NEURAL MODULATION OF PITCH AND FORMANTS DURING ALTERED FEEDBACK

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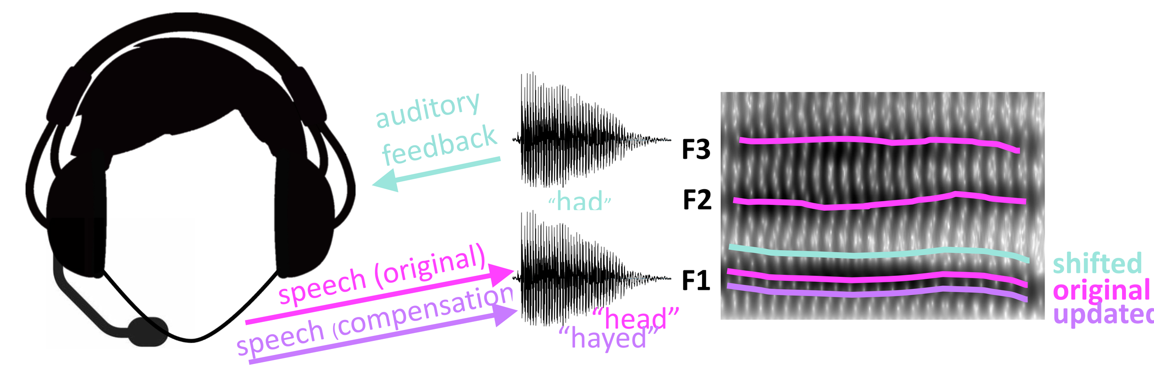
INTRODUCTION

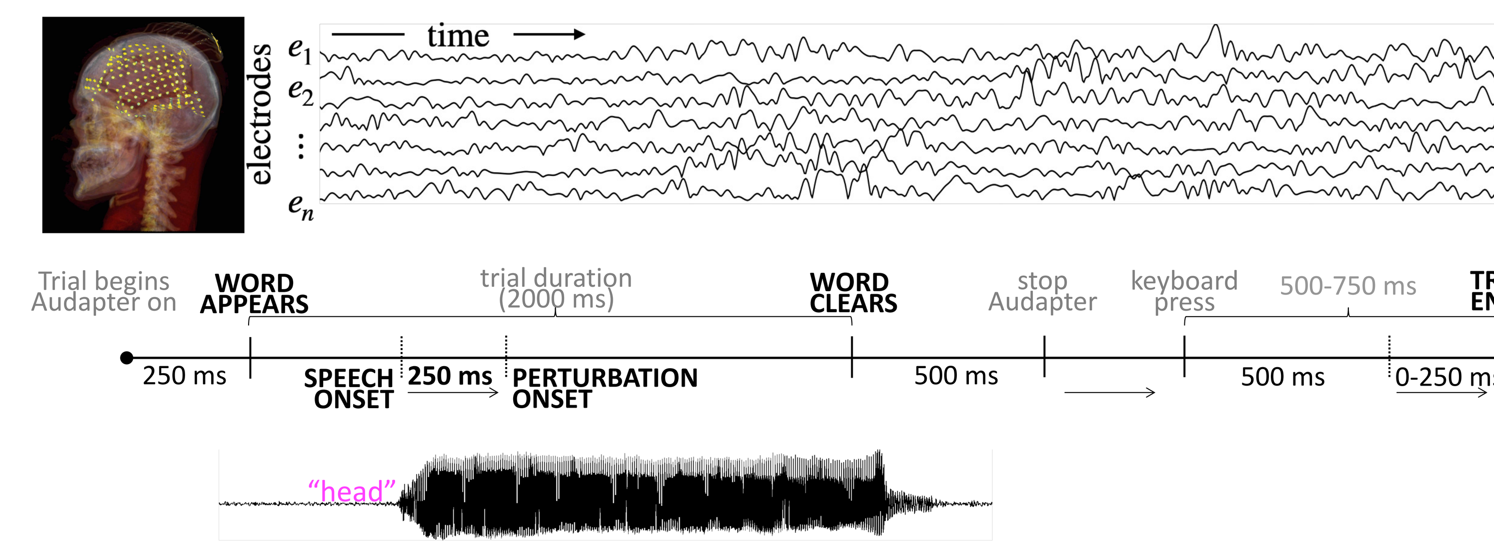
- Precise and intelligible speech output depends on intact neural mechanisms controlling the ability to incorporate auditory feedback into ongoing motor commands. (Guenther, 2016)
- When auditory feedback is perturbed, a typical automatic reaction is to compensate by shifting frequencies in the opposite direction to the perturbation. (Houde & Jordan, 1998; Jones & Munhall, 2005)
- In response to **pitch and formant perturbations**, there is substantial evidence from fMRI for: (Behroozmand et al., 2015; Niziolek & Guenther, 2013; Parkinson et al., 2012; Tourville et al., 2008; Toyomura et al., 2007)
  - Early **error detection** in superior temporal gyrus (STG).
  - Subsequent **motor correction** in sensorimotor regions.
  - However, fMRI lacks the temporal resolution to characterize these dynamics precisely.
- One study employing electrocorticography has shown that **pitch perturbations** elicit **feedback-related responses** in posterior STG and near supramarginal gyrus (SMG). (Chang et al., 2013)
- **Significance:** *First study to characterize cortical mechanisms and spatiotemporal dynamics of response to pitch versus formant perturbations, filling a critical gap by comparing both processes within the same individuals to reveal* ***shared versus distinct feedback circuits****.*

METHODS

- At bedside, patients with epilepsy undergoing clinical monitoring sustained /ɛ/ while acoustic perturbations were applied in real time (negligible delay). Shifts in:
  - **Pitch** (fundamental frequency): ± 200 cents (Behroozmand et al., 2019)
  - **Formant** (first formant frequency): ± 250 mels (Niziolek & Guenther, 2013)
- 150 trials presented with pink noise throughout all trials.
- Within-block randomization of condition (Pitch, Formant), shift direction (Up, Down, No Shift), and word ("bed," "head").

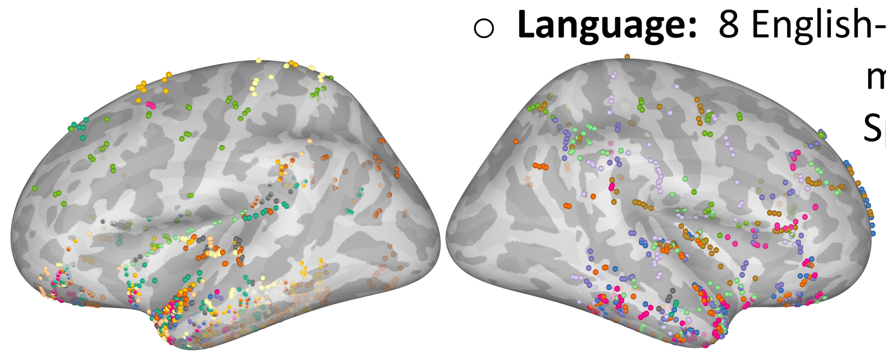


- High spatial and temporal precision in stereotactic electroencephalography (sEEG) to map neural response to perturbations in auditory feedback.
- Analyzed high gamma (HG) broadband neural signal (70–150 Hz), which is correlated with BOLD and single unit responses. (Mukamel et al., 2005)



RESULTS

- 15 patients undergoing cortical monitoring for surgical evaluation.
- 1493 electrodes
  - **Diagnosis:** drug-resistant focal epilepsy
  - **Gender:** 7 male, 7 female, 1 non-binary
  - **Age:** 16-56 years (mean = 32.1, SD = 10.3)
  - **Language:** 8 English-only, 1 Russian-only, 6 multilingual (English + Spanish/French/Portuguese)
  - **Handedness:** 3 left
  - **Laterality:** 8 bilateral; 3 right hemisphere only; 4 left hemisphere only

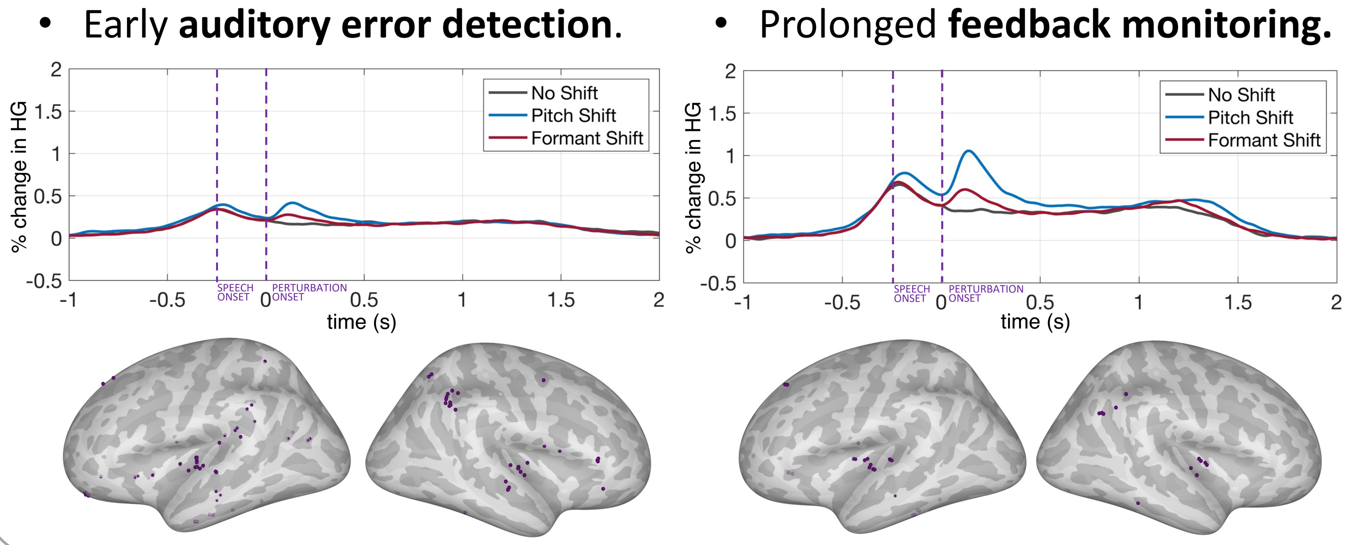


① Major patterns of perturbation-based cortical response

- Unsupervised k-means clustering revealed 2 distinct spatiotemporal patterns in bilateral STG and Heschl's gyrus and right SMG.

Cluster 1: (76 electrodes)
- Brief increase in neural activity 0-400 ms after perturbation onset.
- Early **auditory error detection**.

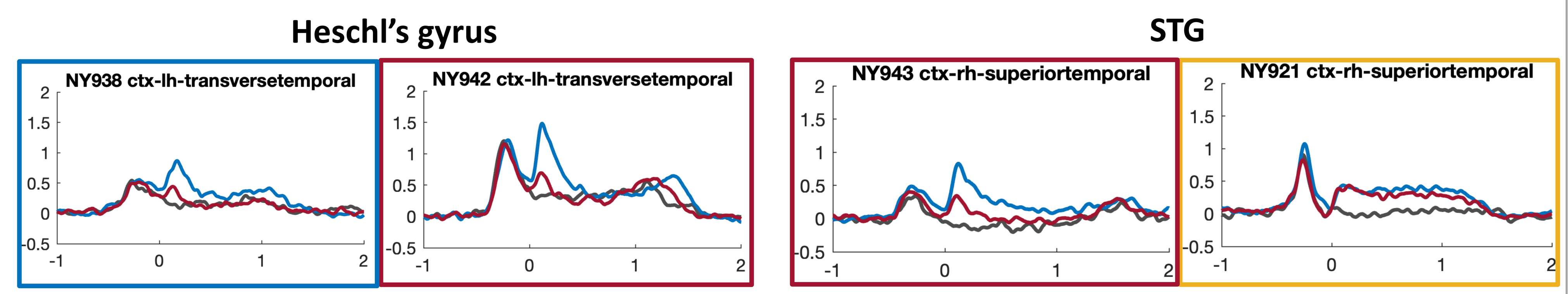
Cluster 2: (33 electrodes)
- Sustained neural activity 0-1500 ms after perturbation onset.
- Prolonged **feedback monitoring.**

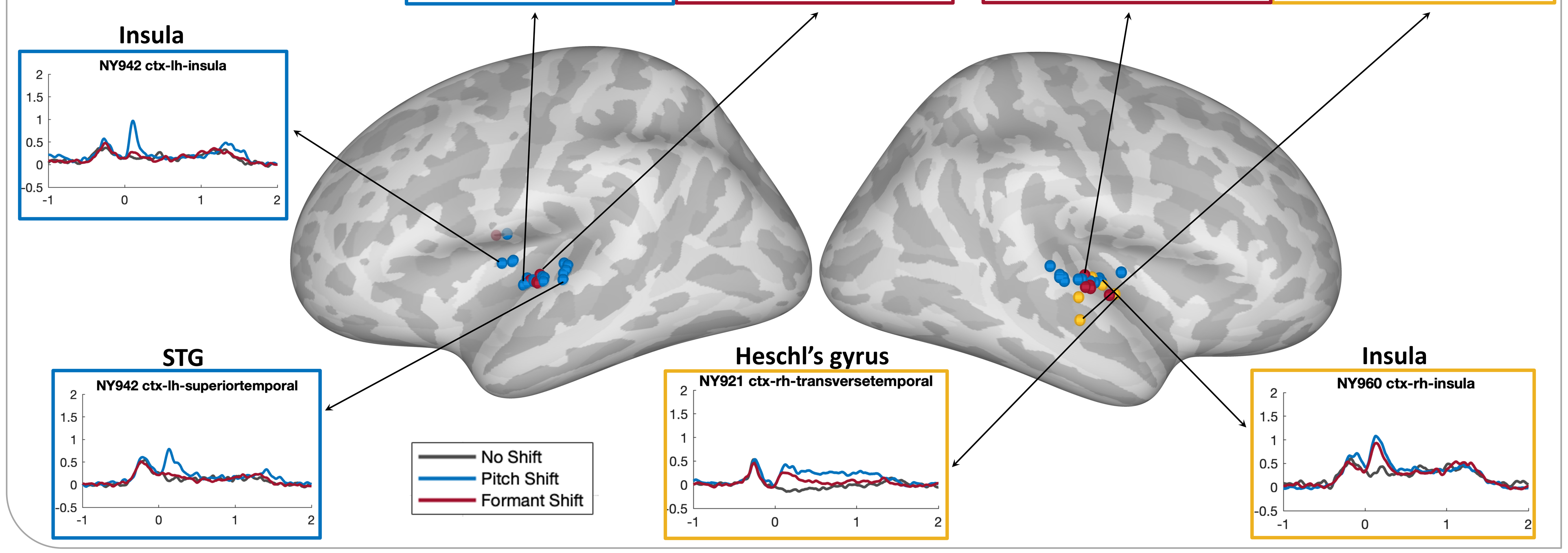


② Spatiotemporal patterns distinguishing trials based on acoustic perturbation type: Pitch versus Formant versus No Shift

- One-way ANOVAs for each time point revealed perturbation-based effects across conditions (Bonferroni correction; ≥100ms significance):
- Electrodes encoding differences ($p<0.002$) between conditions (# electrodes; # patients):

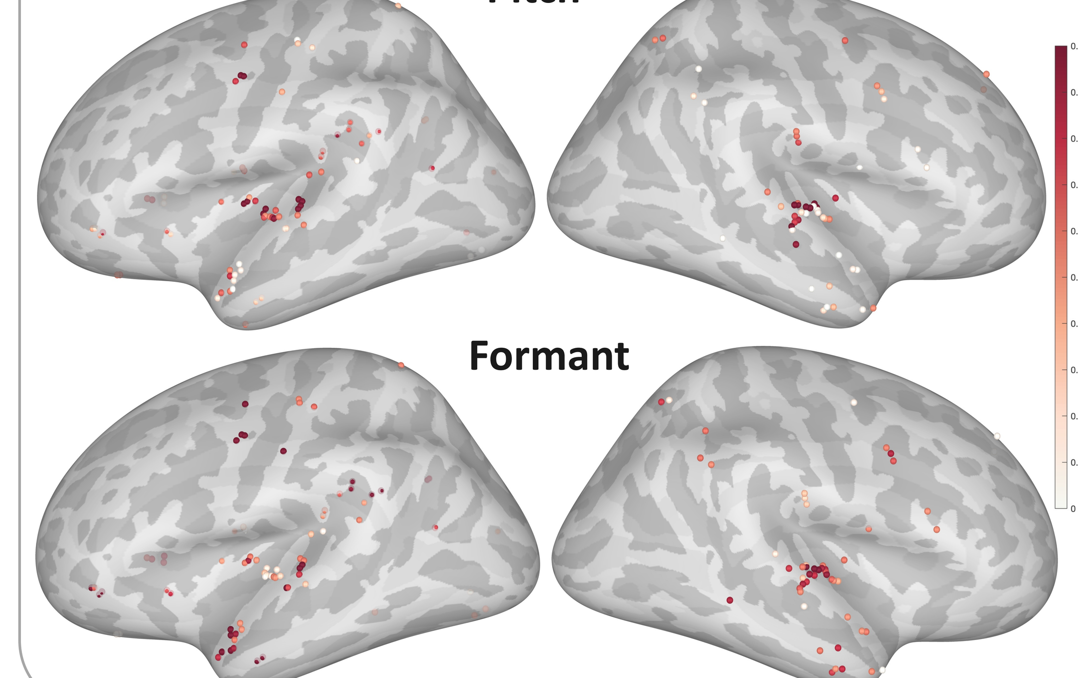
Pitch > No Shift (47;9)
└ **Pitch > Formant** (42;8)
  └ **Formant > No Shift** (15;5)
└ **Pitch ≯ Formant** (5;2)
- Peak difference at 153 ± 52 ms





③ Correlations between neural response and acoustic change (preliminary)

- 131 electrodes with correlations: |average r| > 0.1 across trials in either condition.
  - Response to **Pitch Shifts** (cents):
    - 73 electrodes
    - **STG**: Bilateral correlations
  - Response to **Formant Shifts** (mels):
    - 98 electrodes
    - **STG**: RH > LH; L anterior inferior temporal gyrus correlations
  - 40 electrodes surpassed threshold in both conditions.
- *We plan to run encoding models to distinguish pitch versus formant, upward versus downward shifts, and compensatory versus non-compensatory behavior.*



CONCLUSIONS

① Brief increases in neural activity representing **detection of error signals** versus sustained neural activity representing **ongoing feedback monitoring / transmission of error signals** in response to acoustic perturbations, a distinction consistent with previous work distinguishing onsets from sustained response. (Hamilton Edwards & Chang 2018)

② Regions showing magnitude-based differences separating sensorimotor control of phonatory (pitch) versus articulatory (formant) subsystems include STG and Heschl's gyrus, and also insular cortex, which is aligned with previous research. (Kurteff et al 2024; Woolnough et al 2019)

③ Neural responses show strong and region-specific correlations with compensatory acoustic behavior during pitch versus formant perturbations.

Takeaway: *Pitch and formant feedback share a neural circuit; pitch responses are consistently stronger, with formant responses represented in a selective subset.*

Next steps: Determine relationship between compensatory neural responses and spatial topography based on sEEG clustering (brief versus sustained responses).
- Determine laterality of pitch versus formant sensitivity across analyses; could inform therapeutic applications (e.g., stimulation of rSTG during articulation-based treatment).

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