HONeD-in on Brain Activity: Deconvolving Passive Diffusion on the Structural Network From Functional Brain Signals

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OVERVIEW

Problem: Neural signals measured in fMRI reflect both local region-specific ("innovation") signals and passive global diffusion through white matter structural connectivity (SC), complicating the analysis of true functional activity.

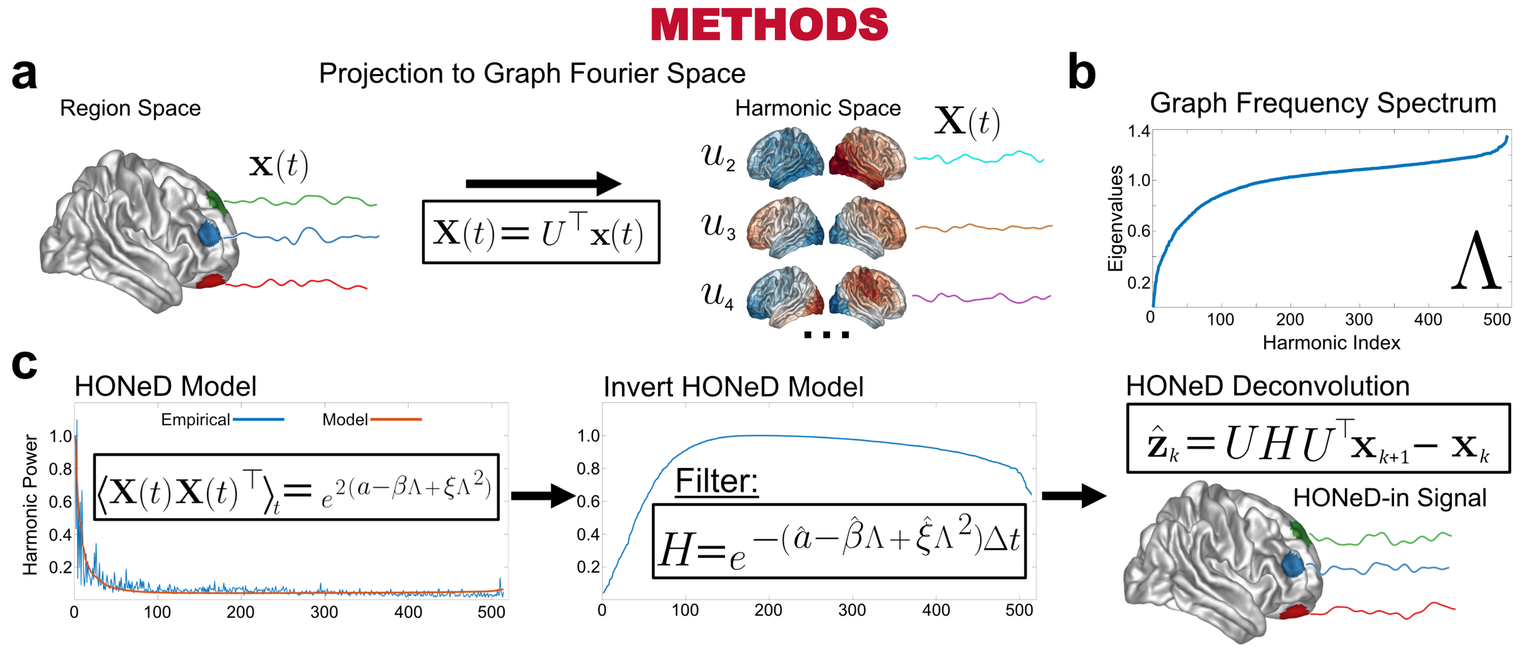
Approach: We use a **H**igher **O**rder **Ne**twork **D**iffusion (HONeD) Model, which extends the Network Diffusion Model[1], to quantify the amount of fMRI signal described by passive diffusion propagating over the SC.

Method: HONeD Deconvolution inverts the model prediction to deconvolve the diffuse signal from the innovation signal in fMRI data.

Findings: HONeD-innovation (HONeD-in) signals have significantly restructured and sparser resting state functional connectivity and GLM task activation maps.

Impact: HONeD Deconvolution offers a generalizable, principled method for extracting and studying the innovation signal in any fMRI experimental design.

METHODS

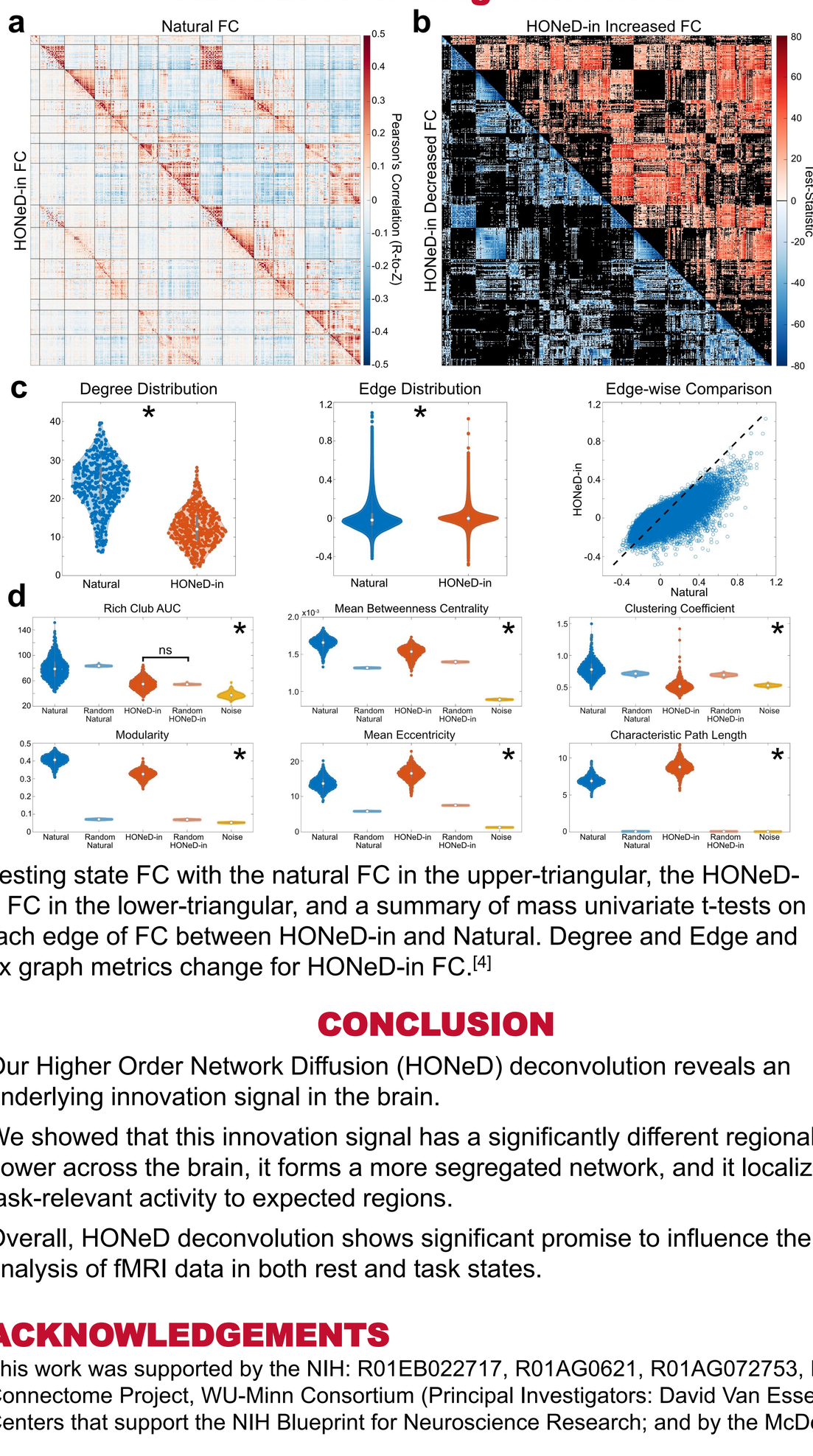


Dataset: 770 Healthy young adult subjects from the Human Connectome Project S1200 release.[2]
fMRI Conditions: Resting State (1-hour) and 6 task conditions.
Brain Atlas: Schaefer 500 cortical parcels + 14 subcortical regions

Processing: Individual structural connectivity and functional time series processed with micapipe[3]
SC Graph Laplacian: $\mathcal{L} = I - D^{-1/2}CD^{-1/2} = U\Lambda U^\top$
HONeD-in signal ($\mathbf{z}$) computed using model parameters during resting state fMRI.

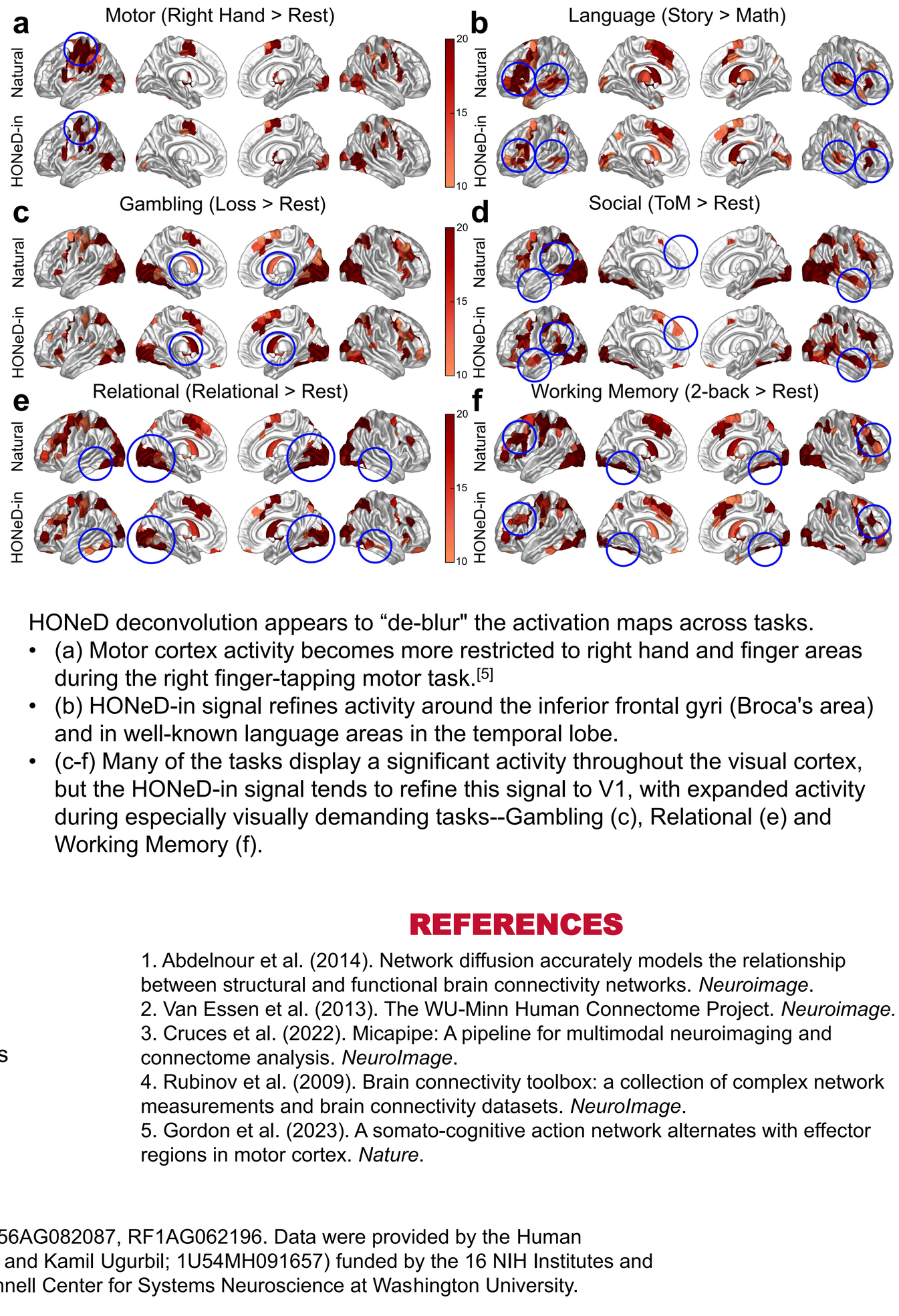
Analyses: Network Metrics[4]: Modularity, Clustering Coef., Small Worldness, Char. Path Length
Rest Contrast: Test-statistic between regional power in natural vs innovation signal
Task Contrast: General Linear Model contrast (Task Active > Task Rest)

RESULTS: Resting State fMRI



Resting state FC with the natural FC in the upper-triangular, the HONeD-in FC in the lower-triangular, and a summary of mass univariate t-tests on each edge of FC between HONeD-in and Natural. Degree and Edge and six graph metrics change for HONeD-in FC.[4]

RESULTS: Task fMRI



HONeD deconvolution appears to “de-blur" the activation maps across tasks.

- (a) Motor cortex activity becomes more restricted to right hand and finger areas during the right finger-tapping motor task.[5]
- (b) HONeD-in signal refines activity around the inferior frontal gyri (Broca's area) and in well-known language areas in the temporal lobe.
- (c-f) Many of the tasks display a significant activity throughout the visual cortex, but the HONeD-in signal tends to refine this signal to V1, with expanded activity during especially visually demanding tasks--Gambling (c), Relational (e) and Working Memory (f).

CONCLUSION

Our Higher Order Network Diffusion (HONeD) deconvolution reveals an underlying innovation signal in the brain.

We showed that this innovation signal has a significantly different regional power across the brain, it forms a more segregated network, and it localizes task-relevant activity to expected regions.

Overall, HONeD deconvolution shows significant promise to influence the analysis of fMRI data in both rest and task states.

REFERENCES

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