# Probing Connectivity among Auditory Cortex Subdivisions and the Multiple Demand Network During Listening to Clear and Degraded Speech


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## Introduction

- Speech comprehension in noise relies on auditory–cognitive frontotemporal circuits, engaging **Multiple Demand (MD)** regions during challenging listening[1-3].

- Frontotemporal **functional connectivity (FC)** in speech comprehension may be modulated by noise—whether within MD regions, within distinct subdivisions of auditory cortex, or between the two networks[2,4-6].

- FC shows how auditory and MD circuits interact to support speech in noise. The brain flexibly reconfigures with changing noise levels, offering insights that may guide interventions for listening difficulties (e.g., hearing loss, aging).

## Methods

### Design

- 44 normal-hearing (self-reported), native English-speaking adults (18–35 yo).
- Passively listened to three stories (10–14 min each) from *'The Moth'* podcast.
- Stories were masked by 12-talker babble at five **signal to noise ratio (SNR)** levels: **clear, +14, +9, +4, and −1 dB**.
- The SNR changed pseudorandomly every 29–32 seconds.

### MRI Acquisition

- Siemens MAGNETOM Prisma 3T (Robarts Research Institute, London, ON)
- T1-w MPRAGE: TR = 2.3 s, TE = 2.98 ms, voxel size = 1 $mm^3$.
- GE-EPI BOLD: TR = 1 s, voxel size = 3 $mm^3$, whole-brain coverage.

### Preprocessing

- Preprocessing was conducted using SPM12, FreeSurfer (v. 7.4.1), and Connectome Workbench (v. 2.0.1) including realignment, confound removal (CSF, WM, GM, frame-wise displacement and motion regressors), mapping to the fsaverage 164K and native surfaces, and **region of interest (ROI)** timeseries extraction.

### Regions of Interest

- Auditory cortex ROIs were defined by deforming the cytoarchitectonic auditory cortex atlas from **Gulban et al., (2020)**[7] to individual participants' native surface using **curvature-based alignment (CBA)**.
- Participant-specific MD regions were anatomically constrained and defined using a GLM contrast showing increased activity with decreasing SNR. The GLM was estimated using only the first run, and vertices with $t > 0.75 \times T_{max}$ within selected **Desikan-Killiany (2006)**[8] ROIs were defined as MD regions.

### Functional Connectivity

- FC was computed between each pair of ROIs using Pearson's correlation, accounting for a 3-second hemodynamic response delay. Estimates were based only on runs 2 and 3 of the experiment.

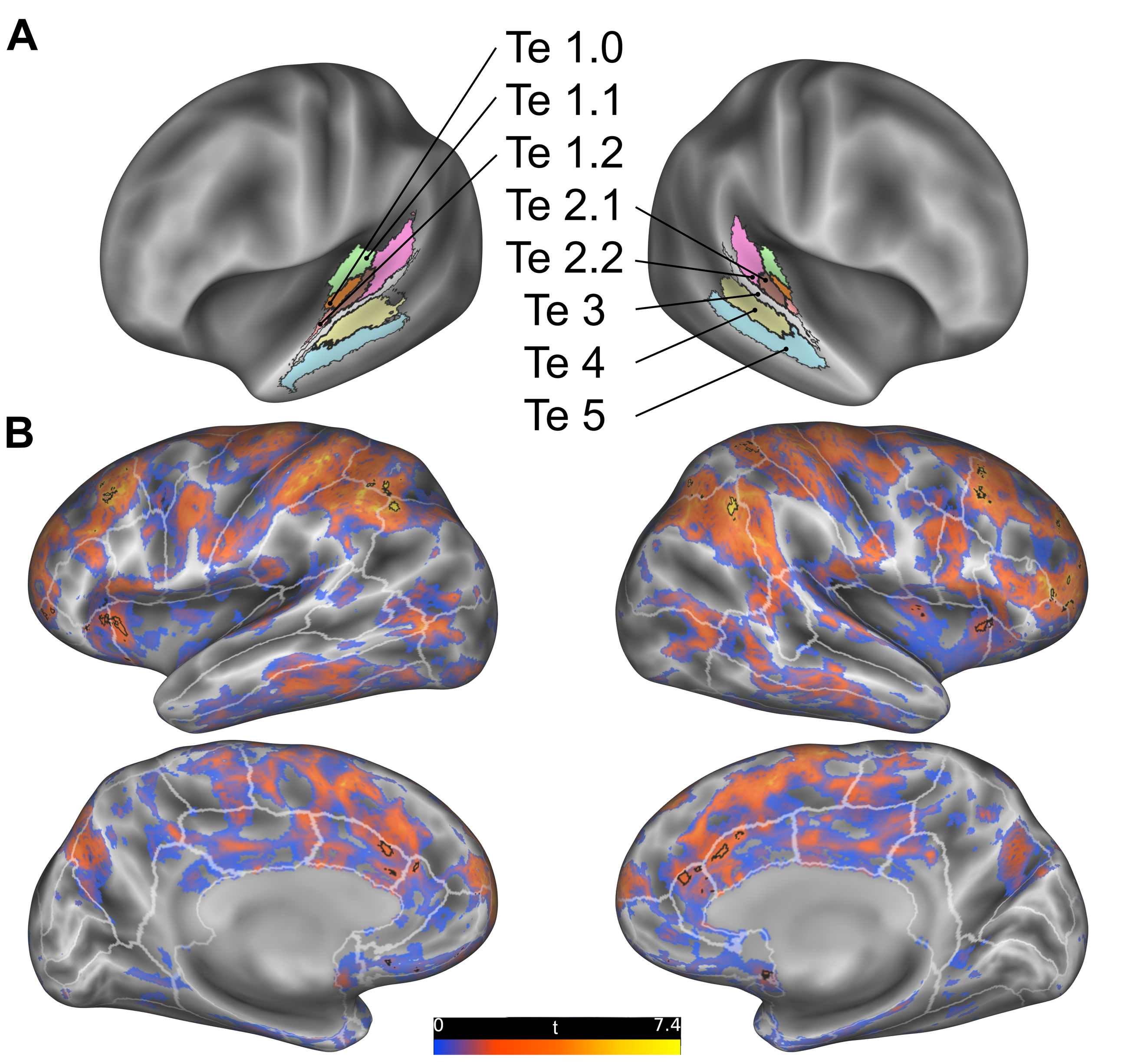


**Fig. 1. Regions of interest.** **A)** Cytoarchitectonically defined subdivisions of the auditory cortex (Gulban et al., 2020)[7], originally defined on a 10-subject surface template and mapped to the fsaverage 164k template surface using sulcal-curvature–based alignment (CBA). **B)** Example individual participant t-map of the linear contrast across conditions, displayed on the native surface. The contrast reflects greater activity with decreasing SNR. White borders delineate all regions from the Desikan–Killiany atlas (2006)[8]. MD regions of interest were then identified within this parcellation: in each relevant anatomical ROI, vertices exceeding $t > 0.75 \times T_{max}$ were relabeled with the corresponding MD region name (black outlines).

## Results

### FC Pattern Across All Listening Conditions

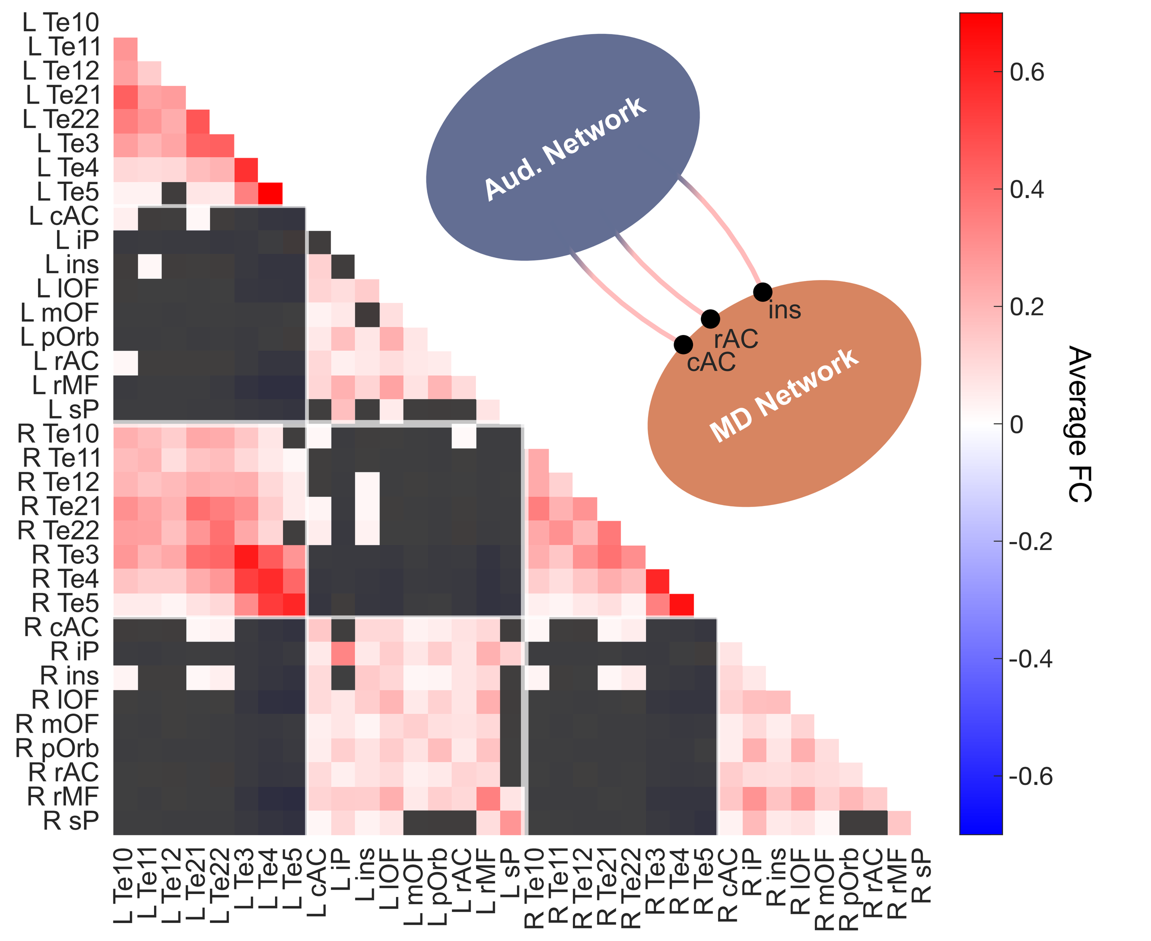


**Fig. 2. Average Functional Connectivity.**

For each participant, FC values were Fisher z-transformed and averaged across conditions to yield an overall measure of connectivity for the speech-comprehension task ($FC_{all}$). The group-average $FC_{all}$ (N = 30) is shown. Masked connections indicate non-significant average FCs (one-tailed t-test, FDR corrected, q < 0.05). Strong connectivity is observed within ipsilateral and contralateral auditory and MD regions. The left and right insula and cingulate cortex serve as key links between auditory and MD networks.

### FC Changes Across Noisy Conditions (Decreasing SNR)

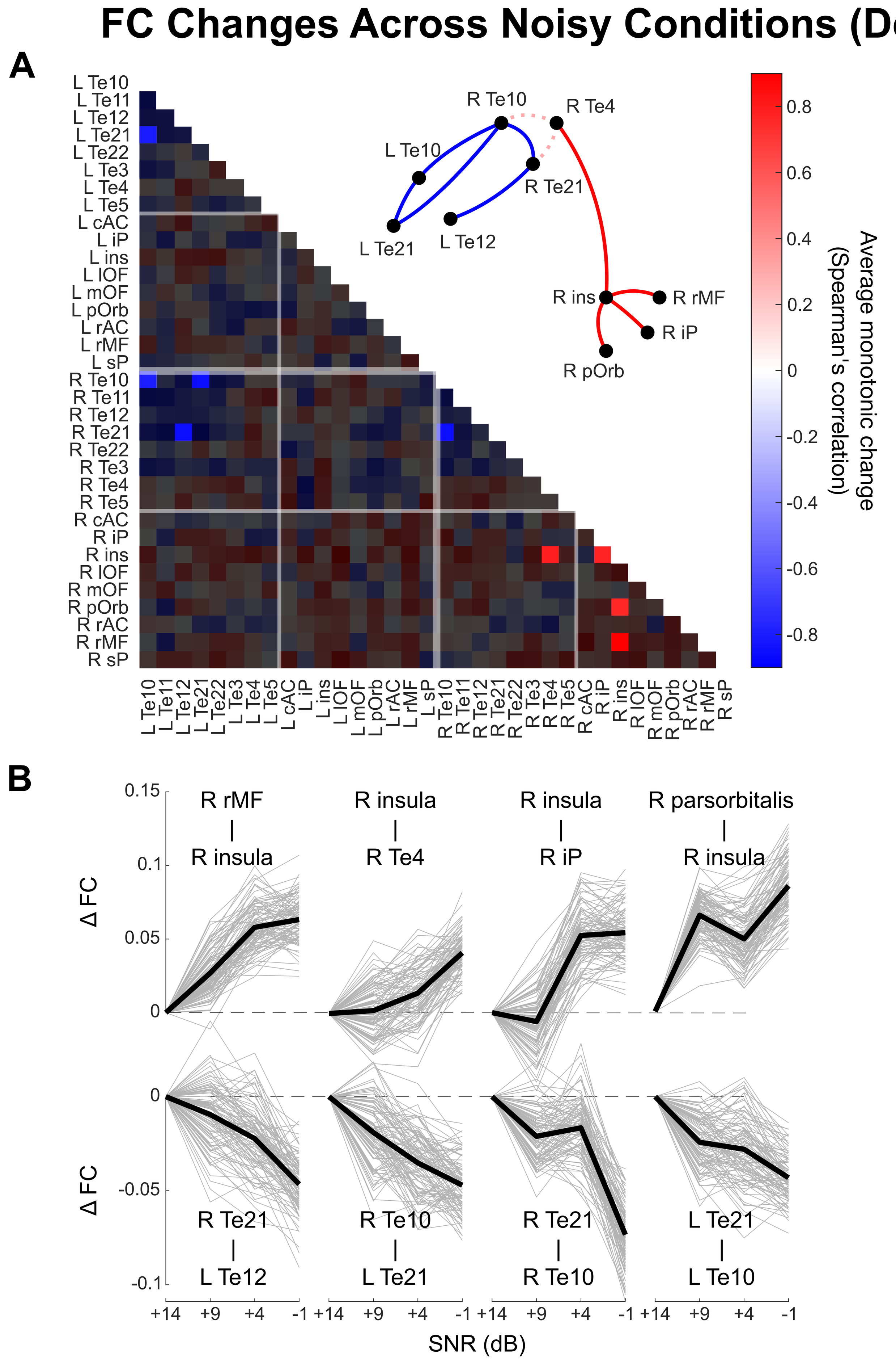


**Fig. 3. Modulation of Functional Connectivity.**

**A)** To examine changes in connectivity with decreasing SNR, Spearman's correlation between FC and condition number was computed across noisy conditions within each participant. This approach captures monotonic increases or decreases in FC as SNR decreases. Participant data were bootstrapped with replacement (100,000 iterations) to assess significance. The average Spearman's correlation across all iterations is shown. Masked connections represent non-significant correlations (two-tailed bootstrap test, FDR corrected, q < 0.05). The graph highlights connections showing significant monotonic increases or decreases.

**B)** Changes in FC across noisy conditions are shown relative to the first condition (SNR = +14 dB) for the significant connections identified in panel **A**. Thin lines represent 100 random iterations of the bootstrapped data, while the thick black line indicates the overall average.

## Conclusions

- **Connectivity shifts with SNR:** As the signal-to-noise ratio decreases and listening conditions become less favorable, connectivity within the MD network increases, while connectivity within the auditory network—particularly in primary auditory regions—decreases.

- **Right insula as a hub:** The right insula appears to function as a hub linking the MD and auditory networks.

- **Right Te 4 involvement:** The right Te 4 area, whose connectivity with the insula increases under challenging listening conditions, aligns with regions involved in higher-level speech-sound processing (particularly phonemic processing)[9], whereas connectivity with Te 5 or lower-level auditory areas shows no significant change.

## References


1. Duncan. 2010. "The Multiple-Demand (MD) System of the Primate Brain: Mental Programs for Intelligent Behaviour." Trends in Cognitive Sciences 14 (4): 172–79.
2. Davis & Johnsrude. 2007. "Hearing Speech Sounds: Top-down Influences on the Interface between Audition and Speech Perception." Hearing Research 229 (1–2): 132–47.
3. Ritz et al. 2022. "Parametric Cognitive Load Reveals Hidden Costs in the Neural Processing of Perfectly Intelligible Degraded Speech." The Journal of Neuroscience: The Official Journal of the Society for Neuroscience 42 (23): 4619–28.
4. Morosan et al. 2001. "Human Primary Auditory Cortex: Cytoarchitectonic Subdivisions and Mapping into a Spatial Reference System." NeuroImage 13 (4): 684–701.
5. Hackett et al. 2001. "Architectonic Identification of the Core Region in Auditory Cortex of Macaques, Chimpanzees, and Humans." The Journal of Comparative Neurology 441 (3): 197–222.
6. Hackett, 2011. "Information Flow in the Auditory Cortical Network." Hearing Research 271 (1–2): 133–46.
7. Gulban et al. 2020. "Improving a Probabilistic Cytoarchitectonic Atlas of Auditory Cortex Using a Novel Method for Inter-Individual Alignment." eLife 9 (August).
8. Desikan et al. 2006. "An Automated Labeling System for Subdividing the Human Cerebral Cortex on MRI Scans into Gyral Based Regions of Interest." NeuroImage 31 (3): 968–80.
9. Gong et al. 2023. "Phonemic Segmentation of Narrative Speech in Human Cerebral Cortex." Nature Communications 14 (1): 4309.



CIHR IRSC Canadian Institutes of Health Research Instituts de recherche en santé du Canada
NSERC CRSNG
INNOVATION Canada Foundation for Innovation Fondation canadienne pour l'innovation
CONCH Cognitive Neuroscience of Communication and Hearing