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NYU Grossman School of Medicine

TIMING AND LOCATION OF SPEECH ERRORS INDUCED BY DIRECT CORTICAL STIMULATION

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Introduction

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Direct electrocortical stimulation (DES) mapping

- Identify brain regions controlling:
  - motor function
  - speech/language
- DES is the **gold standard** for preventing speech/language loss following epilepsy surgery.

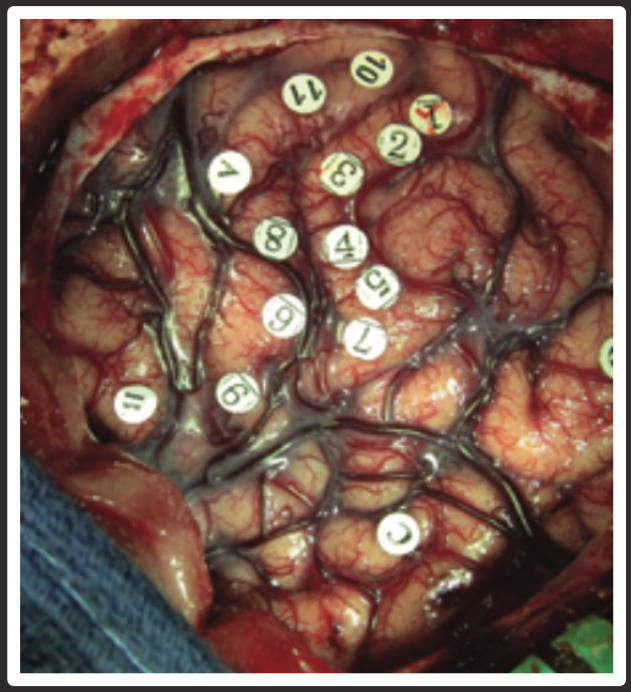

Image: Chang et al. (2017)

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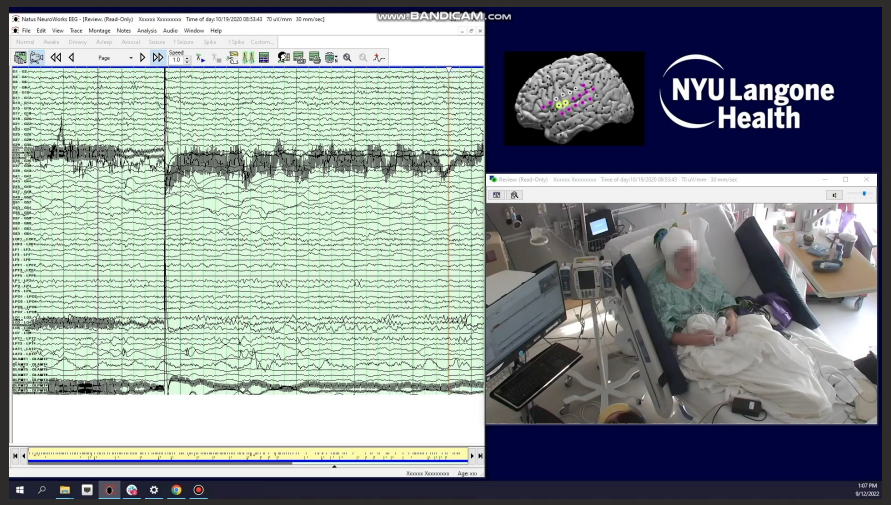
Speech/language interruptions induced by DES

- Stimulate cortex during task:
  - Continuous speech
  - Visual/auditory naming
  - Sentence completion
- Various speech/language interruptions:
  - Other behaviors: anomia, hesitation, slurring, distortion, perseveration, confusion (Penfield & Roberts. 1959)
  - **Speech arrest:** *the complete interruption of the ability to continue speaking not directly explained by oral or laryngeal movements.* (Nakai et al., 2017; Lu et al., 2021)



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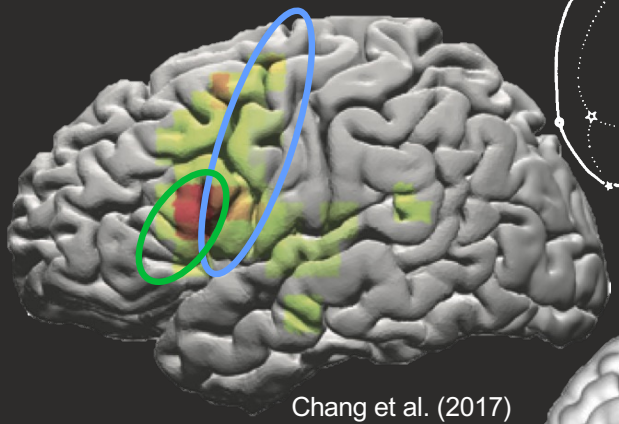
Across numerous studies, speech arrest is linked to:

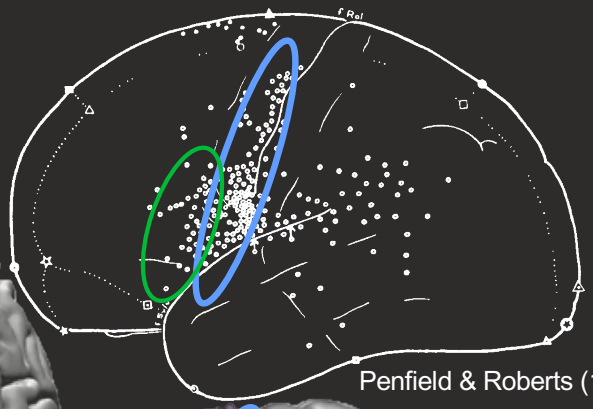
- **precentral gyrus**
  (Motor Cortex)
- **pars opercularis**
  (inferior frontal gyrus; IFG)

(Penfield & Roberts, 1959; Wu et al., 2015; Chang et al., 2017; Lu et al., 2021)

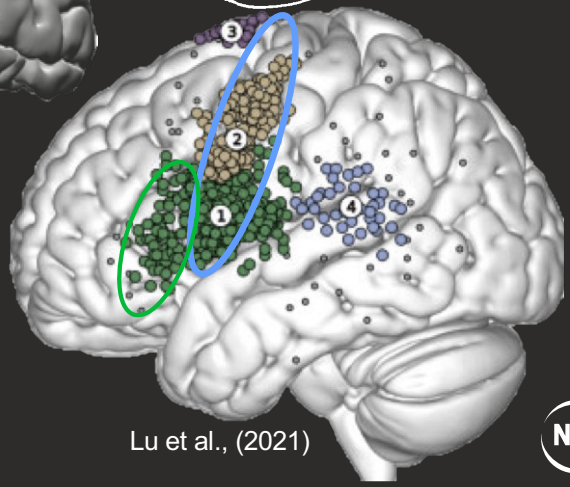
- High probability of speech arrest if stimulated in these sites. (Chang et al., 2017; Wu et al., 2015)



Chang et al. (2017)



Penfield & Roberts (1959)



Lu et al., (2021)

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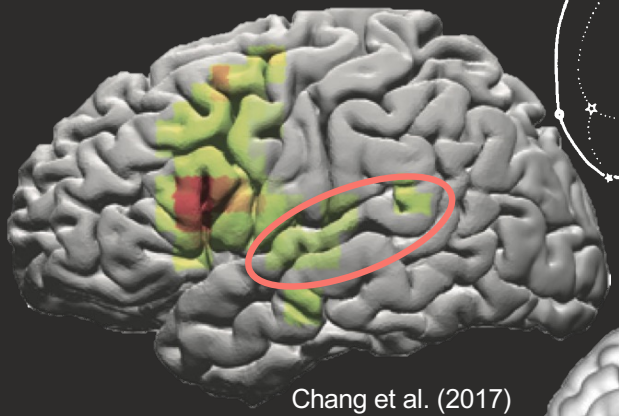
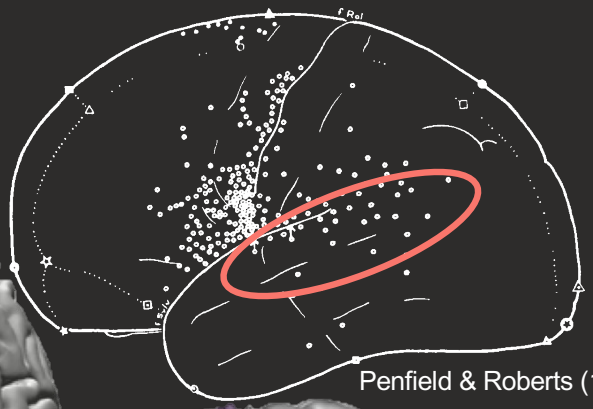
Inconsistently, speech arrest is also linked to:

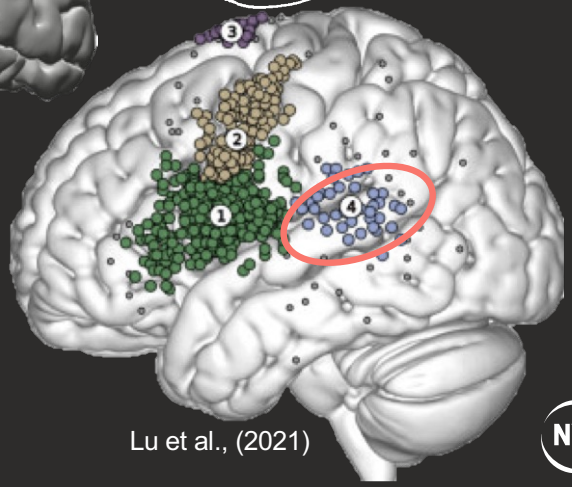
- **superior temporal gyrus (STG)**
  - 4th largest cluster (Lu et al., 2021)
  - Relatively low likelihood of eliciting speech arrest (Wu et al., 2015)
  - Highest variability (Chang et al., 2017)



Chang et al. (2017)



Penfield & Roberts (1959)



Lu et al., (2021)

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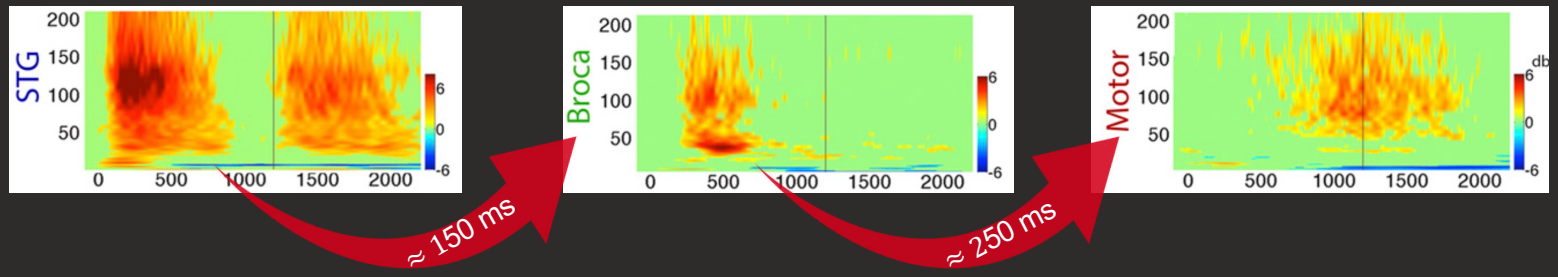
What measuring timing tells us

- Multiple studies have reported *location* of speech arrest in IFG and Motor Cortex, but the role of STG in eliciting speech arrest is less understood.
- Reporting the *timing* of speech arrest during continuous speech in these various broad regions during extra-operative DES will tell us when in the speech production process the disruption occurred.
  - motor execution → immediate
  - planning → temporal lag

Question

Do latencies from stimulation onset to speech arrest during a continuous speaking task differ across broad cortical regions?

- Predictions for Speech Arrest based on word repetition task (Flinker et al., 2015):



- Shortest latencies are in Sensorimotor Cortex → interruption of motor execution
- Longer latencies are in IFG → adjustments to already established motor plans

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Methods

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DES mapping

- Continuous speaking tasks
  - Counting
  - Recitation: days; months
- DES applied to electrode pairs, as dictated by clinical protocol:

Pulse width: 300-500 μS	Pulse frequency: 50 Hz
Max train duration: 5s	Max threshold: 12 mA

- Stimulation repeated until response is elicited $\geq \frac{2}{3}$ trials or site is cleared.

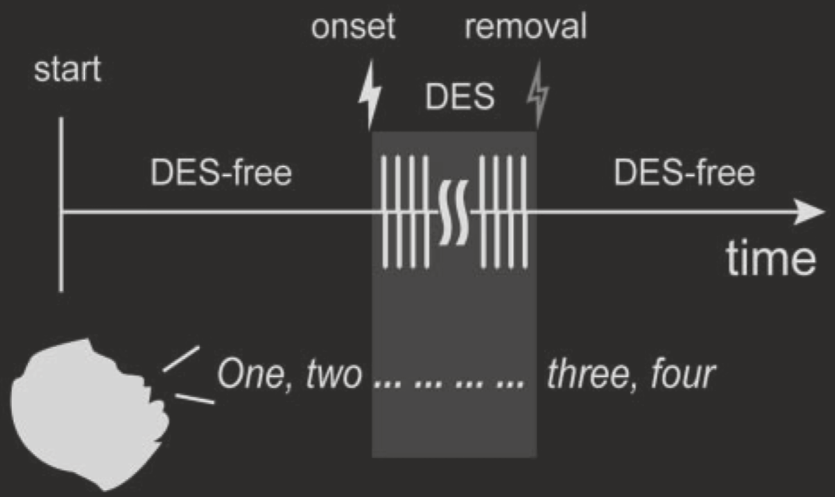

Image: Lu et al. (2021)

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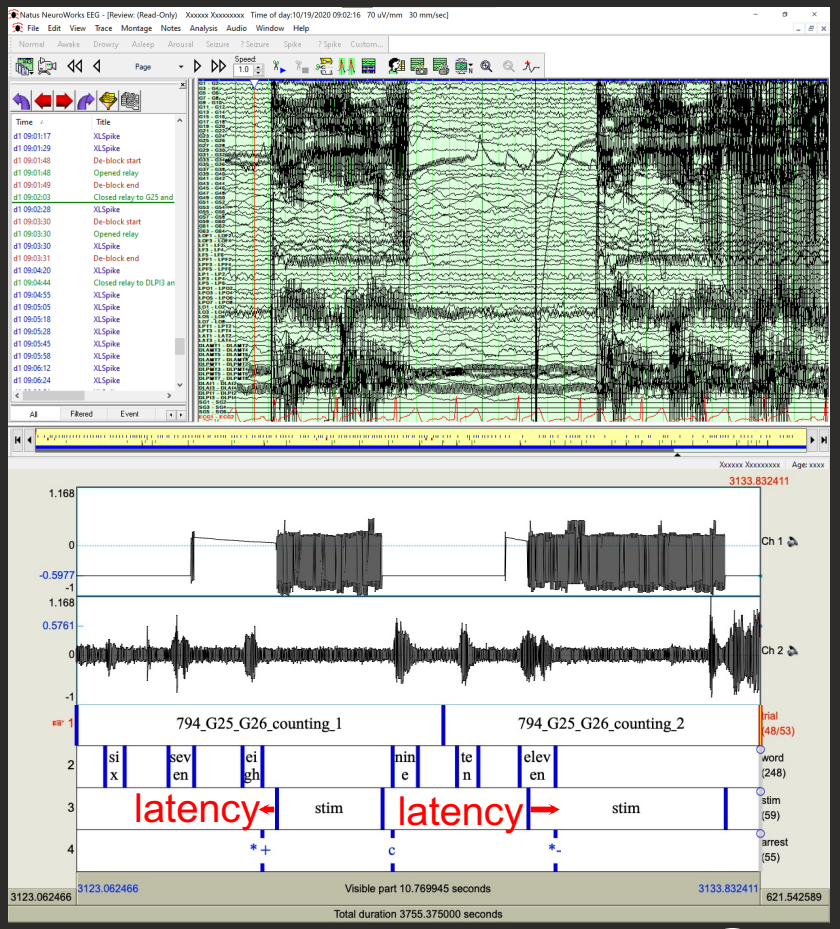
Procedure

1. **Neuroworks**: identify all motor or speech arrest events for 20 patients.
2. **Matlab**: align stereo audio for each target grid location:
   - ► Channel 1: stimulation signal
   - ► Channel 2: time-synced audio
3. **Praat**: measure exact timing of stimulation onset and interruption for each motor or speech arrest event.
   - ► Adjust latencies to control for speech rate.



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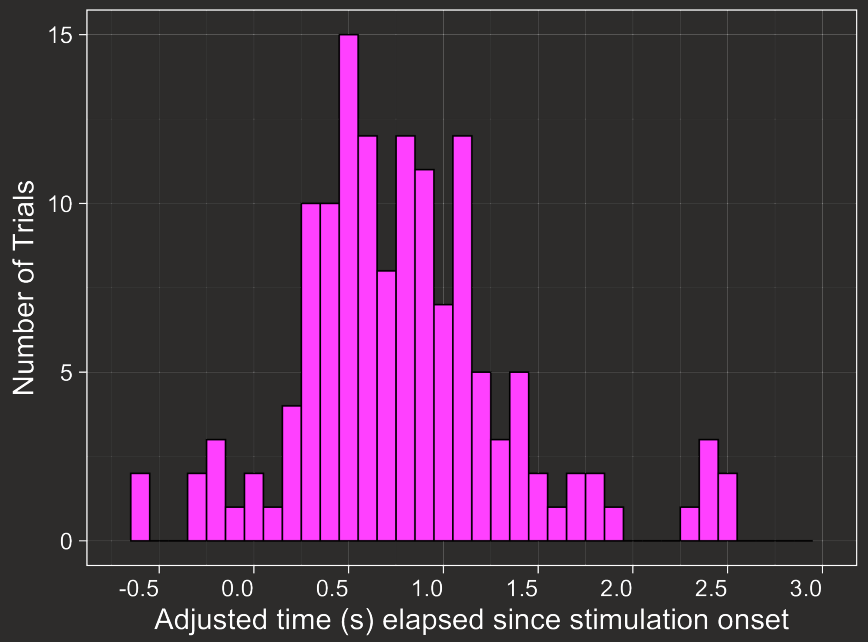
Data set



- **360 trials** labeled “motor” or “speech arrest” by clinical team.
  - Remove >2SD outliers (n = 6).
  - Remove soft arrest trials (n = 80).
  - Remove regions not in STG, IFG, or Sensorimotor Cortex (n = 70).
  - Remove trials with afterdischarges (n = 65).

139 trials < 135 (in) / 105 (out) > 240 data points

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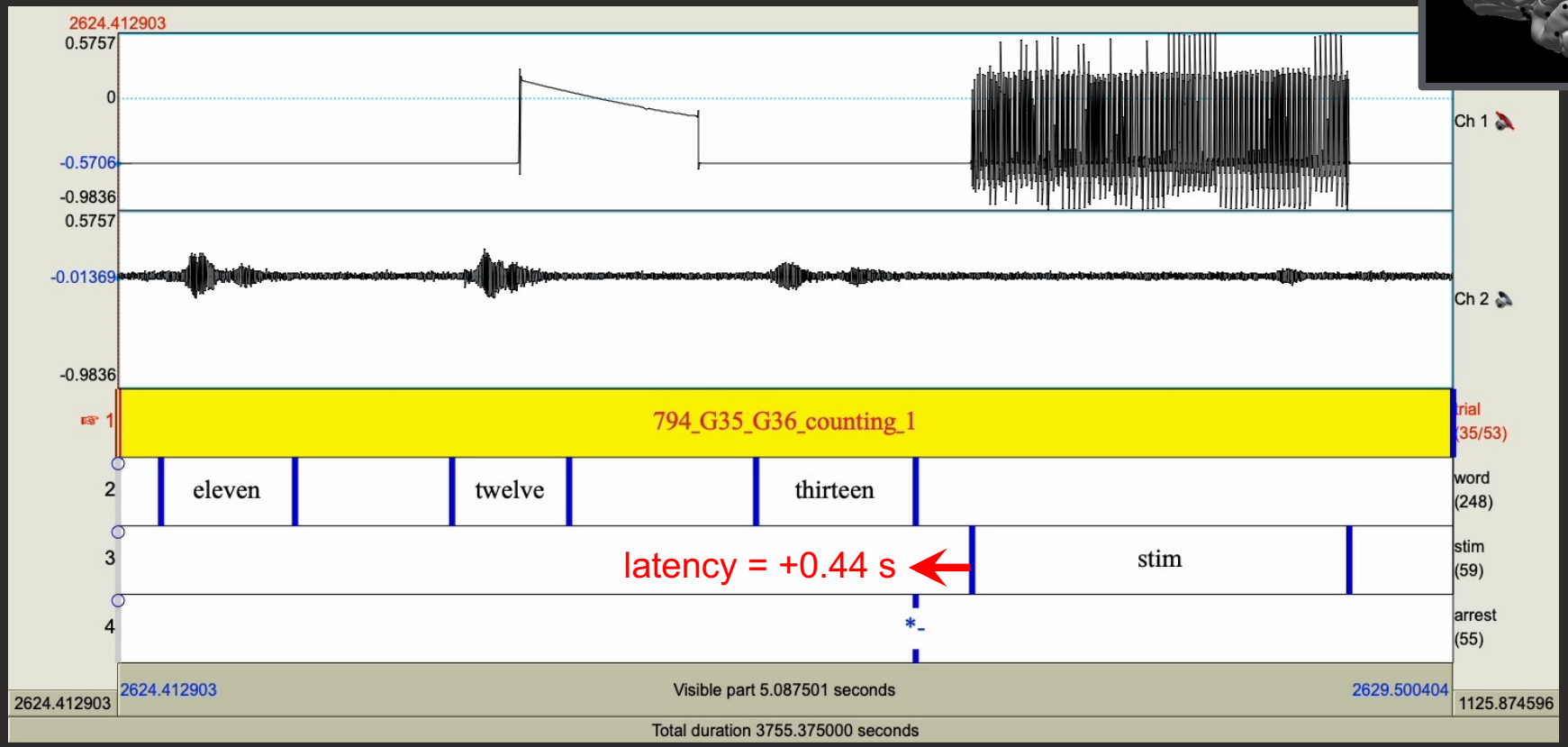
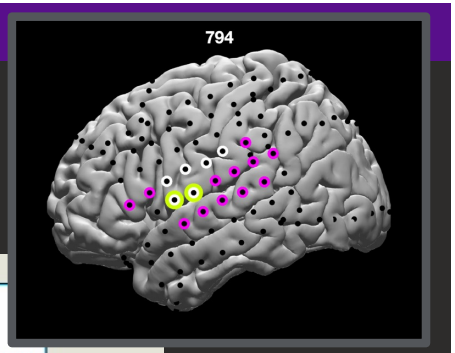
“Motor” hit in sensorimotor cortex





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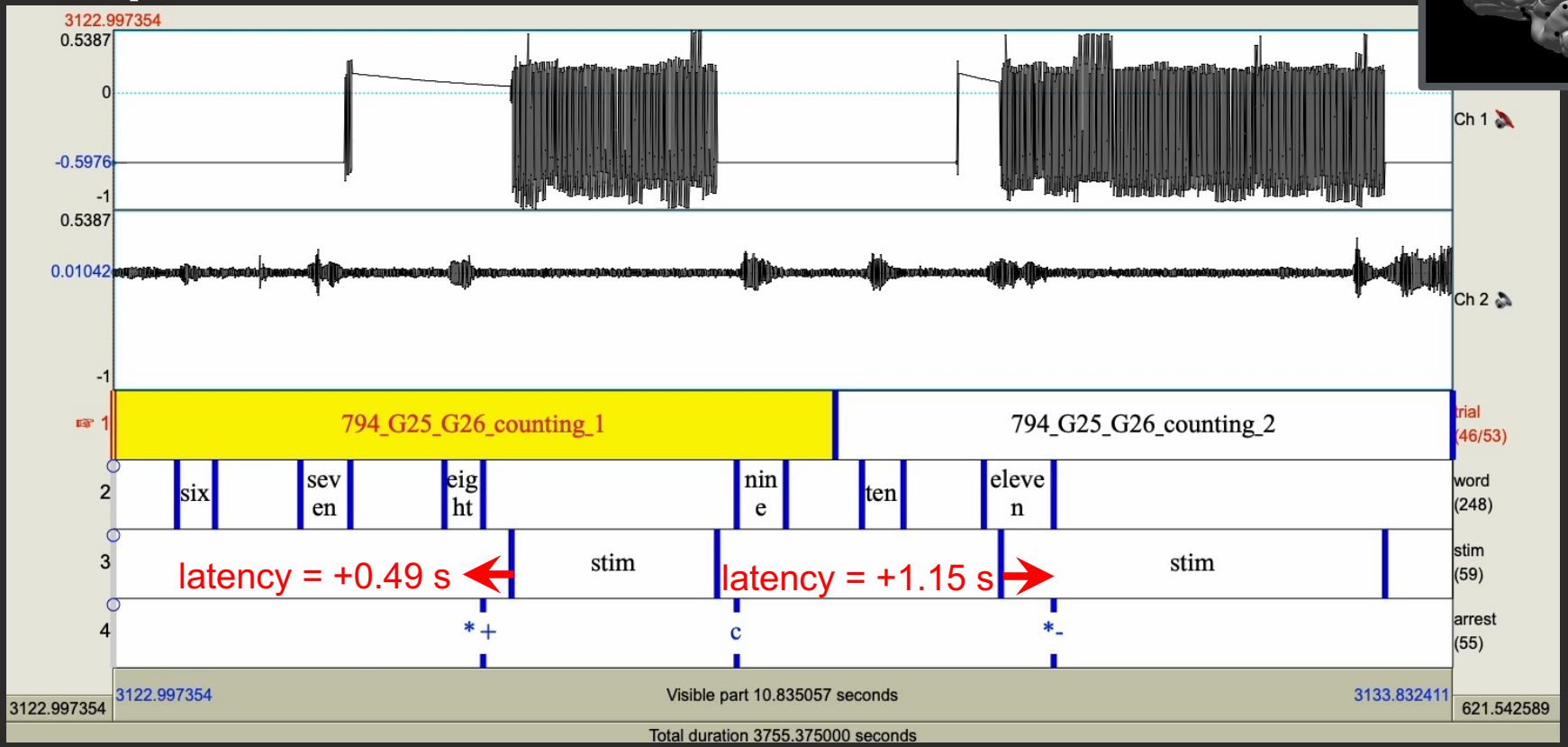
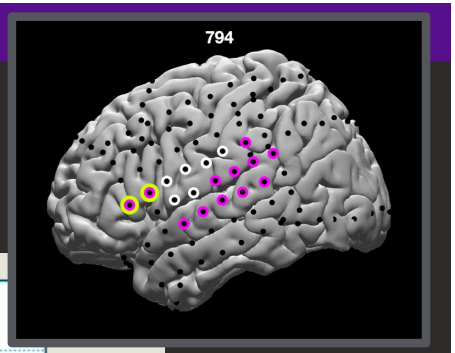
“Speech arrest” hit in IFG





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Results

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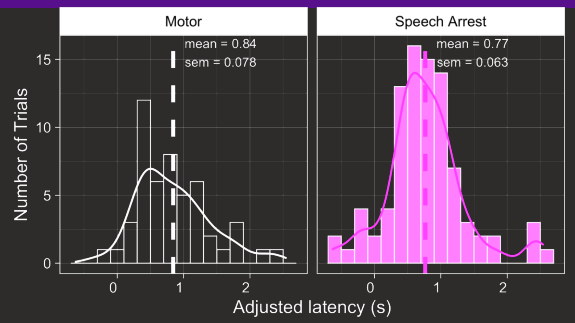
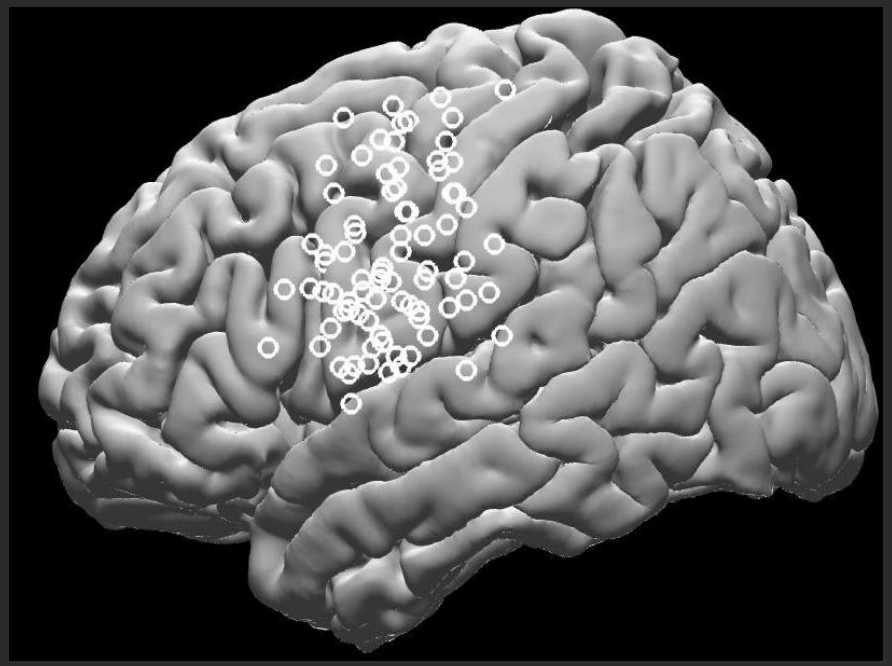
Location

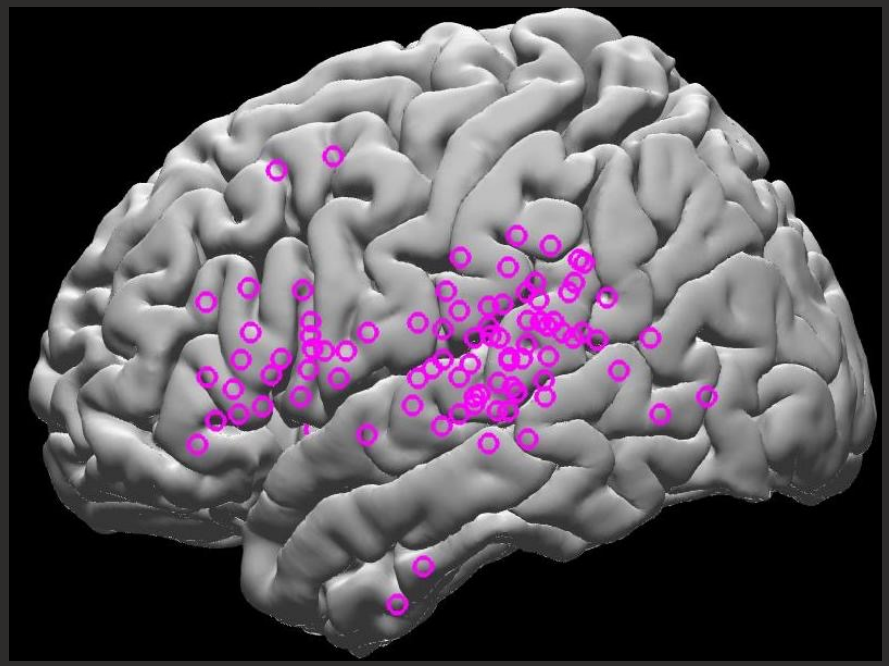


t(137) = 0.759, p = 0.449

Motor Hits



Speech Arrest Hits



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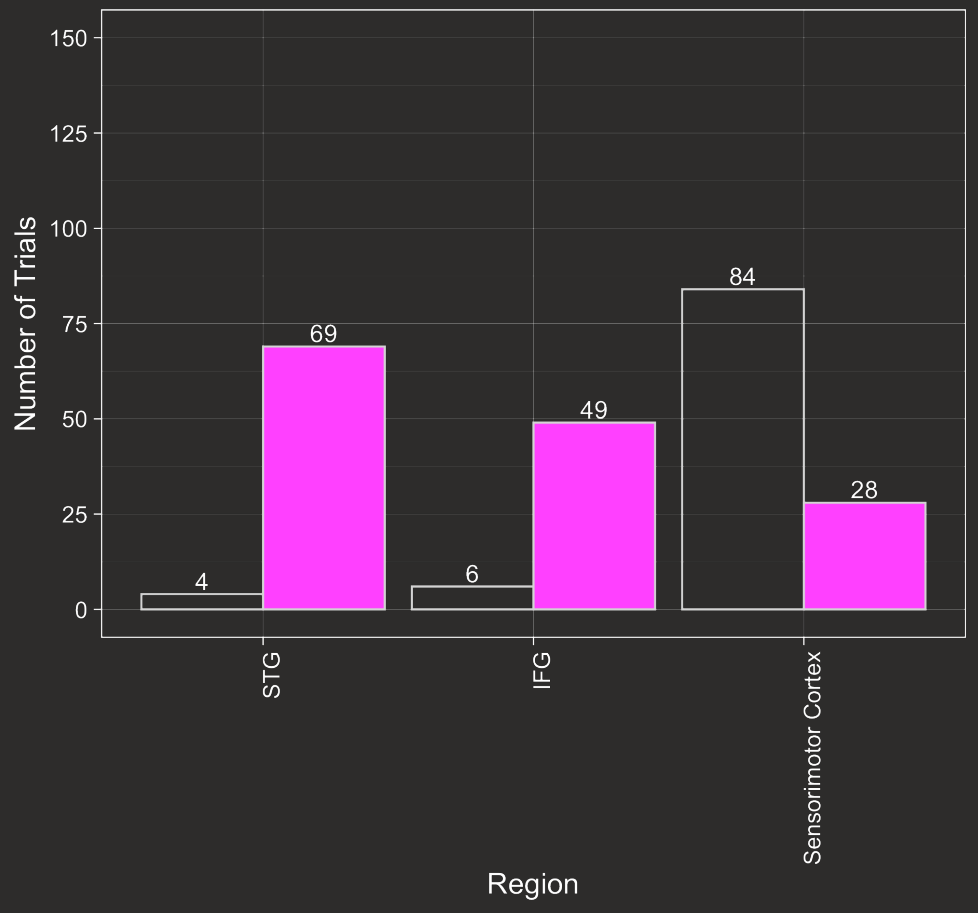
Counts

- Sensorimotor Cortex
  - motor > speech arrest
- STG/IFG
  - speech arrest > motor



Timing

- For speech arrest, region predicts latency.

$\chi^2(2) = 14.98$, p = 0.00056

  - STG < IFG

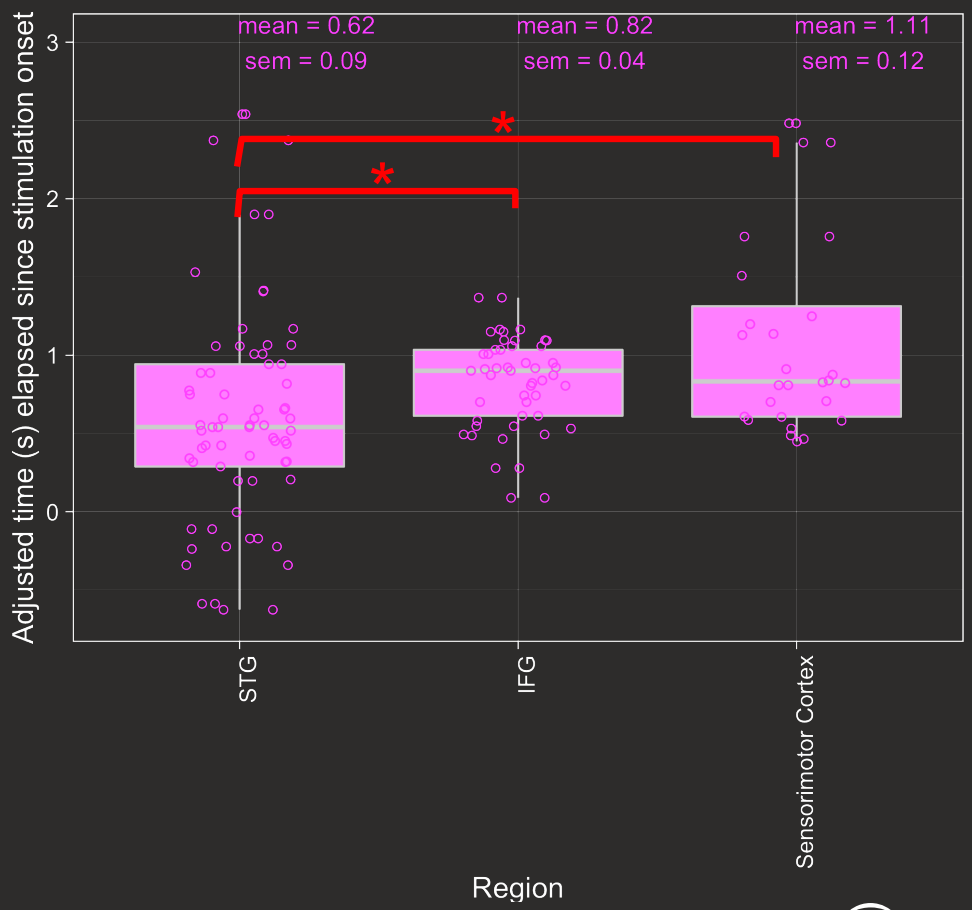
  D = 0.35, p = 0.0017

  - STG < Sensorimotor Cortex

  D = 0.41, p = 0.0026

  - Sensorimotor cortex ≮ IFG

  D = 0.28, p = 0.12



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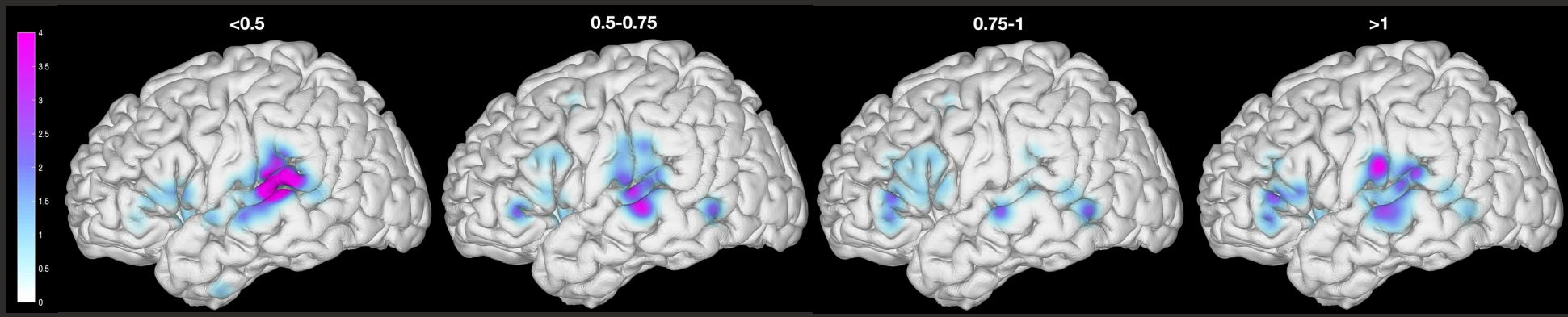
Interruption density after stimulation onset



1. Early STG interruption

2. STG interruption fades

3. IFG interruption ramps up

4. Late STG & peak IFG interruption

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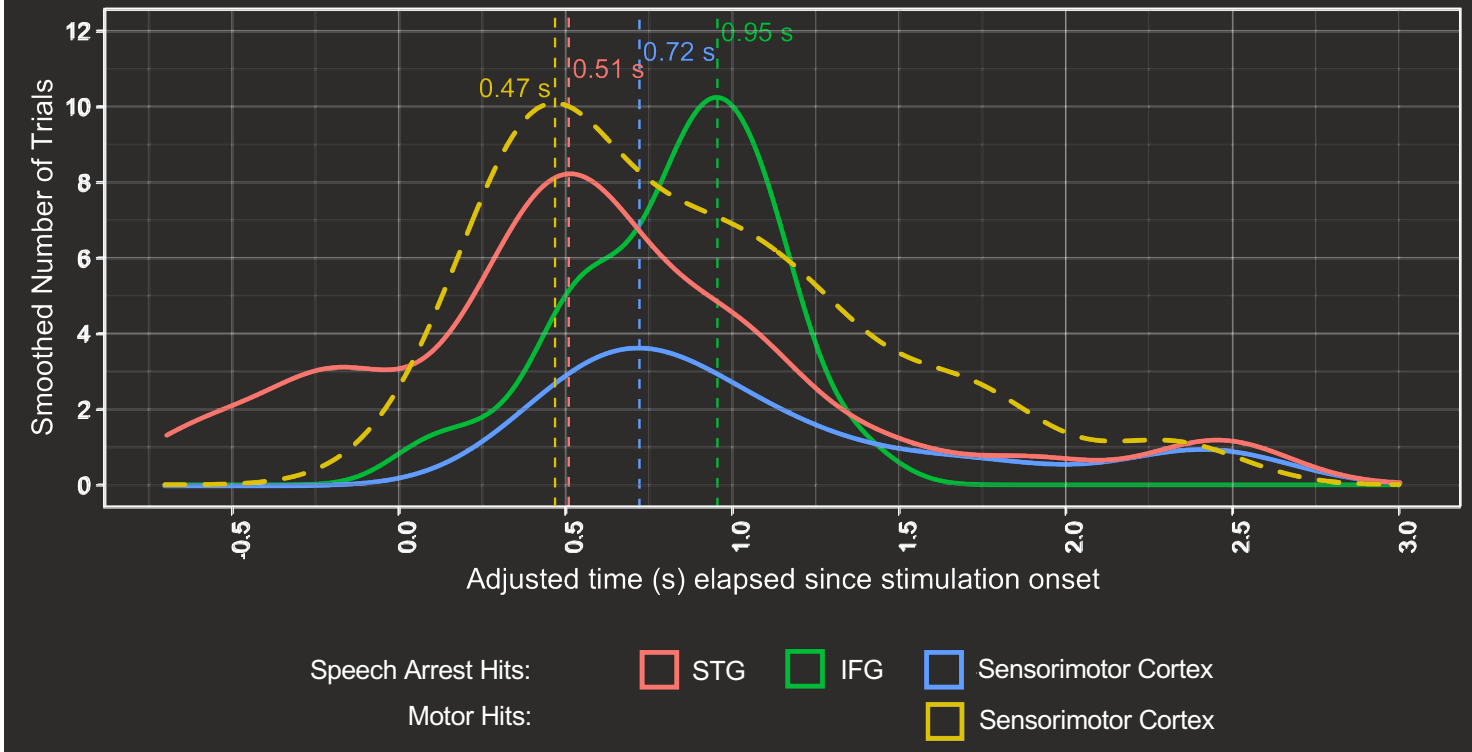
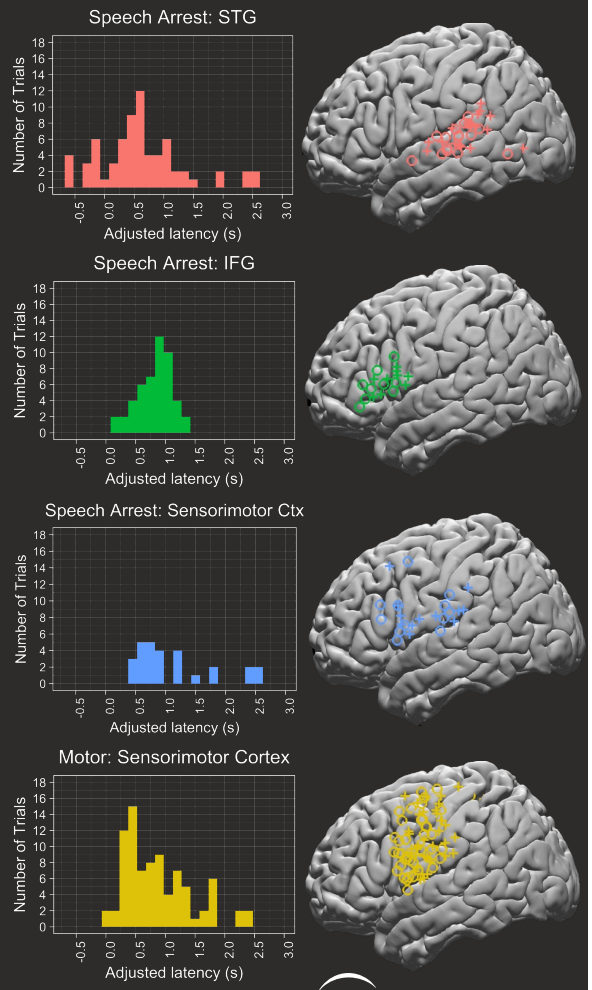
Speech arrest latency by region





(bin width = 0.15 s)

Discussion

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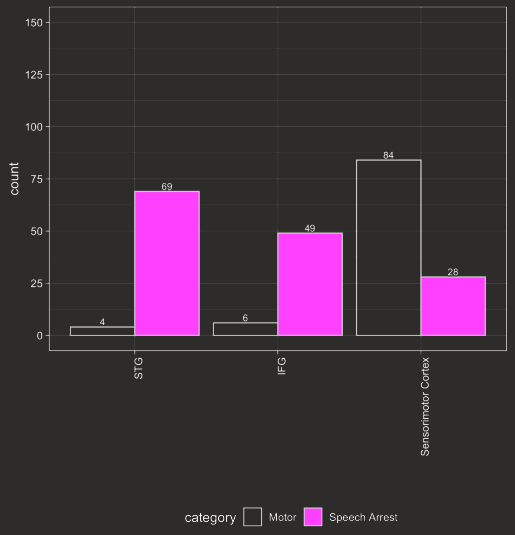
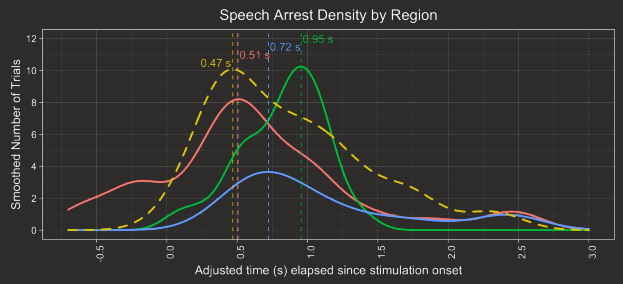
Summary

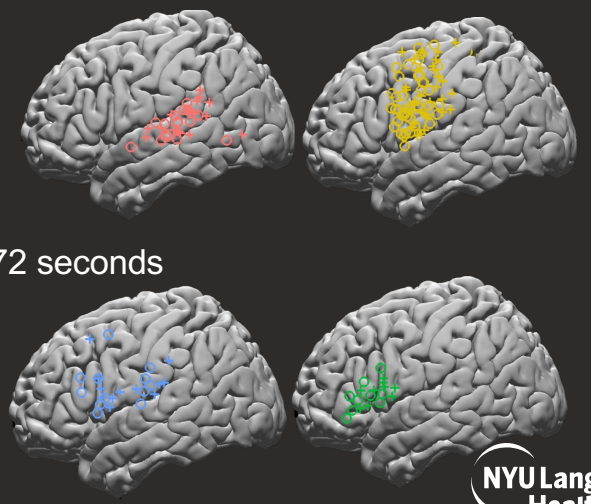
- More motor hits in motor cortex, and more speech arrest hits in STG/IFG.



- Timing analysis reveals:



  - Early:
    - STG: 0.51 seconds
    - Motor hits: 0.47 seconds
    - **Motor execution?**
  - Late:
    - Sensorimotor Cortex: 0.72 seconds
    - IFG: 0.95 seconds
    - **Planning?**



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What timing tells us about STG

- Latencies in STG reveal region's unique role in speech production.

Lexical access hypothesis

- Stimulation interferes with lexical access for the next word in the sequence.
- Sites for speech arrest and anomia in pSTG are nearby but distinct. (Lu et al., 2021)
- Our data do not support this hypothesis.

Self-monitoring hypothesis

- Stimulation interrupts auditory feedback loop.
- Evidence for efference copy in temporal regions (Forseth et al., 2020; Khalilian-Gourtani et al., BioRxiv)
- Early and late latencies in STG could reflect interruption at distinct stages in feedback loop.

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Thank you Flinker Lab!

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