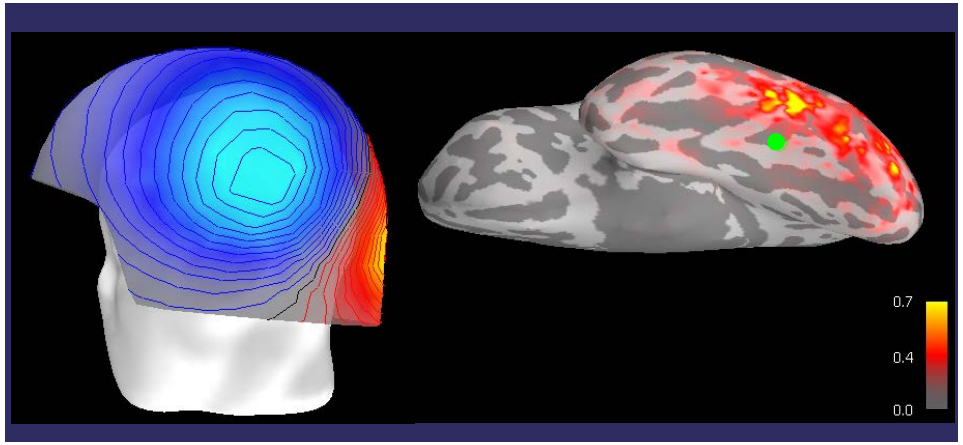
Good

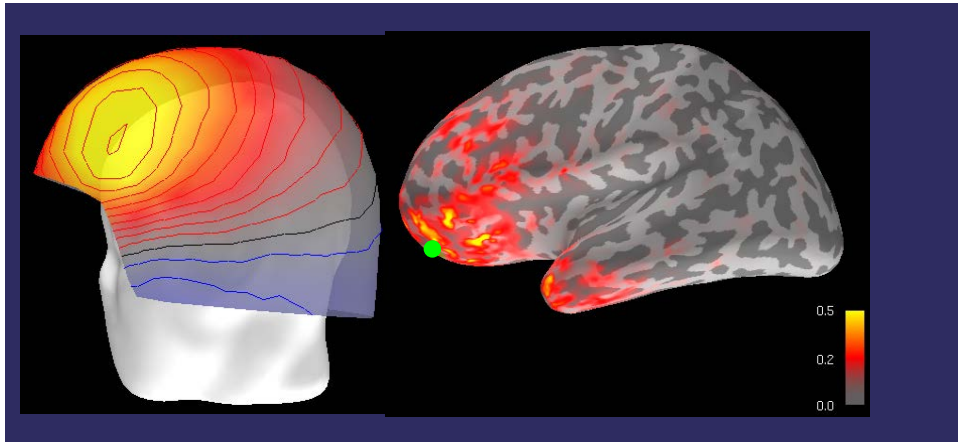




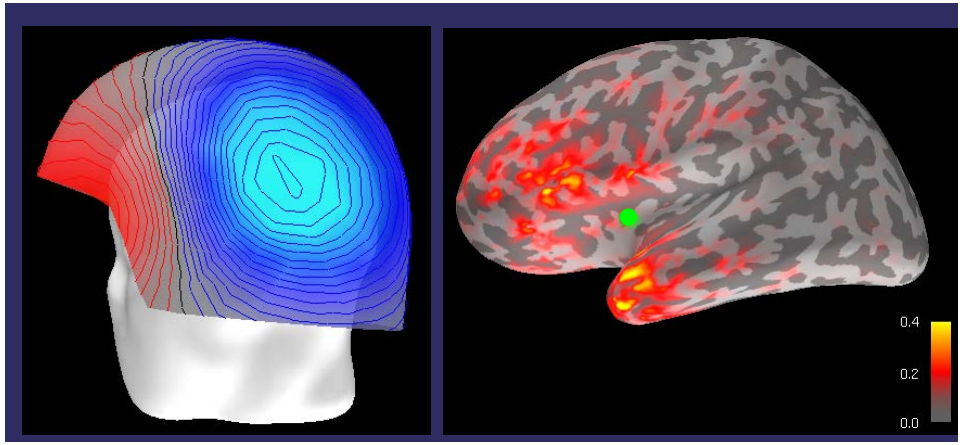
PSFs and CTFs for Some ROIs

For MNE, PSFs and CTFs turn out to be the same



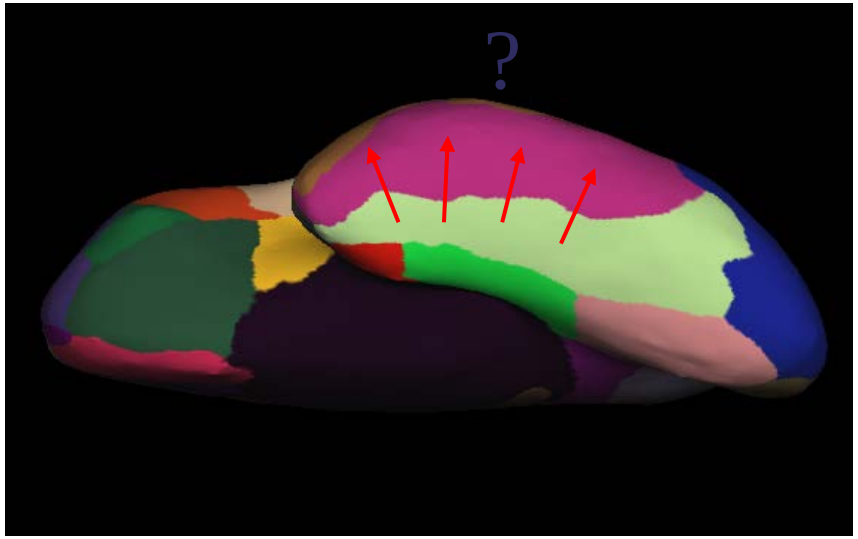


Less good

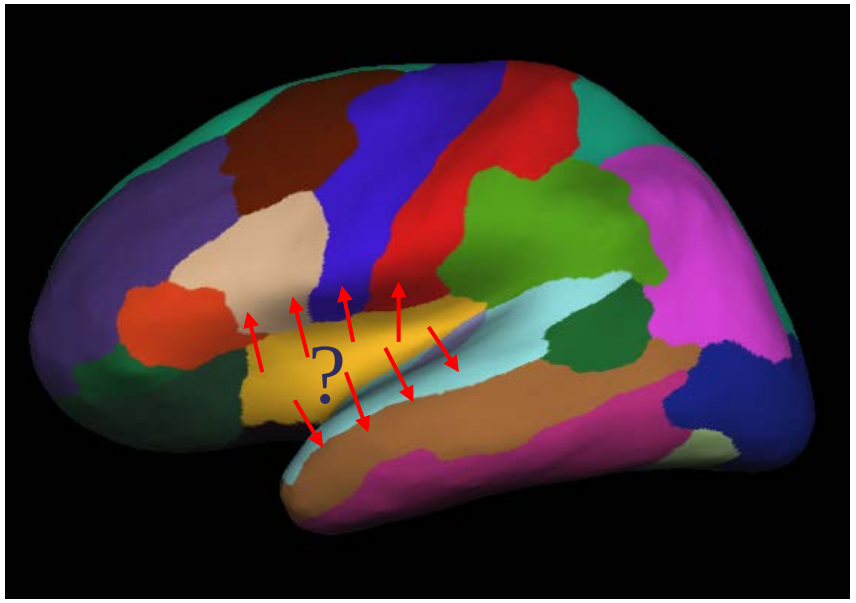


Localisation Bias Has Consequences for ROI analysis

PSFs/CTFs Can Tell You How It Looks Like

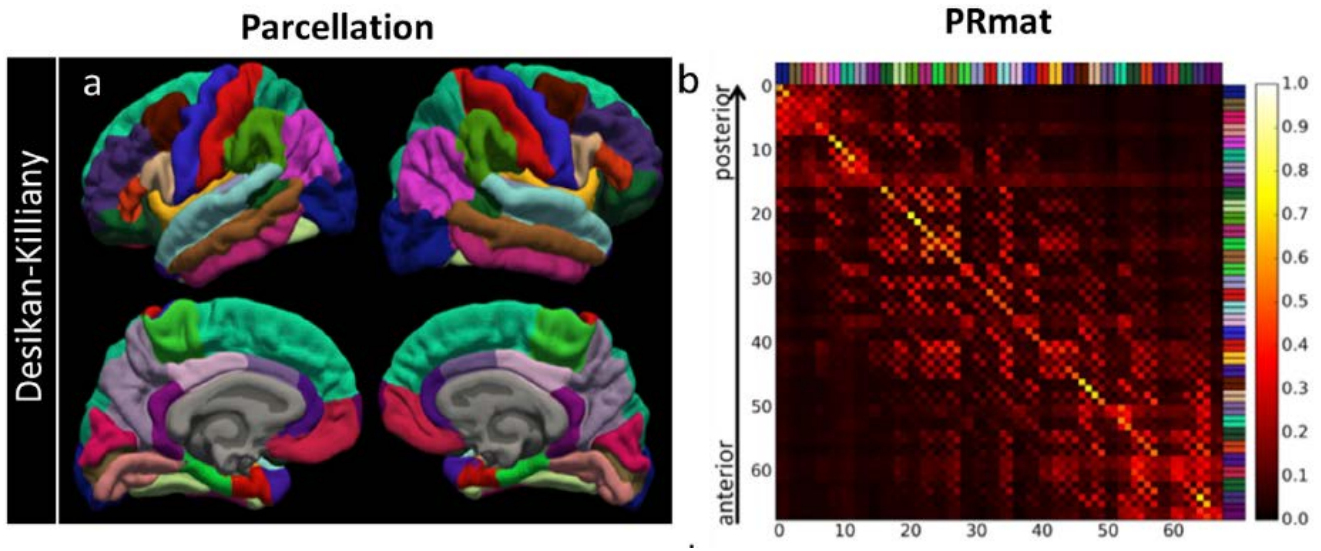


Desikan-Killiany Atlas parcellation

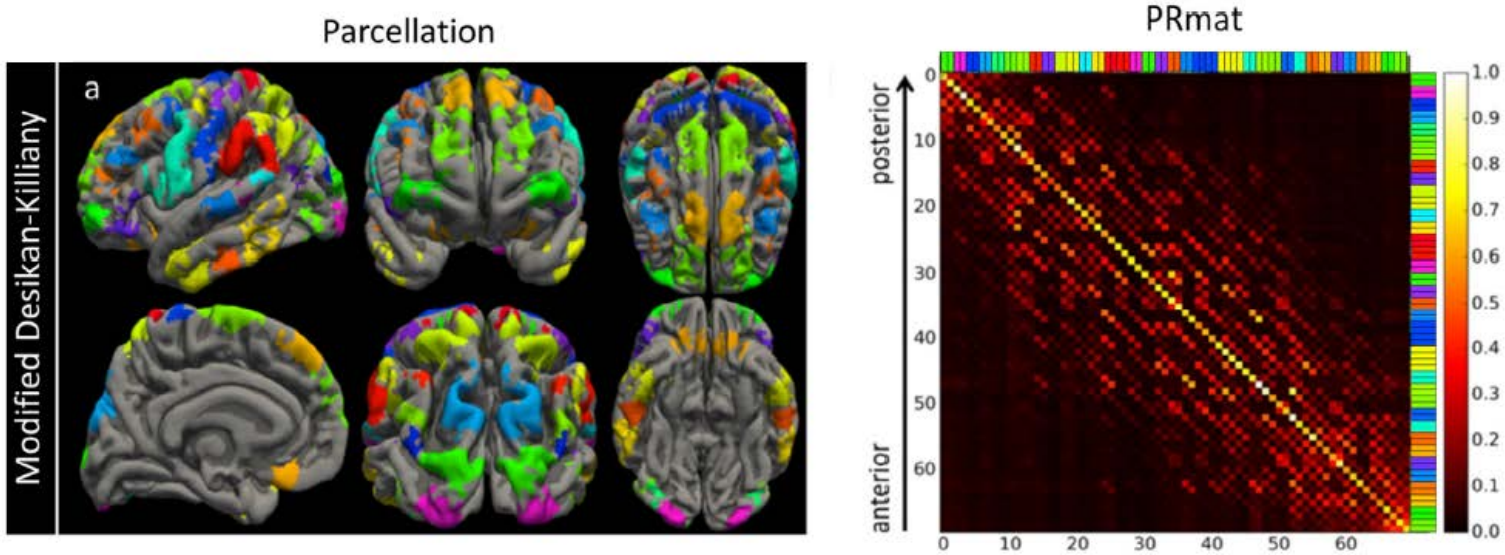


Adaptive cortical parcellation based on resolution matrix

Original Parcellation



Modified Parcellation



Farahibozorg/Henson/Hauk NI 2018
https://pubmed.ncbi.nlm.nih.gov/28893608/

And Beyond…

Most of the previously introduced measures are spectral measures, i.e. they are computed for specific frequencies (or frequency bands).

They rely on the assumption that brain signals can meaningfully be decomposed into “oscillations” or “frequency bands”.

This is a big assumption, and may not be the case for all modalities, stimuli, tasks etc., or may not even be true in general.

Therefore…

Non-Spectral and Effective Connectivity

Granger Causality: Is one time series useful to predict another?
x(t) Granger-causes y(t) if past values of x(t) add information to past values of y(t) for predicting future values of y(t).

http://www.scholarpedia.org/article/Granger_causality
Multivariate Granger Toolbox: http://www.sussex.ac.uk/sackler/mvgc/
http://journal.frontiersin.org/article/10.3389/fnsys.2015.00175/full

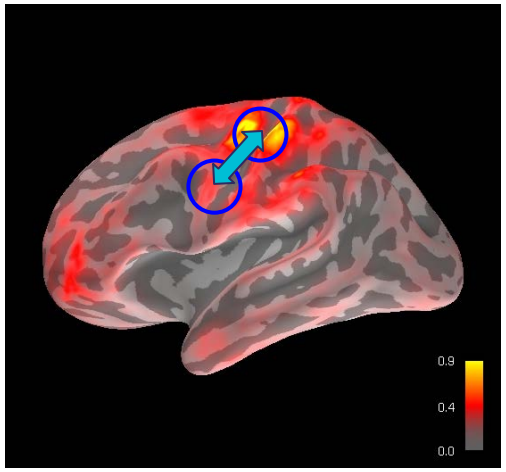
Structural Equation Modelling (SEM):
Models covariance structure of brain activation across brain regions (e.g. “path analysis”).

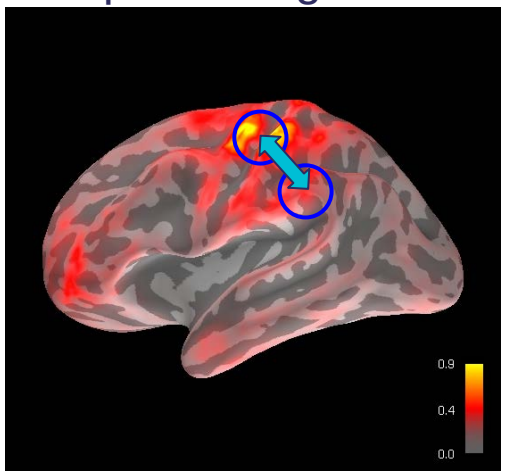
Dynamic Causal Modelling (DCM):
Models brain dynamics across regions as differential equations, in combination with Bayesian parameter/model estimation.

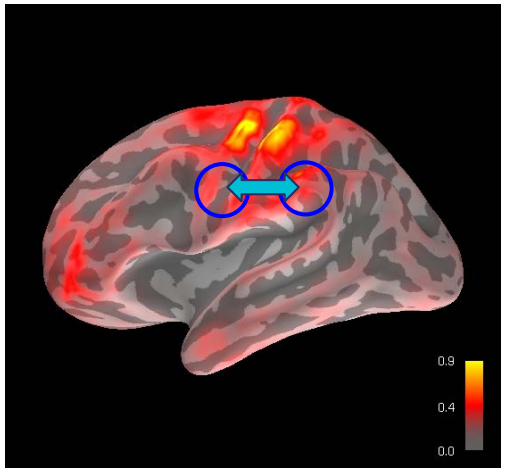
http://www.scholarpedia.org/article/Dynamic_causal_modeling

Bivariate vs Multivariate Connectivity

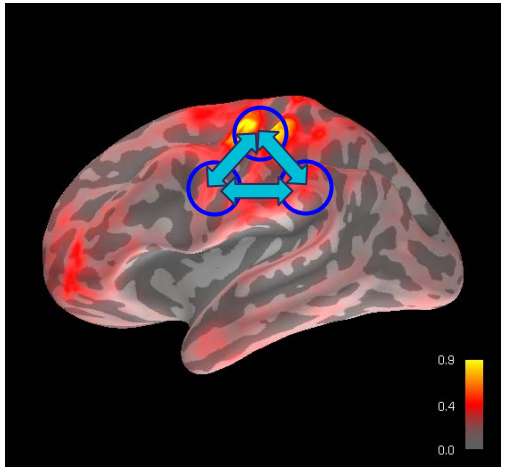
Bivariate measures test one pair or regions at a time:





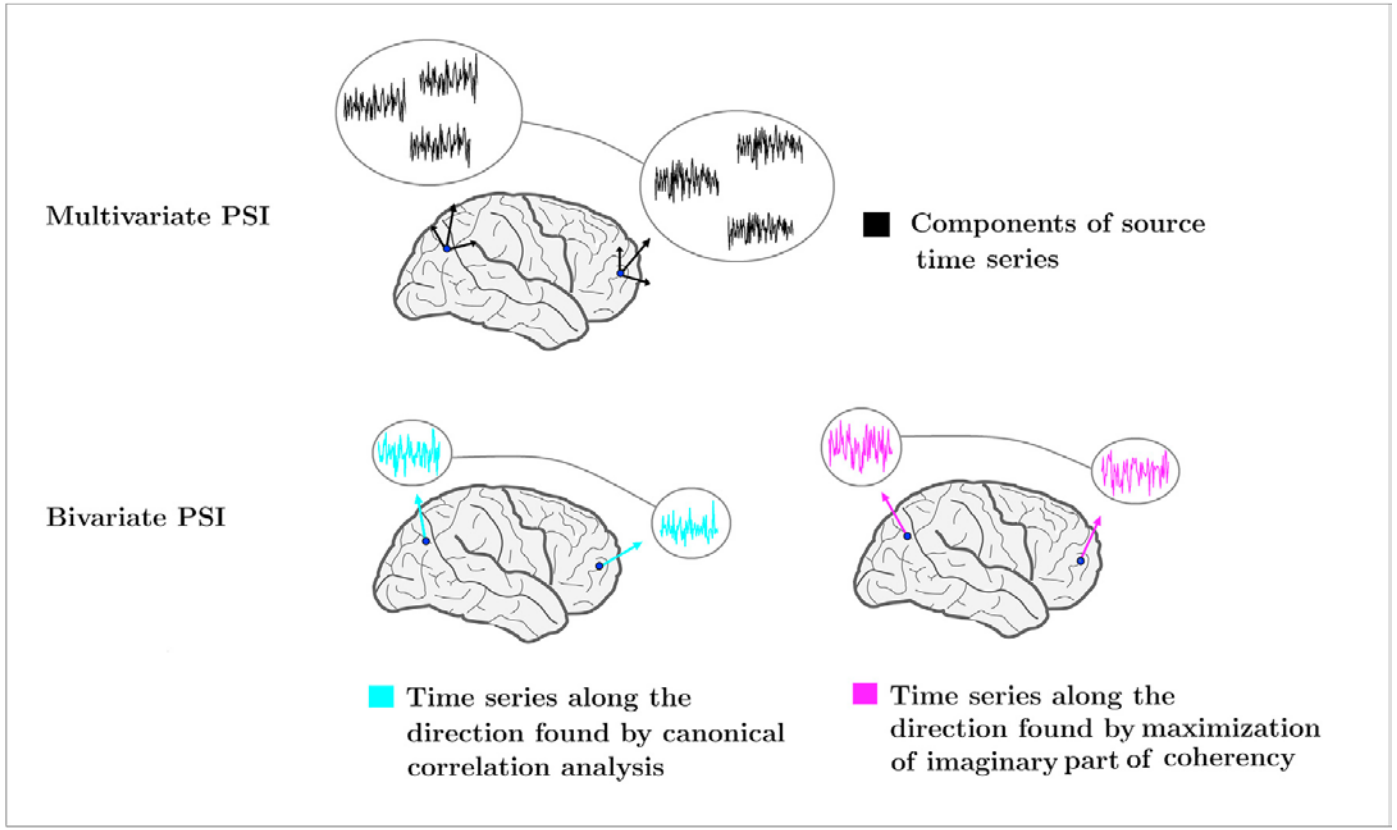


Multivariate measures test multiple regions simultaneously:



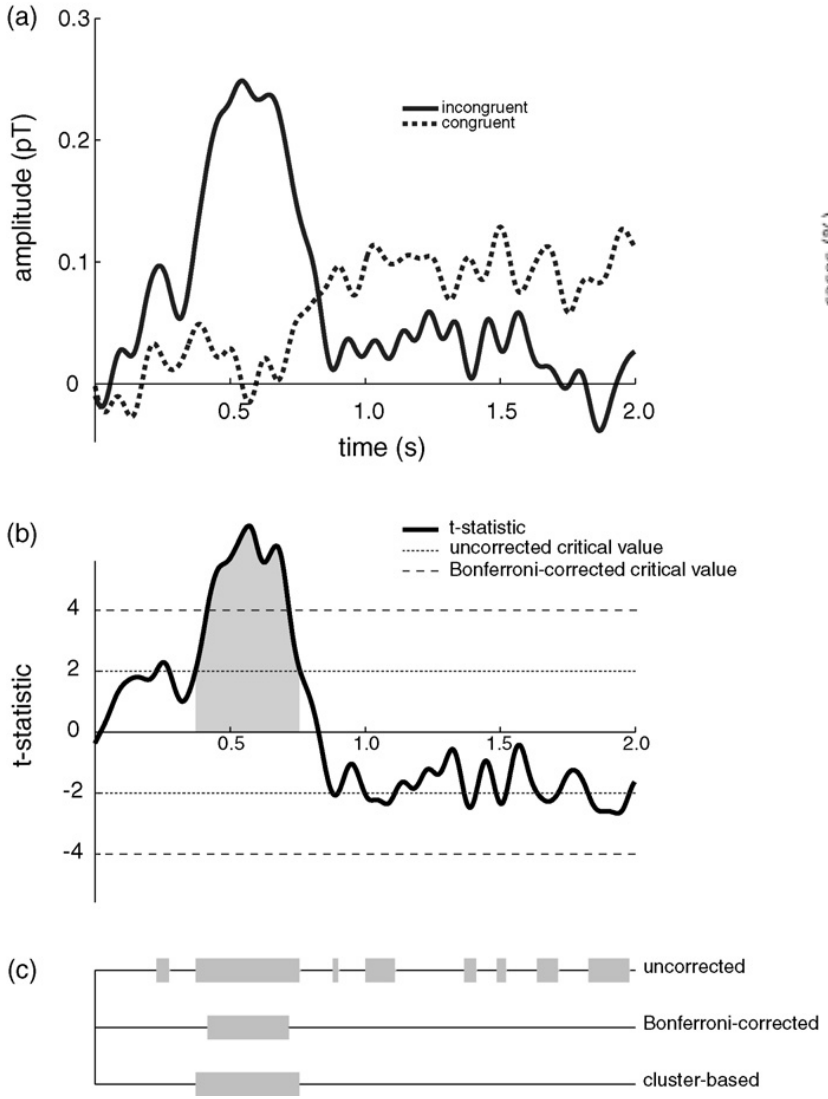
Multi-Variate and Multi-Dimensional Connectivity

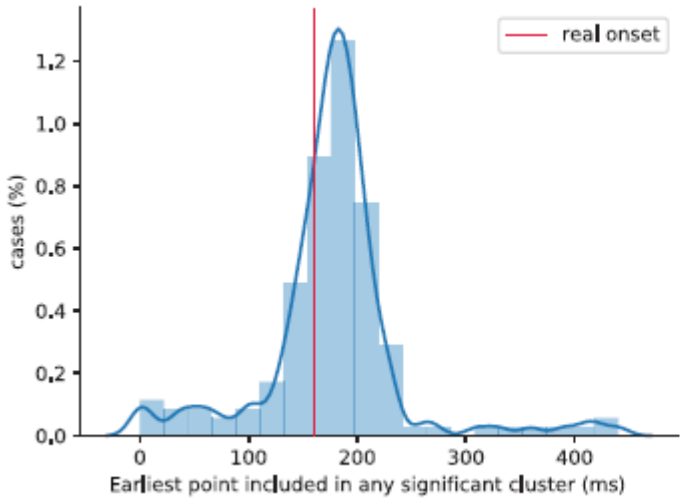
Currently, most connectivity methods use one time course per ROI. However, brain activity is multivariate, and there is potentially a lot of information lost by collapsing across vertices or voxels. “Multi-dimensional” methods are now emerging.

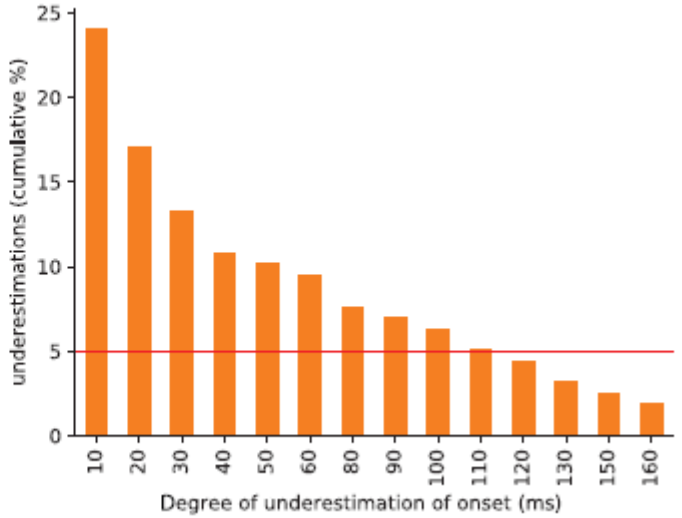


Basti et al., NI 2018, https://www.sciencedirect.com/science/article/pii/S1053811918301897
Also:
Basti/Nili et al., NI 2020, https://www.sciencedirect.com/science/article/pii/S1053811920306650
Anzellotti & Coutanche, T Cogn Sci 2018, https://pubmed.ncbi.nlm.nih.gov/29305206/
Basti et al., PLoS 2019, https://journals.plos.org/plosone/article/comments?id=10.1371/journal.pone.0223660

Statistics – Cluster-Based Permutation Tests







Cluster-based permutation tests of MEG/EEG data do not establish significance of effect latency or location

Sassenhagen & Draschkow, Psychophysiol 2018, https://pubmed.ncbi.nlm.nih.gov/28893608/

Maris and Oostenveld, JNscM 2007, https://pubmed.ncbi.nlm.nih.gov/28893608/

MRC Cognition and Brain Sciences Unit

UNIVERSITY OF CAMBRIDGE

Thank you