Distributed Frontal Cortex Activity Encodes Task-specific Language Recruitment

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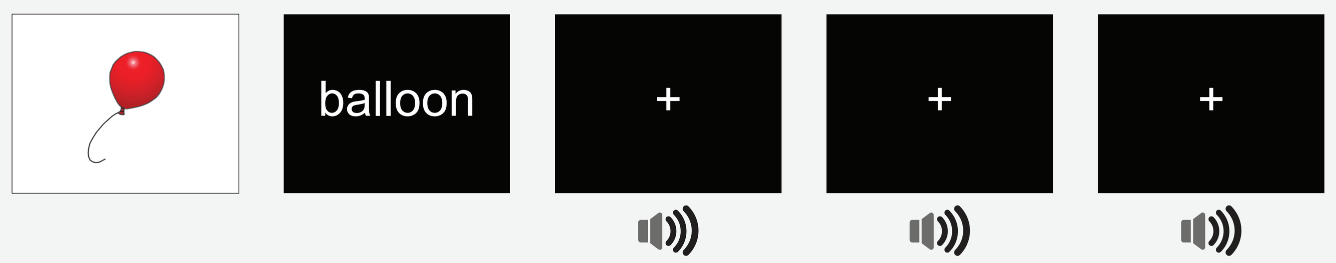
INTRODUCTION

Speech production critically depends on frontal and temporal cortex activity to retrieve, plan, and execute speech utterances (Hickok, 2012; Haller et al., 2018). For example, broca's area for speech preparation and production (Flinker et al.,2015), superior temporal gyrus for auditory perception (Mesgarani et al., 2014), and motor cortex for speech production (Bouchard et al., 2013). But the extent to which the regions are involved across different task demands and modalities remains unspecified. To investigate this, we employed a battery of five language tasks including word reading, picture naming, auditory naming, auditory word repetition, and sentence completion in a cohort of 13 neurosurgical patients undergoing treatment for refractory epilepsy while intracranial EEG data was acquired.

METHODS

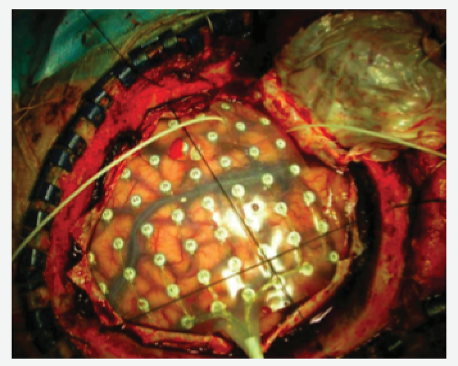
Picture Naming | Visual Word Reading | Auditory Word Repetition | Auditory Naming | Auditory Sentence Completion



"balloon" | "a rubber object you inflate with helium" | "the clown inflated the"

Five speech production tasks with auditory and visual modalities, with the production of the same 50 items across tasks.

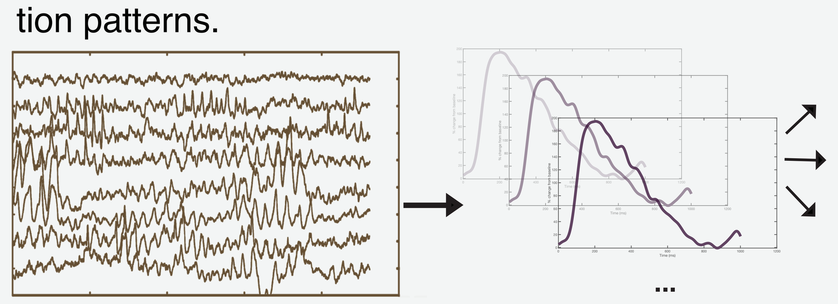
Electrocorticography (ECoG)



Subjects: 13 consenting epilepsy patients participated in the experiments. During the experiments, patients sat comfortably in their hospital beds. Visual stimuli were presented from a laptop screen placed in front of them. Auditory stimuli were presented from a speaker in front of them during which they were asked to fix their gaze on the cross in the middle of the screen. Patients' answers were recorded using a microphone synced to EEG recordings.

ECoG Recordings: Neural activity was recorded from up to 256 intracranial electrodes, including grids and strips of surface electrodes that were implanted subdurally on cortex (5-10 mm inter-electrode distance) and depth electrodes that penetrate cortex.

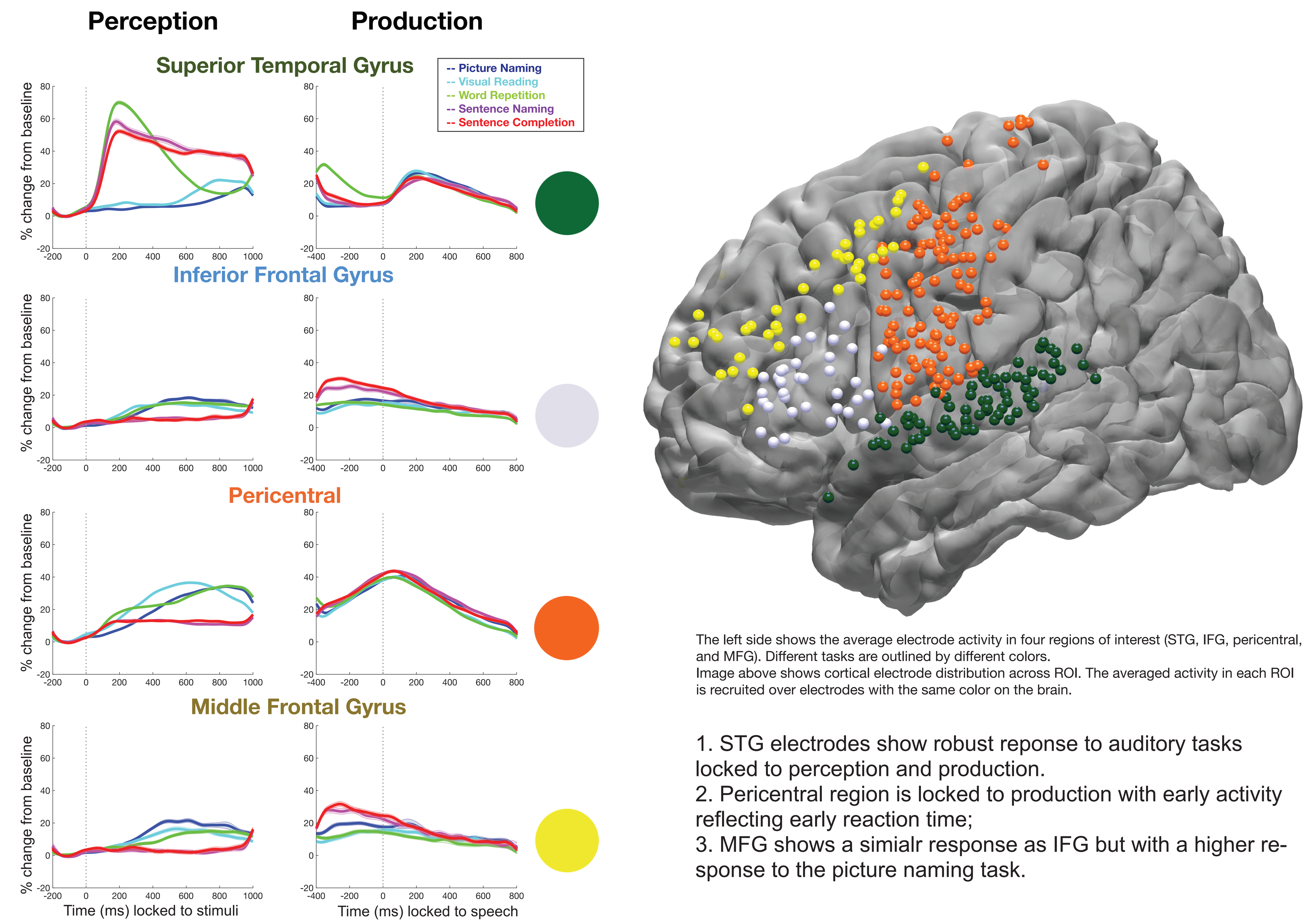
Preprocessing and data analysis: The average raw signal across all surface electrodes was subtracted from each individual electrode's signal (common average referencing). Power in the high-gamma broadband (HGB) range was calculated for each trial by averaging signal power between 70 to 150 Hz and measured as percent change from the pre-stimulus baseline (-250 to -50 ms). Electrodes were identified as active if they were consecutively above 50% amplitude and significantly differed from baseline for over 100 ms in 1200 ms perception or production windows. Active electrodes were selected for further analysis. Nonnegative matrix factorization was used as an unsupervised learning technique to cluster electrodes (Hamilton et al). The number of clusters was determined by the explained variance as a function of number of clusters. Logistic classification models were used to quantify each frontal electrode's contribution to predicting one task against the others over time (using a sliding window approach of size 40 ms with 50% overlap). Principal component analysis was applied to the models AUC results over time in order to cluster the prediction patterns.



→ Region of Interest (ROI) Analysis
→ Nonnegative Matrix Factorization
→ Logistic classification model
↓
Principal Component Analysis (PCA)

RESULTS

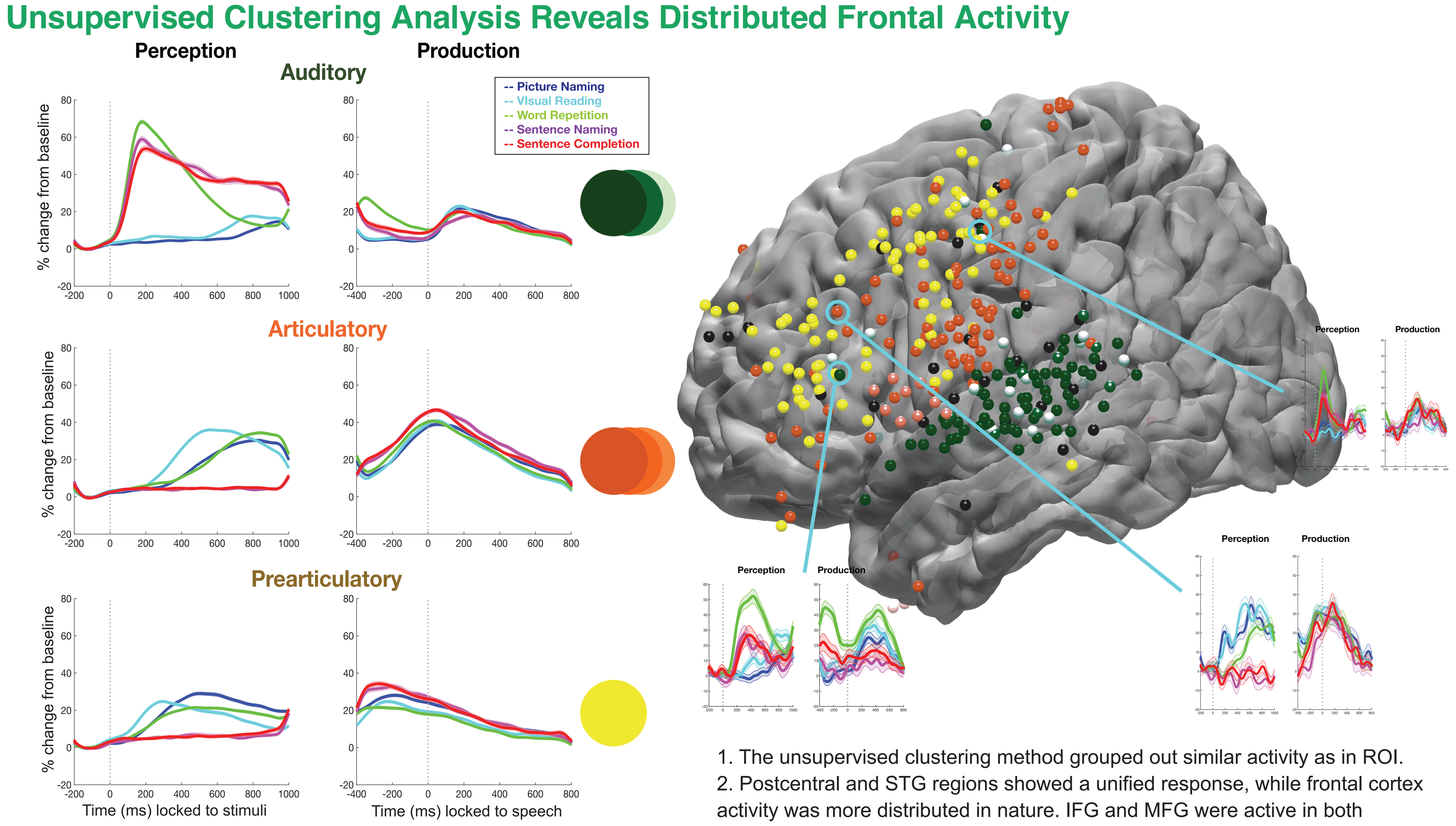
High Gamma Shows Prototypical Pre-articulatory and Articulatory Responses



The left side shows the average electrode activity in four regions of interest (STG, IFG, pericentral, and MFG). Different tasks are outlined by different colors.
Image above shows cortical electrode distribution across ROI. The averaged activity in each ROI is recruited over electrodes with the same color on the brain.

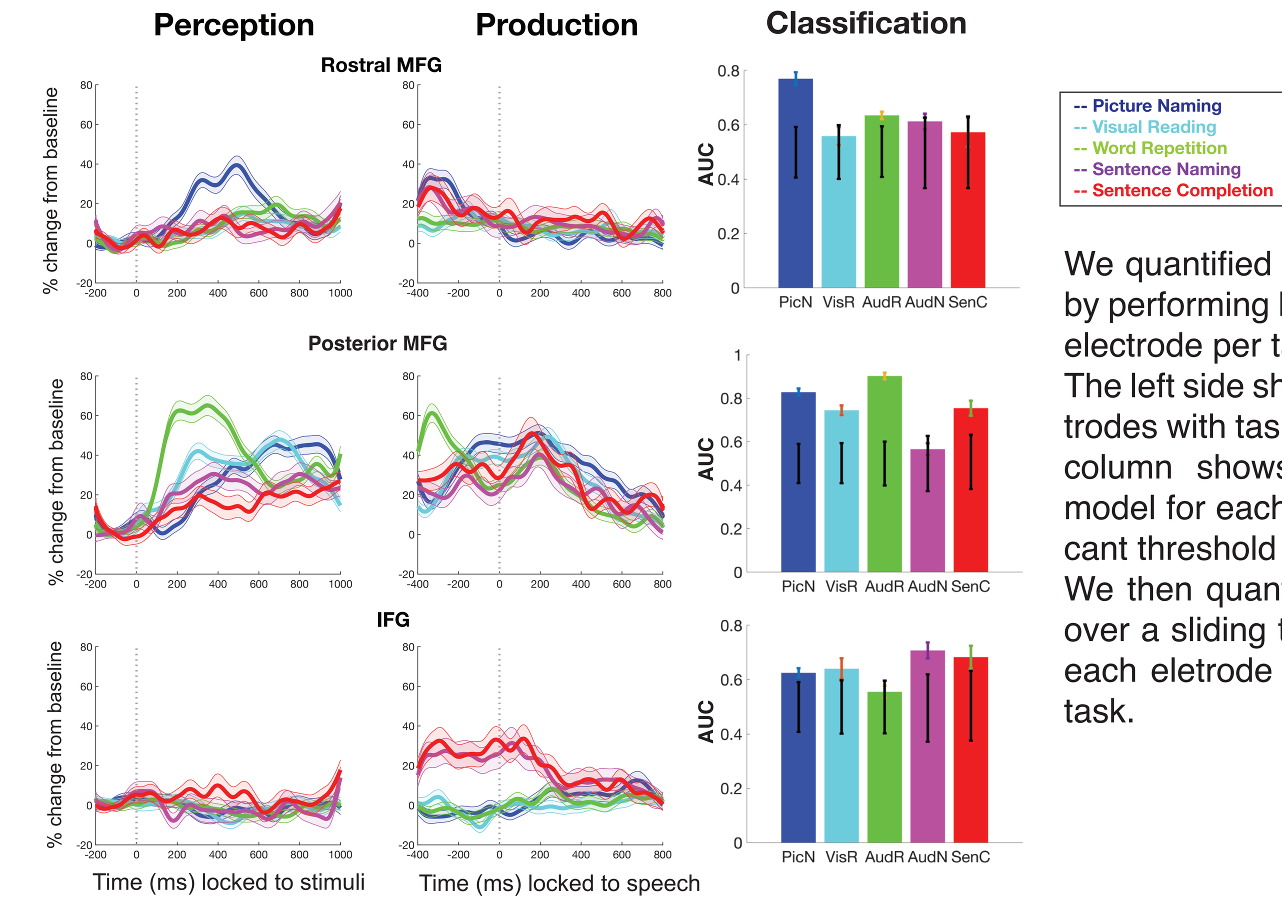
1. STG electrodes show robust reponse to auditory tasks locked to perception and production.
2. Pericentral region is locked to production with early activity reflecting early reaction time;
3. MFG shows a simialr response as IFG but with a higher response to the picture naming task.

Unsupervised Clustering Analysis Reveals Distributed Frontal Activity



1. The unsupervised clustering method grouped out similar activity as in ROI.
2. Postcentral and STG regions showed a unified response, while frontal cortex activity was more distributed in nature. IFG and MFG were active in both prearticulatory and articulatory periods.

Frontal Cortex Electrodes Show Varying Task Specificity

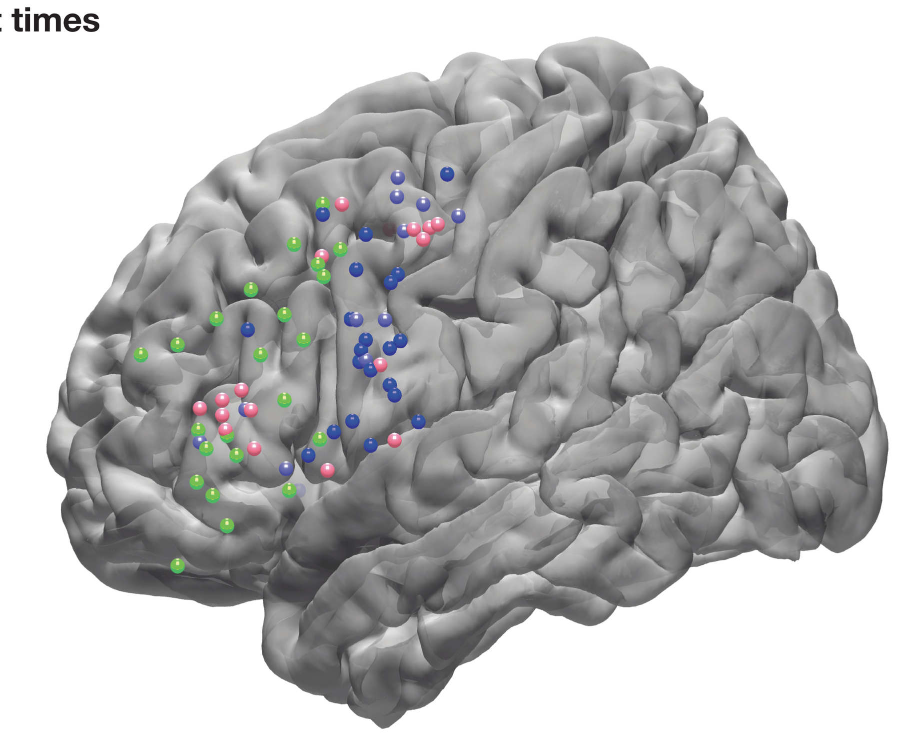


We quantified the electrode's task specificity by performing logistical classification on each electrode per task.
The left side shows three representative electrodes with task-specific responses. The third column shows the AUC of the decoding model for each task. Black lines mark significant threshold ($p < 0.05$) by permutation test.
We then quantified the task-decoding ability over a sliding time window to examine when each eletrode was able to decode a certain task.

Electrode clusters contribute to tasks at different times

Blank electrodes were not significantly selected for that task

Task / Principle Component	Picture Naming	Visual Word Reading	Auditory Repetition	Auditory Naming	Sentence Completion
(dark blue)		400 ms after stimulus onset		700 ms after stimulus onset	700 ms after stimulus onset
(lavender)	400 ms after stimulus onset	200 ms after stimulus onset		300 ms after stimulus onset	300 ms after stimulus onset
(green)				200 ms before speech onset	200 ms before speech onset
(pink)	300 ms after stimulus onset		250 ms after stimulus onset		



Group clustering based on the AUC over time of decoding models

Conclusion

1. STG and pericentral regions are mostly homogenous in auditory and motor responses.
2. Frontal cortex is recruited for both perception, prearticulatory, and production periods.
3. Frontal cortex exhibited task-specific patterns within electrodes. This task specificity manifested in distributed decoding patterns across frontal cortex with varying recruitment for specific tasks at specific time periods.

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