Shared and distinct precentral areas for speech production and receptive language in individual brains

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Summary

To communicate, our productive and receptive language systems must interface to some extent, and the neural manifestation of this relationship has long been an area of interest in cognitive neuroscience. Previous approaches include lesion-symptom mapping, group-averaged imaging data, and meta-analysis [1,2,3]. Here, we leveraged fMRI localization in individual brains to characterize the co-localization of precentral areas engaged in an expressive working memory task and a receptive language task. Consistently, receptive-specific areas were situated more anterior (midMC, midPMC) and expressive-specific areas spanned from midMC to vMC, with overlap primarily in midMC. The overlap area had a diverse, transmodal fMRI response profile and structural signatures of "Area 55b" [4], suggesting it may be involved in broader functions than previously reported.

Methods

MRI data: We used anatomical, diffusion-weighted, and functional volumes (n = 25; mean age = 23.2; typical language). fMRI tasks and contrasts included:

- Receptive Language Localizer (LangLoc; intact speech > acoustically degraded, unintelligible speech) [5]
- Nonword Repetition (NWRep; 4-syllable > 1-syllable)
- Real Word Repetition (RWRep; 4-syl. > 1-syl.)
- Nonword Discrimination (NWDis; 4-syl. > 1-syl.)
- Auditory/Verbal WM (Digit Span; 6-item > 3-item)
- Visual/Spatial WM (Corsi Blocks; 6-item > 3-item)

fROI delineation: For the LangLoc and NWRep tasks, we adapted the GCSS parcellation approach [6] to circumscribe areas on the *fsaverage* surface where significant vertices were likely to be found across subjects. Our search-space for defining fROIs was the union of the precentral parcels from these two tasks. We plotted effect size against activation significance percentile to find individualized fROI boundaries. **LangLoc**, **NWRep**, and **Overlap** (LangLoc ∩ NWRep). fROIs were defined in native surface space.

Probability map: fROIs defined from within-subject fixed-effects models (data from 2-3 runs) were transformed into *fsaverage* space and summed across subjects.

fMRI response profile: fROIs defined from one run were used to extract parameter estimates from a second run. Values were z-scored within-parcel beforehand.

Neuroanatomy-based classifier: We fit a multinomial regression model with an elastic net penalty (*glmnet*) [7] to find which structural features were more associated with the LangLoc-specific, NWRep-specific, and Overlap fROIs. Nested leave-one-subject-out CV was used. Features included vertex-specific connectivity to targets via FSL *probtrackx* tractography (seeding streamlines from the surf.-fROIs) as well as curvature, thickness (FreeSurfer *recon-all*), intracortical myelin (ICM) [8], fractional anistropy, and axial diffusivity (FSL *dtifit*).

References: [1] Banerjee et al. (2015). *NeuroImage*, [2] Silbert et al. (2014). *Proc. Natl. Acad. Sci. U.S.A.*, [3] Walenski et al. (2019). *Hum. Brain Mapp.*, [4] Glasser et al. (2016) *Nature*, [5] Scott et al. (2017). *Cogn. Neurosci.*, [6] Fedorenko et al. (2010). *J. Neurophysiol.*, [7] Zou & Hastie (2005). *J. R. Stat. Soc. Ser. B Stat. Methodol.*, [8] Glasser & Van Essen (2011). *J. Neurosci.*, [9] Tourville & Guenther (2012). *Soc. Neurosci. Abstr.*, [10] Wolna et al. (2025). *bioRxiv*, [11] Sitek et al. (2016). *Front. Hum. Neurosci.*, [12] Roussel et al. (2024). *bioRxiv*, [13] Saur et al. (2008). *Proc. Natl. Acad. Sci. U.S.A.*, [14] Weiner (2023). *Nat. Rev. Neurosci.*

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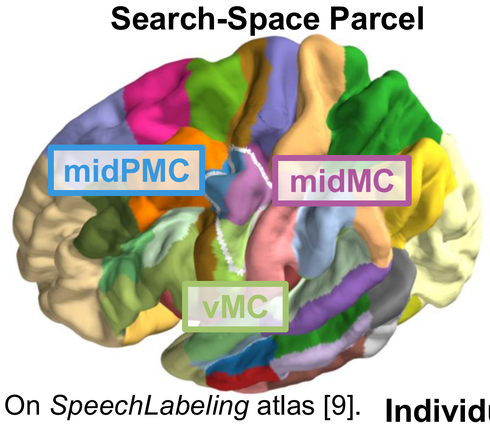
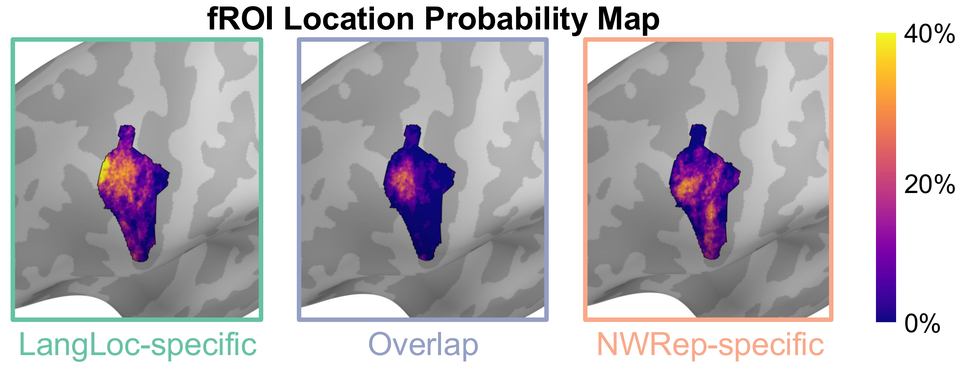
fROIs: LangLoc, NWRep, Overlap

Search-Space Parcel

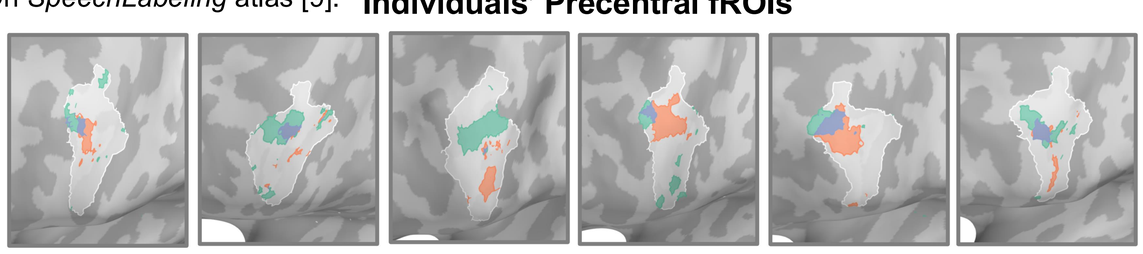


On *SpeechLabeling* atlas [9].

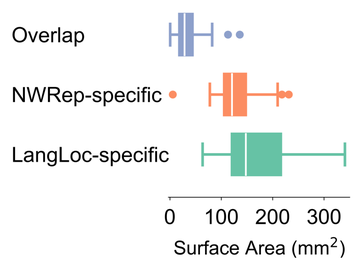
fROI Location Probability Map



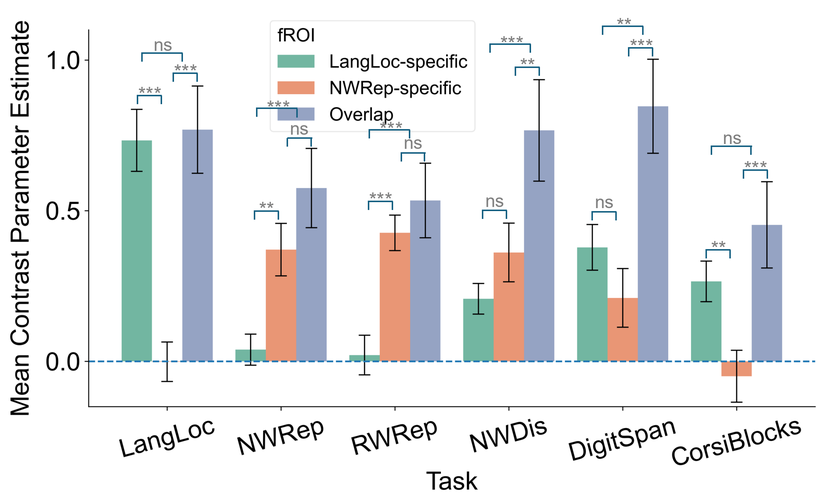
Individuals' Precentral fROIs



fROI sizes



fMRI Response Profile



fMRI Response by Task and fROI

- The LangLoc-NWRep overlap fROI has preserved selectivity for the LangLoc and NWRep contrasts (n.s. difference in selectivity between the overlap-fROI and the respective task-fROIs)
  - The overlap areas were not simply peripheral areas within each task fROI that had weaker response to the contrasts of interest
- The overlap fROI was also strongly engaged by all of the other fMRI tasks, including both visuospatial working memory, and auditory / verbal working memory
- Part of the PrCG Receptive LangLoc node may have more of a domain-general role

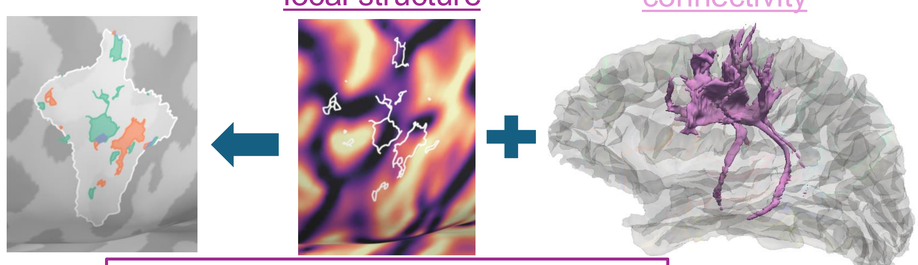
Structural Correlates

Multinomial Regression Model

fROI membership

outcome: vertex ∈…

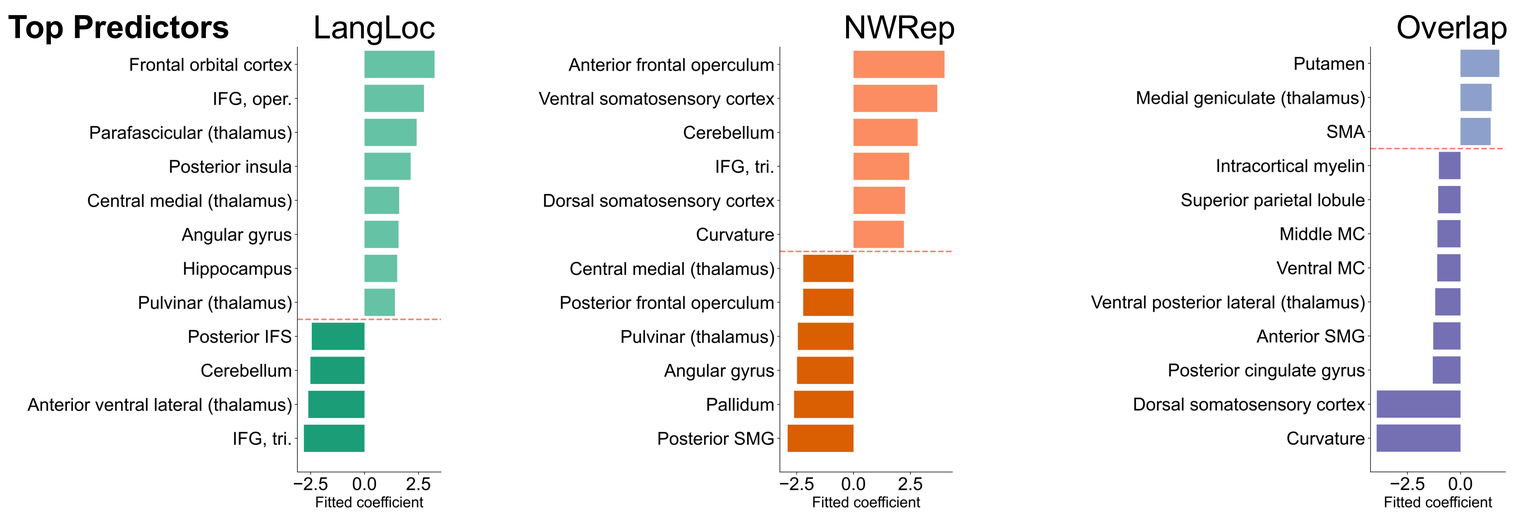
- LangLoc-specific
- NWRep-specific
- Overlap



curvature (shown), thickness, intracortical myelin, fractional anisotropy, axial diffusivity

probabilistic tractography (fROI vertex → atlas target); model input was the number of streamlines seeded from that vertex that reached a given target atlas region

Top Predictors



- [+] pars operc., hippocampus → (ext.) language network [10]
- [-] cbm, pars tri. → speech motor areas [11, 12]

- [+] cbm, pars tri. → speech motor areas
- [+] f. operculum → monitoring via extreme capsule [13]

- [-] curvature → hypothesis of fundal cognition [14]
- [-] ICM → "area 55b" [4]
- [-] primary sensory / motor connectivity