Augmenting the source-level EEG signal using structural connectivity

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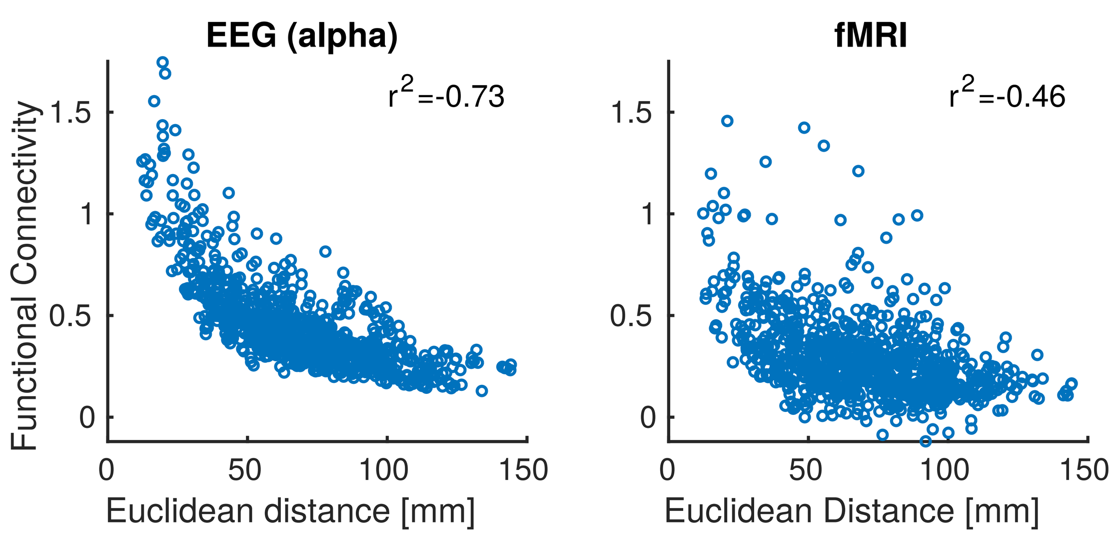
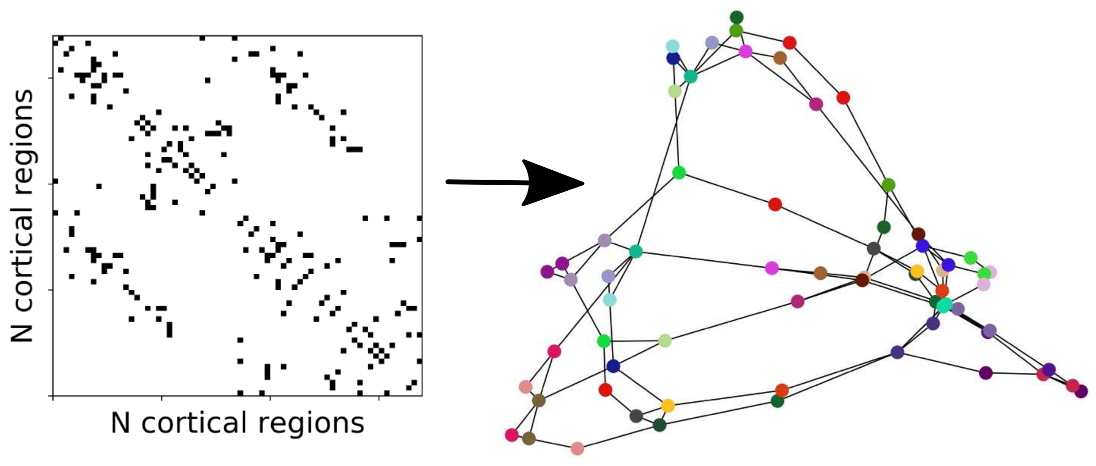
Introduction

· Problem with EEG: Volume conduction leads to distance-dependent zero-shift correlations
· But there is also a real fall-off of functional connectivity (**FC**) with distance
· This problem persists when working in source space with a parcellation [1]

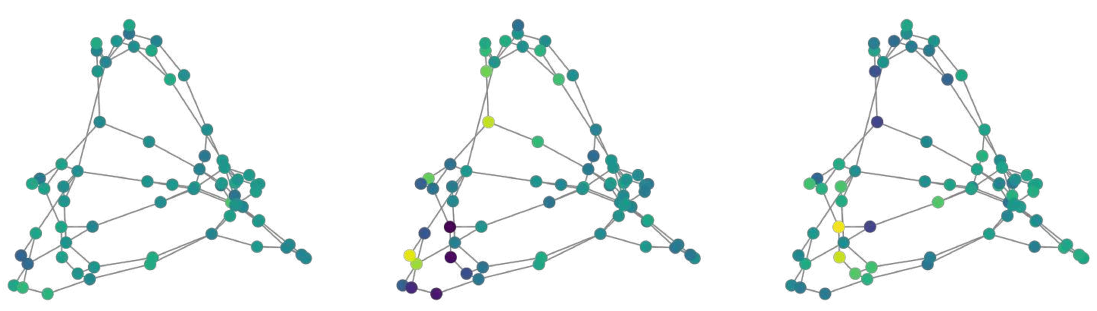


· Actually, the signal lives on a graph [2]:

*Graph topology defined by structural connectivity (**SC**):*



Signal at different points in time:



· ...so we smooth the signal using its nearest neighbors in graph space:

$$\hat{x}_i(t) = x_i(t) + G\sum_j (C_{ij}x_j(t))$$

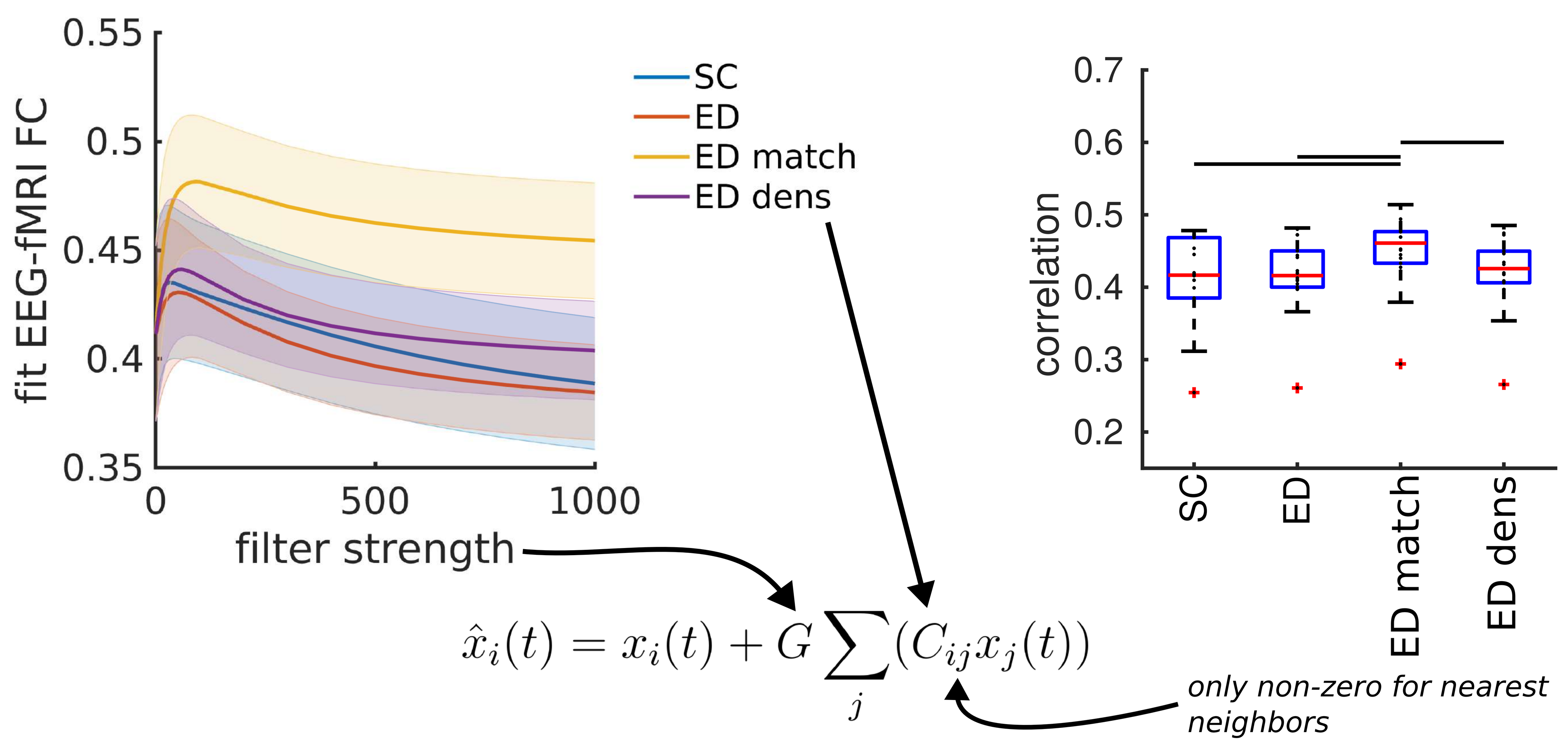
· Validation:

1. Correlation with fMRI-FC
2. Comparison between SC+ and SC- connections

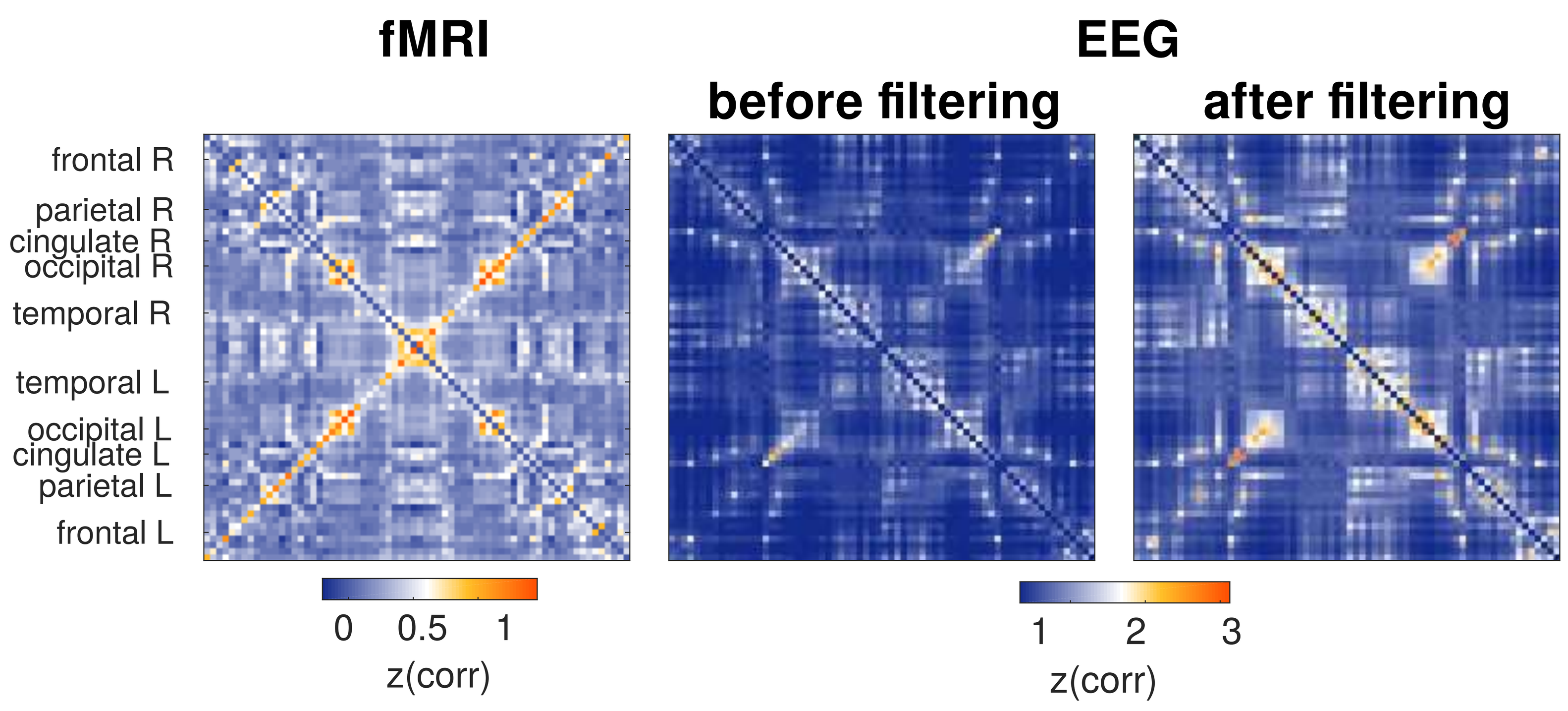
Methods

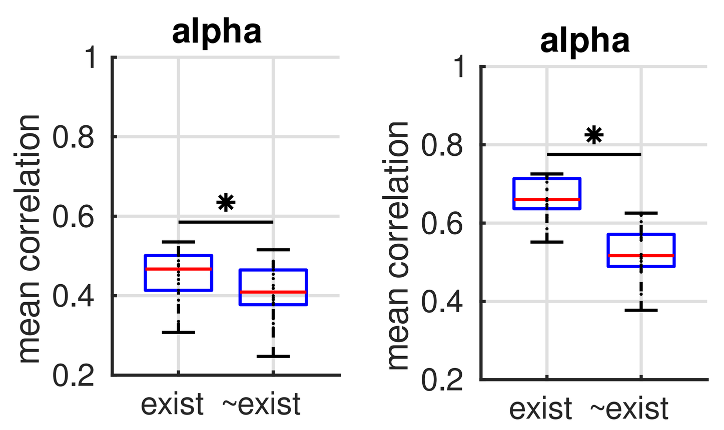
EEG-FC: signal > filter (alpha: 8-13 Hz, beta: 13-30 Hz, gamma: 30-40 Hz) > power envelopes > correlations
EEG data: 18 subjects, resting state, different durations, several minutes; source reconstruction with ~5000 solution points
Parcellations, individual head models: T1-weighted images of same subjects
SCs: Diffusion imaging with same subjects
fMRI: Taken from [4]

Combining information from functional and structural connectivity



1. Smoothing the signal in graph space increases the similarity between EEG and fMRI FC
2. The best result is obtained using weights derived from the Euclidean distance, masked by existing fibers as measured with diffusion MRI tractography ("ED match")
3. Using only local connections does not increase performance ("ED dens")





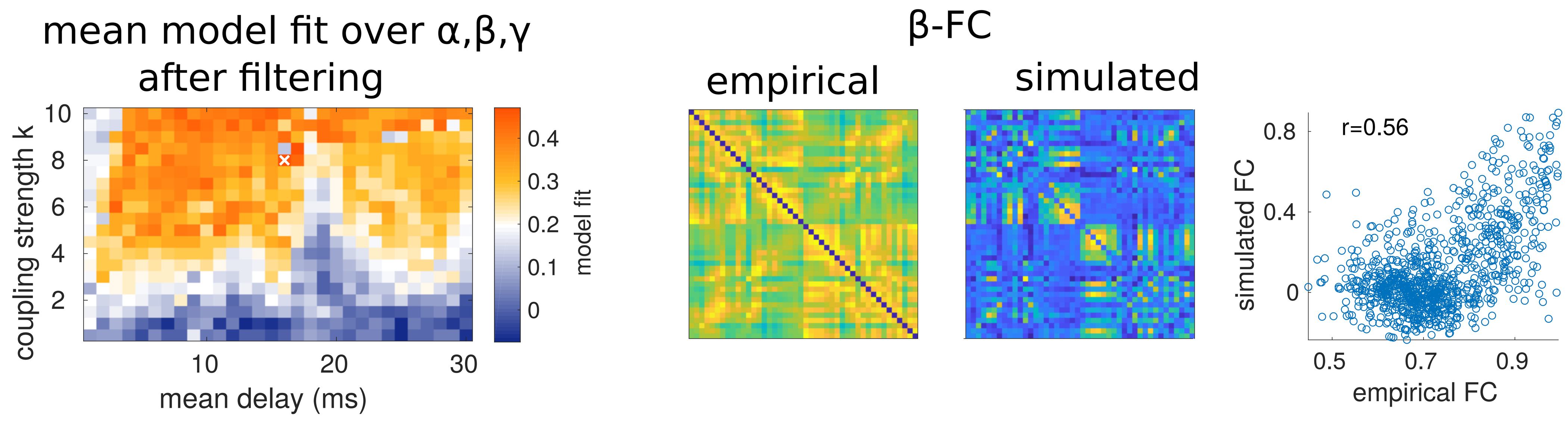
anatomically connected ("exist") pairs have stronger FC than unconnected ("~exist") pairs:

Modelling results

· each brain region n is an oscillator with natrual frequency ω~40 Hz, phases θ of oscillators coupled using empirical SC (Cnm):

$$\frac{d\theta_n}{dt} = \omega + k\sum_{m\in N_n} C_{nm}\sin(\theta_m(t-\tau_{nm}) - \theta_n(t))$$

· τ is the delay determined by the fiber length, k is the coupling strength
· simulated FCs computed in the same way as for empirical data > correlation > model fit
· distribution of phases changes over time: $R(t) = (1/N)\sum_n \exp(i\theta_n(t))$, SD(R(t)): "metastability"



· fit improves to level of previous MEG-based publications [3] without changing dynamics
· main features of FCs captured
· main problem: this only works for filtering with the actual SC > improvement of fit to fMRI-FC is small (~10%) > validation?
· also: unclear what this does to non-0-phase-lags in data

Conclusions & Outlook

· Information from the structural connectome can be used to augment the EEG signal
· The binary SC graph is important while the fiber count does not contribute
· FC between nearby, anatomically connected pairs is strengthened, that between far-away, non-connected pairs is weakened, leading to a better fit with fMRI-FC
· **This suggests that graph signal processing is more generally applicable to EEG**

References
[1] Hagmann et al., PLoS B (2008)
[2] PyGSP: github.com/epfl-lts2/pygsp
[3] Cabral et al., NIMG (2014)
[4] Griffa et al., NIMG (2017)

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