

Auditory Experience Modulates Resting-State Functional Connectivity Networks: A Functional Near-Infrared Spectroscopy Study

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D112, 2019-03-25

INTRODUCTION

A large body of work suggests that experience listening to acoustically-degraded speech modulates how the brain perceives and processes speech and language information, ultimately shaping the structure and function of the brain.¹⁻⁹ Here, we use functional near-infrared spectroscopy (fNIRS) to investigate the effects of early-life, chronic exposure to acoustically-degraded speech on resting-state functional connectivity (rsFC) networks in the prefrontal and bilateral temporal-parietal brain regions. Resting-state FC between brain regions is thought to reflect the ability of the brain to predict and adapt to the environment.¹⁰ Recent fNIRS investigations of rsFC found reduced inter-hemispheric connectivity in cochlear implant (CI) users compared to typically-hearing (TH) listeners.⁸ However, little research has been done on the effects of different kinds of early-life auditory experiences. For the first time, we directly compare the effects of early, long-term CI and hearing aid (HA) use on neural networks during rest.

QUESTION & HYPOTHESES

Do variations in early-life auditory experience modulate functional connectivity in the prefrontal and bilateral temporal-parietal brain regions at rest (i.e., rsFC neural networks)? We offer the following competing hypotheses:

H1: Early, chronic exposure to acoustically degraded speech modulates the rsFC networks in brain regions crucial for language processing and cognitive executive functioning.

P1: Resting-state FC networks in early-deafness will exhibit decreased inter-hemispheric connectivity compared to typically-hearing listeners.

H2: Early, chronic exposure to acoustically degraded speech *does not* modulate the rsFC networks in brain regions crucial for language processing and cognitive executive functioning.

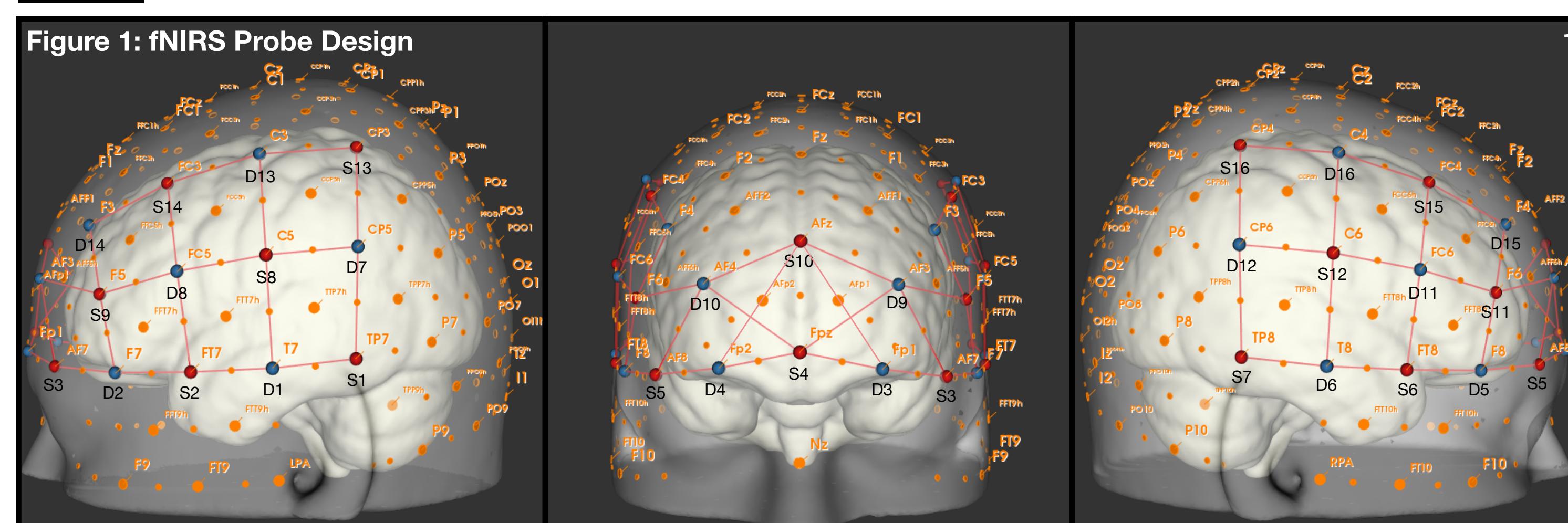
P2: Resting-state FC networks will be the same across groups.

METHODOLOGY

Participants: Young, right-handed, healthy, monolingual English-speaking adults (N=38) participated in this study (see Table 1). Participants were divided into three groups: TH listeners, early, long-term CI users*, and early, long-term HA users*. Participants were matched based on a battery of language and cognitive assessments. *Received by and used since age 5;0.

Task: Resting-state fNIRS data were collected from each participant for 5 minutes in a quiet, dark room.^{12,13} During the scan, participants were asked to relax and remain still with their eyes closed but not to fall asleep.¹³

| Participant Demographics | TH | CI | HA |
|----------------------------|----------------|---------------|--------------|
| N | 30 | 4 | 4 |
| Age range | 19.11-40.99 | 18.08-19.62 | 18.14-20.88 |
| Age M (SD) | 30.85 (6.03) | 18.74 (0.65) | 19.44 (1.12) |
| Gender | 12 M; 18 F | 4 M; 0 F | 3 M; 1 F |
| NV IQ ¹¹ Range | 60-132 | 74-115 | 90-100 |
| NV IQ ¹¹ M (SD) | 102.93 (15.87) | 93.25 (16.98) | 94.75 (4.99) |



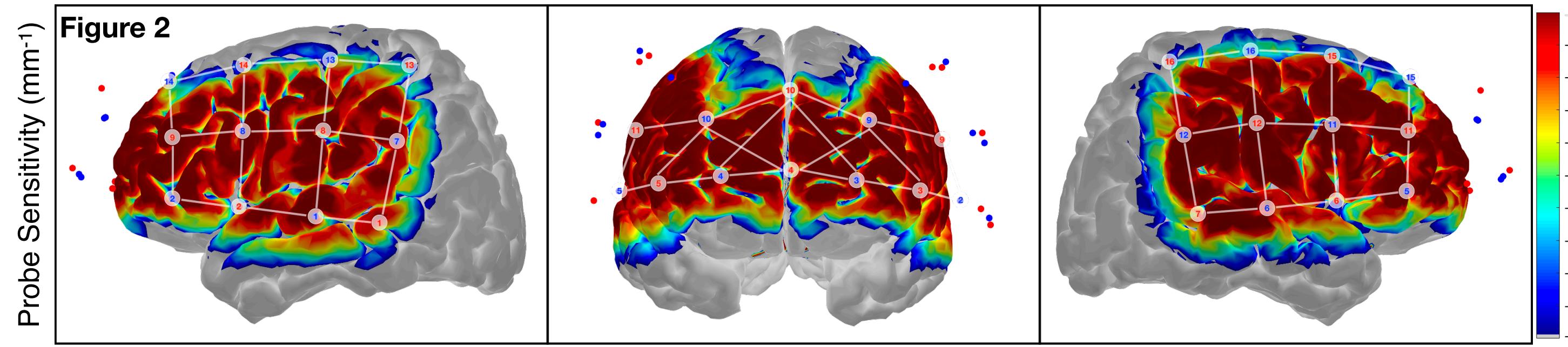
ANALYSES

NIRS probe spatial sensitivity was assessed by modeling photon migration ($1e8$ photons) through human soft tissue using the Monte-Carlo algorithm via AtlasViewer.¹⁴ A spatial sensitivity profile (i.e., forward matrix) was generated.

Resting-state fNIRS data were preprocessed and analyzed using the NIRS Brain AnalyzIR Toolbox.¹⁵ *Individual Analysis:* We used robust general linear regression modeling with an auto-regressive iterative re-weighted least squares (AR-IRLS)¹⁶ pre-whitening method and a max model order of four times the sampling rate. *Group Analysis:* Group-level comparisons were made using mixed-effects statistical models. Each channel was compared to all other channels using Pearson's R, then Fisher's Z-transform.

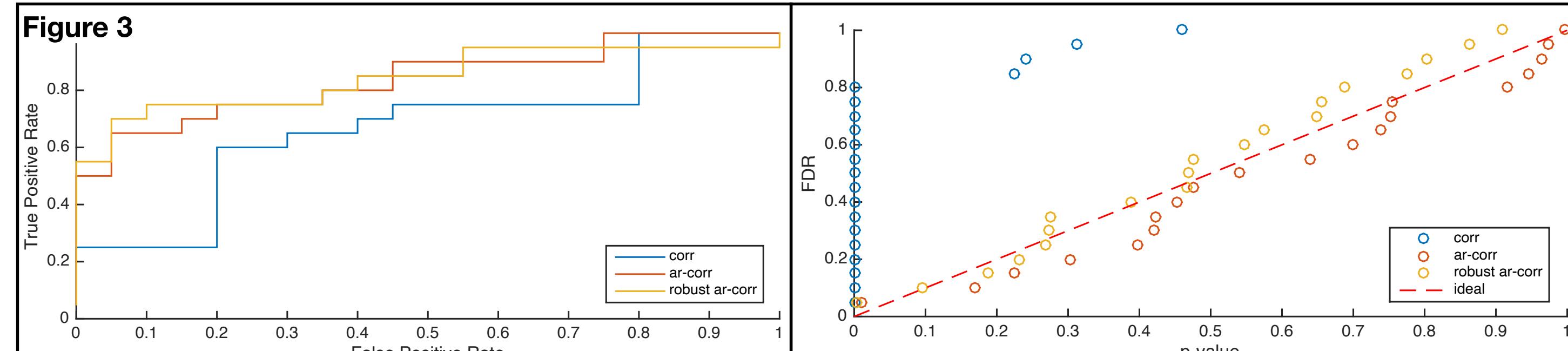
SPATIAL SENSITIVITY PROFILE

The forward matrix of the fNIRS probe design (Figure 2) shows coverage and sensitivity over prefrontal and bilateral temporal-parietal regions.



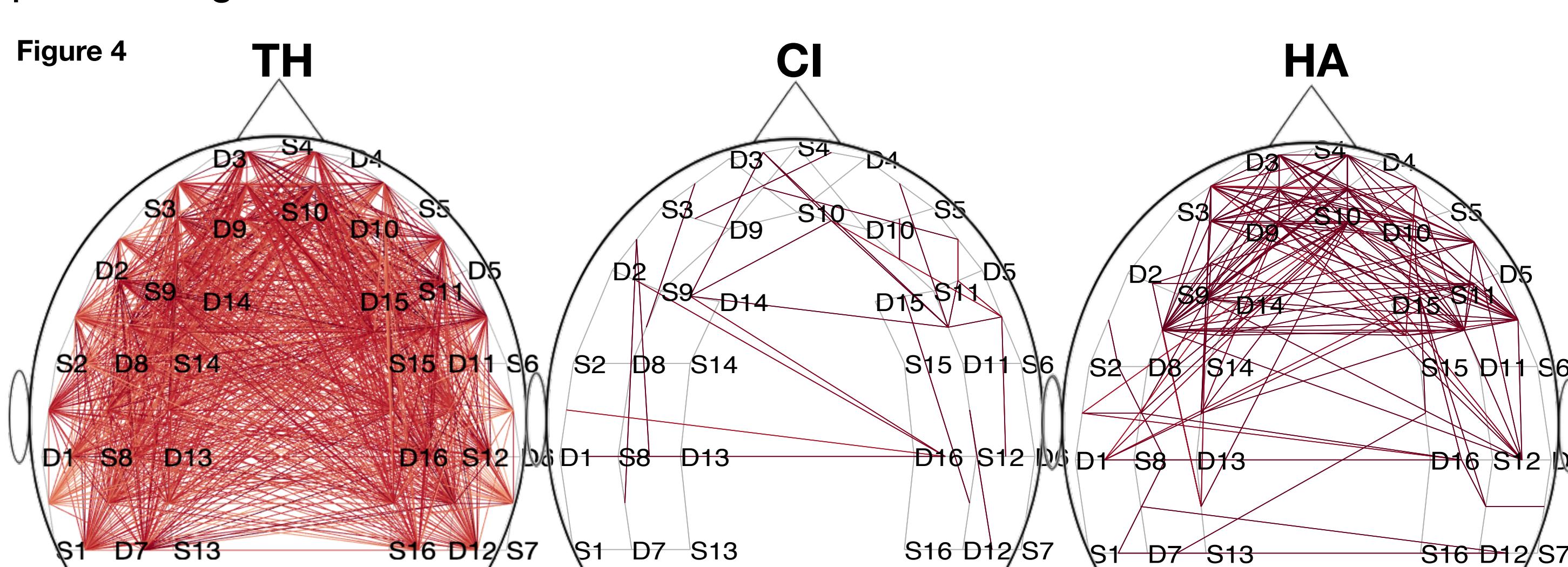
MODEL SENSITIVITY & SPECIFICITY

We used a robust auto-regressive correlation model. To assess the model's sensitivity and specificity, we compared its performance against standard correlation and standard auto-regressive correlation models. The receiver operator characteristic (ROC) curves for sensitivity and specificity (Figure 3) predict that the robust auto-regressive correlation model outperforms the two standard models for this data set.



fNIRS rsFC RESULTS

We observed rsFC differences across groups as a function of auditory experience (Figure 4). **TH listeners** have greater overall gross rsFC than HA and CI users that spans all regions of interest. **CI users** have sparse rsFC that spans prefrontal and bilateral temporal-parietal regions. Finally, **HA users** show robust rsFC in the prefrontal regions and more rsFC in bilateral temporal-parietal regions than CI users, but less than TH listeners.



$HbO_2 \text{ pFDR} < 0.0001; Z(R) = [-1:-0.7 \ 0.7:1]$

DISCUSSION

Consistent with previous fNIRS investigations of rsFC,⁸ we find that CI users exhibit much less inter-hemispheric connectivity than TH listeners. Further, we predicted that HA users would exhibit this same connectivity pattern. As the first study to directly compare rsFC networks in CI and HA users, we observe differences based on type of early-life, chronic auditory experience; our findings support the notion that the rsFC networks are indeed sensitive to and influenced by early-life auditory experiences.⁹

SCIENTIFIC DISCOVERIES:

- Advanced photon migration modeling ($1e8$ photons) reveals that our fNIRS probe design¹⁻⁴ is adequate both in terms of sensitivity and coverage for measuring hemodynamic and network activity in the prefrontal and bilateral temporal-parietal brain regions.
- For this data set, a comparison of statistical models¹⁷ of correlation suggests that robust auto-regressive correlation models outperform standard correlation and standard auto-regressive models.
- H1: Early-life, chronic exposure to acoustically degraded speech via HAs and CIs modulate rsFC networks in prefrontal and bilateral temporal-parietal regions. Robustness of the rsFC networks is largely dependent on early-life auditory experience, and crucially, the type of experience.

LIMITATIONS:

- This study relies on recruiting special populations that meet a strict inclusion criteria, thus the sample sizes of our control and experimental groups are quite different. This may impact the reliability and validity of our rsFC statistical models.
- It should be noted that all of our participants had good speech recognition abilities ($\geq 78\%$ on CID Everyday Sentences^{18,19}), and these results may not be generalizable to all CI or HA users.
- Our rsFC statistical models, although quite sophisticated and robust, are still susceptible to aggregate motion and physiological artifacts and scalp hemodynamics.

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Funding: Graduate Student Research Travel Award (White, Berger), Office of the Dean of the Graduate School and Continuing Studies, Gallaudet University; Small Research Grant (White), Office of Research Support and International Affairs, Gallaudet University; Graduate Research Fellowship Program (Berger), National Science Foundation (DGE1848931).

Citation: White, B. E., Berger, L., & Langdon, C. (2019, March). Auditory experience modulates resting-state functional connectivity networks: A functional near-infrared spectroscopy study. Poster presentation at the annual meeting of the Cognitive Neuroscience Society, San Francisco, CA.