Changes in Cortical Directional Connectivity during Difficult Speech Listening in Younger and Older Adults

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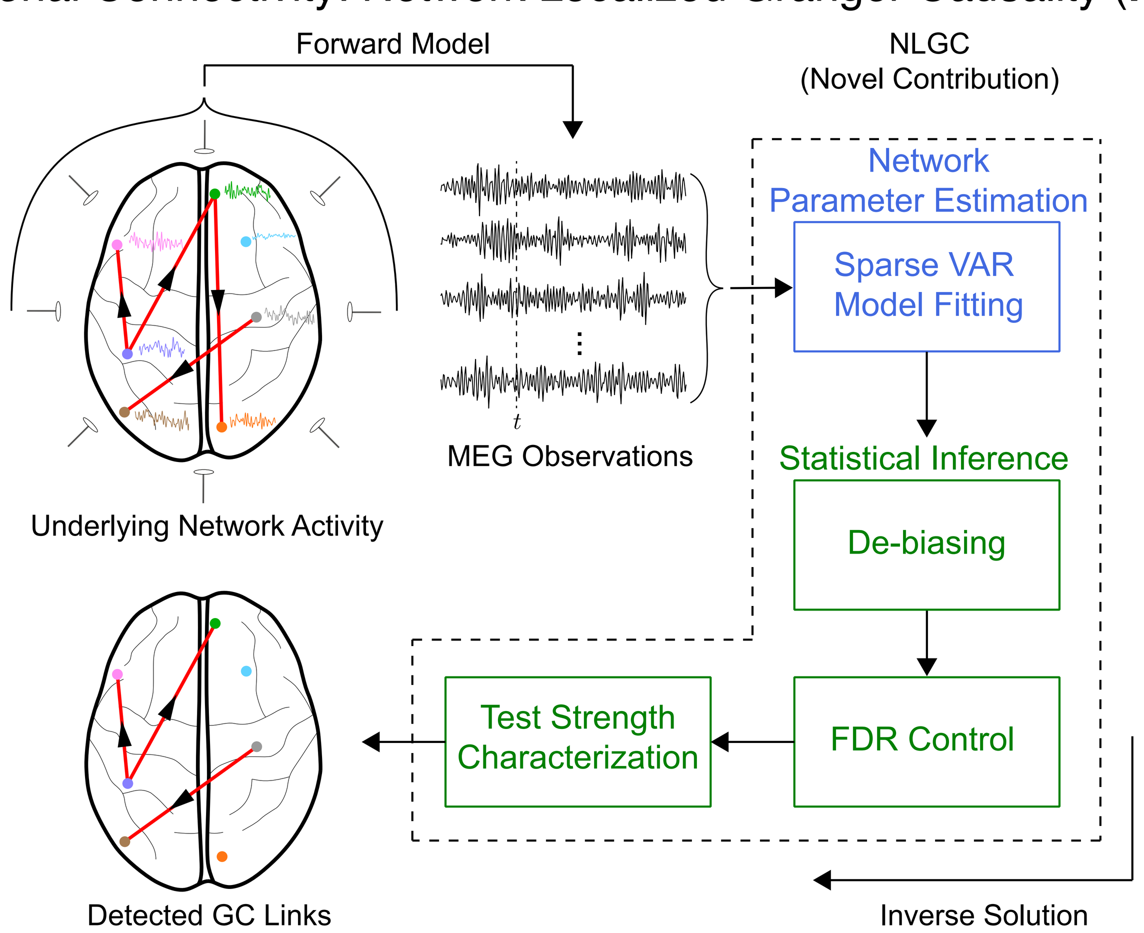
Introduction

- Speech comprehension in noisy environments is crucial in daily life, yet becomes more challenging with age, even for healthy aging.
- Network localized Granger causality (NLGC), a new neural connectivity analysis method, detects Granger causal links in magnetoencephalography (MEG) data with minimal neural source spatial uncertainty, allowing us to:
  - determine the *direction of* information flow during difficult speech listening
  - quantify cortical connectivity as a function of the *spatial distribution of the links*, *age*, and *listening condition*, for two frequency bands (delta & theta),
  - classify the *nature* (e.g., additive vs. subtractive) of the connection

NLGC Setup

Directional Connectivity: Network Localized Granger Causality (**NLGC**)



- Sparse state-space modeling

MEG measurements: $y_t = Cx_t + n_t$ (Empty room recording)

Neural sources activity: $x_t = \sum_{k=1}^{K} A_k x_{t-k} + w_t$, K = 2 samples (@ 25 Hz)

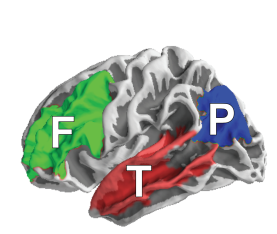
$y_t \in \mathbb{R}^{155}$, $x_t \in \mathbb{R}^{84\times4}$ — 155 MEG sensors, 84 cortical areas × 4 eigenmodes

- Considered regions of interests (ROIs) for the analysis are,

Frontal: parsopercularis, parsotriangularis, rostalmiddlefrontal, cuadalmiddlefrontal

Temporal: superiortemporal, middletemporal, transversetemporal

Parietal: inferiorparietal, posteriorcingulate



Full NLGC details and explanations are in Soleimani et al. (2022)

MEG Experiment

Participants

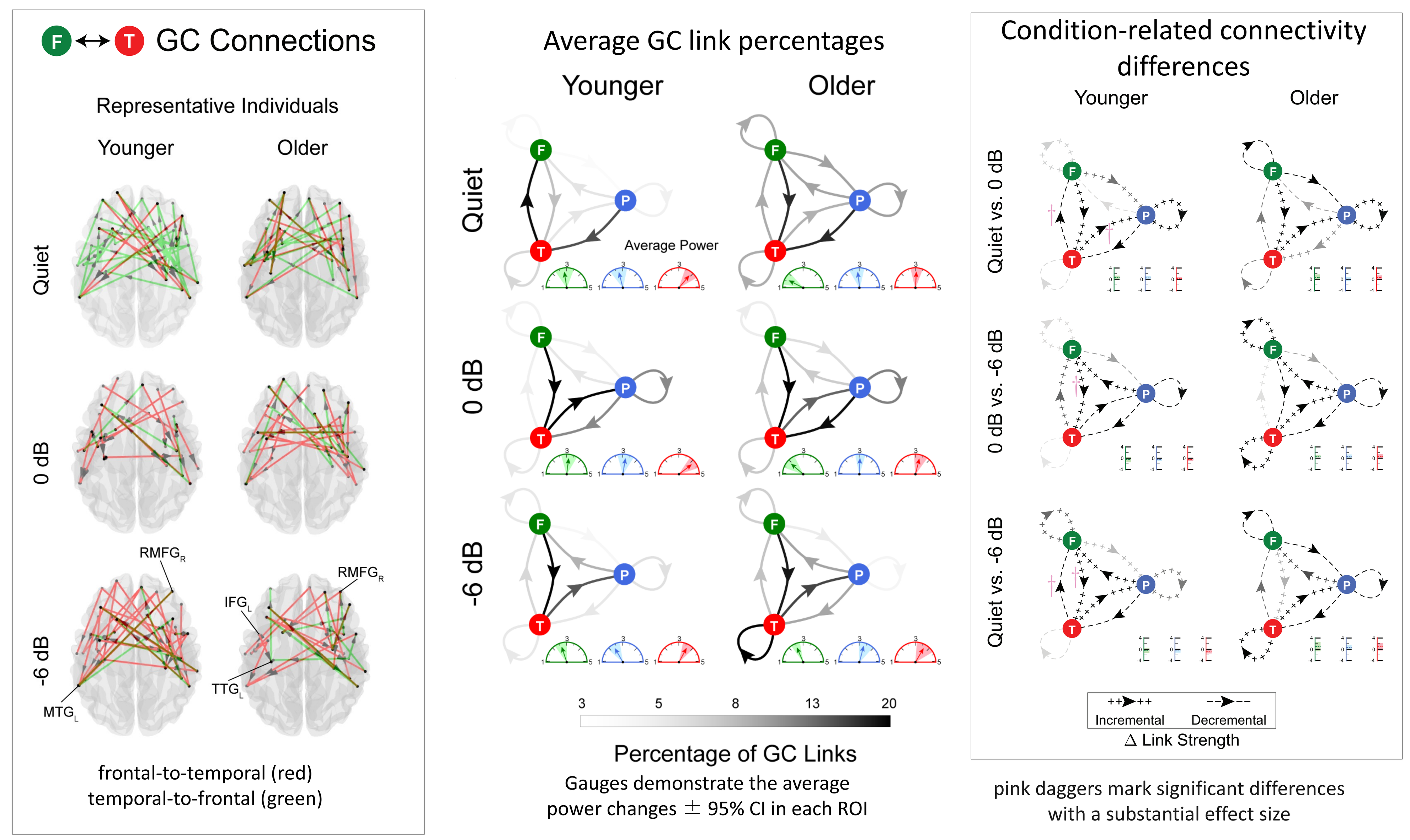
- 13 younger adults (5 males; age: 18-26 y)
- 9 older adults (3 males; age: 66-78 y)
- Normal Hearing (125-4000 Hz, ≤25 dB HL)

Task

- listening to 60 s-long speech segments from an audio book
- Single talker (background quiet) [Quiet]
- Mixed Speech (Background another talker) [0 dB SNR, -6 dB SNR]

More details in Karunathilake et al. (2023) "Effects of Aging on Cortical Representations of Continuous Speech" J Neurophysiol 129, 1359–77.

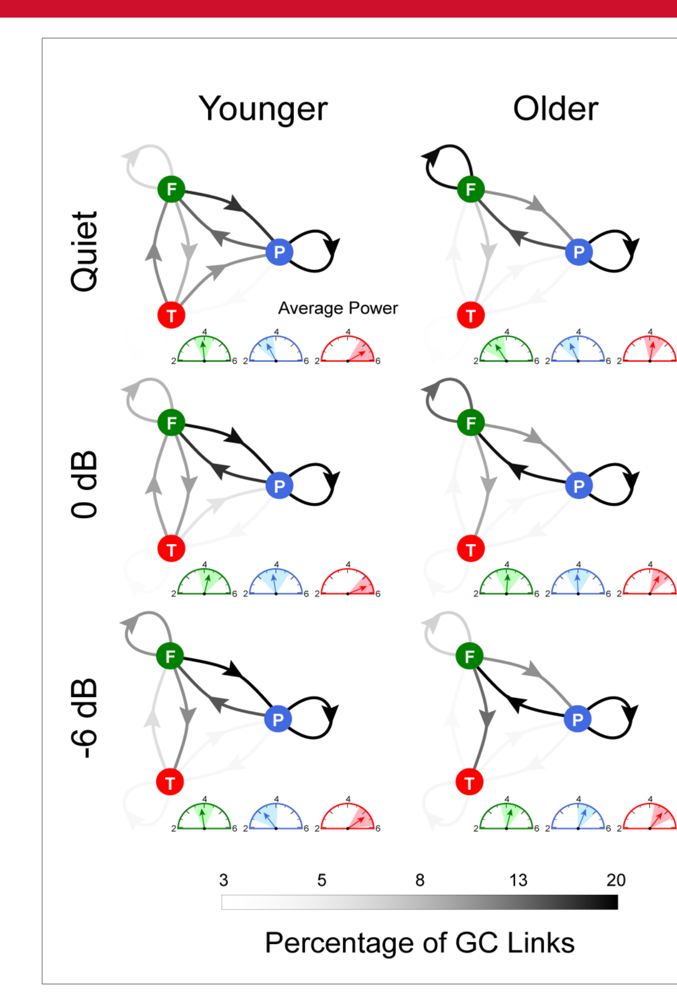
Theta Band (4-8 Hz) Connectivity Analysis



- Younger adults show temporal-to-frontal connectivity in speech-in-quiet, but the reverse under noisy conditions. In contrast, older adults show frontal-to-temporal connectivity regardless of condition
- Older adults show greater frontal-to-frontal connectivity and greater (bidirectional) frontal-parietal connectivity than younger adults for all conditions
- Older adults show a greater increase in theta power with increasing background noise than younger
- Connectivity is unrelated to neural source power (see power and power difference gauges)
- Younger adults show enhanced temporal-to-parietal connectivity, when switching from speech in quiet to the two noise conditions, and also decreased parietal-to-temporal connectivity (older adults also show both these patterns but with a smaller effect size).
- In the worst condition (−6 dB SNR) older adults show enhanced temporal-to-temporal connectivity.

Delta Band (0.1-4 Hz) Connectivity Analysis

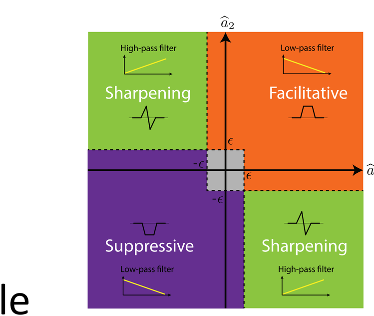
- Older adults show greater frontal-frontal connectivity than younger for speech-in-quiet
- For both noise conditions, there is greater parietal-parietal connectivity, with large effect size, in older adults than younger
- In the worst condition (−6 dB SNR) older adults show increased parietal-to-frontal and decreased frontal-to-parietal connectivity than younger
- Younger adults show increased frontal-to-parietal connectivity with increasing background noise
- Frontal-frontal connectivity, as well as overall frontal and temporal connectivity, decreases in older adults with increasing noise level



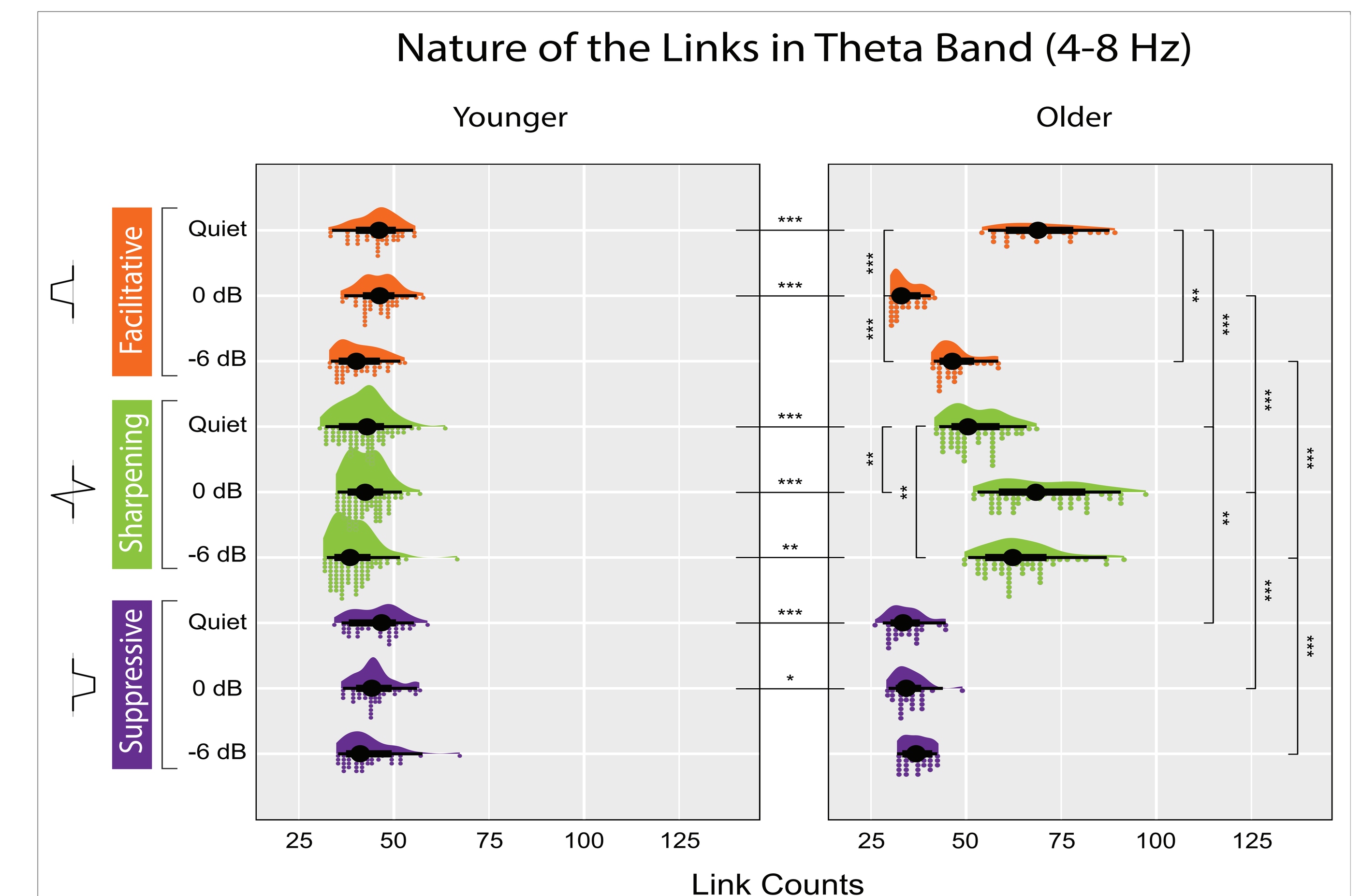
Nature of the Links Change with Condition

- The $(j \rightarrow i)$ link: $x_t^i = \hat{a}_1 x_{t-1}^j + \hat{a}_2 x_{t-2}^j$ + other terms
- Cross-coupling link coefficient sign gives nature of link:

$$H_{j\rightarrow i}(z) = \frac{\hat{a}_1 z^{-1} + \hat{a}_2 z^{-2}}{1 - \hat{b}_1 z^{-1} + \hat{b}_2 z^{-2}}$$

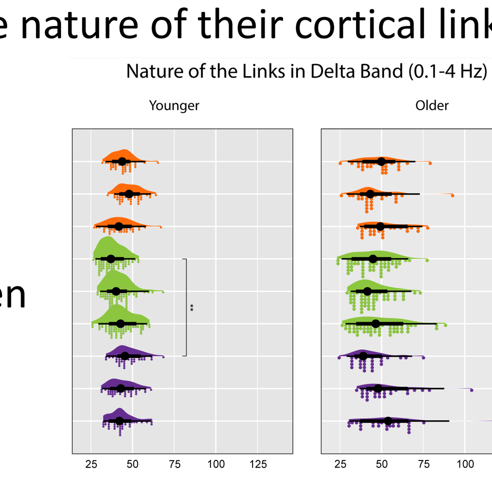


- This categorization can be thought of as the mesoscale equivalent of excitation/inhibition at the neuronal level



The significant differences are marked with their corresponding p-value ($^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$)

- Nature of links varies across age and condition only for theta band
- Younger listeners did not show changes in the nature of their cortical links for different listening conditions
- General decrease in suppressive connectivity is consistent with the age-related decrease in GABA-based inhibition
- Older adults exhibit dynamic tradeoff between excitatory and inhibitory connections when shifting from listening to speech in quiet to speech in noise



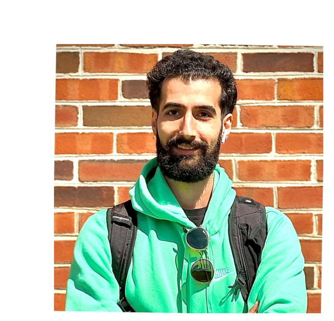
Summary

- Delta band connectivity pattern is quite different from theta band
- Age-related Top-Down and Bottom-Up Changes in the Theta Band
- Age-Related Reversal in Frontal-Parietal Connectivity in the Delta band
- Nature of theta band connectivity depends on condition in older adults

References

NLGC Methods Paper:
B. Soleimani, P. Das, I.M. D. Karunathilake, S. E. Kuchinsky, J. Z. Simon, and B. Babadi, NLGC: Network Localized Granger Causality with Application to MEG Directional Functional Connectivity Analysis. *NeuroImage, Vol. 260, 119496, 2022.*

NLGC Python Package:
Soleimani B, Das P. Network Localized Granger Causality. (2022) GitHub Repository at https://github.com/BabadiLab/NLGC



Behrad Soleimani
1993-2023
We miss him!!

Supported by NSF (OISE2020624, SMA1734892, and CCF1552946) and NIH (R01-DC019394, R01- 970 DC014085, P01-AG055365, and R21-AG068802).

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