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# SENSORIMOTOR CONTROL OF PITCH AND FORMANTS IN PATIENTS WITH PARKINSON'S DISEASE AND DEEP BRAIN STIMULATION

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# Introduction

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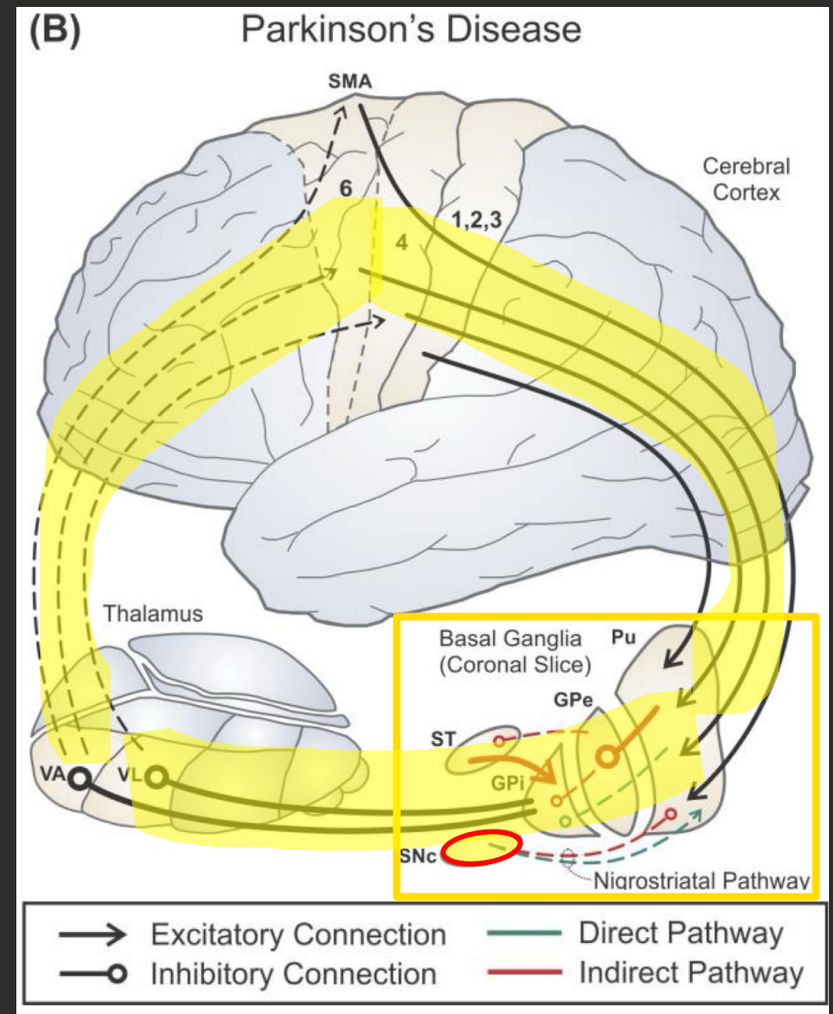
# Parkinson’s disease (PD)

- “Sensorimotor control” of speech: incorporation of sensory feedback into ongoing motor commands. (Guenther, 2016)
- The **cortico-basal ganglia motor** loop is crucial for coordinating timely & precise motor execution.
- In PD, reduced dopamine weakens excitation and inhibition within the cortico-basal ganglia motor loop. (Göttlich et al., 2013; Guenther, 2016)
  - tremor, rigidity, bradykinesia, postural instability
  - changes in speech




Guenther (2016) Ch. 10



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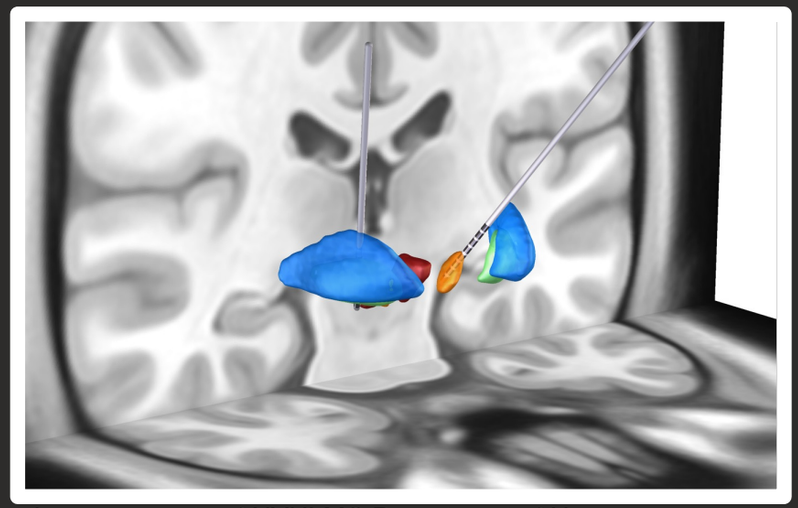
# Deep Brain Stimulation (DBS)

- Surgical implantation of electrodes within cortical-basal ganglia motor loop provides a “virtual lesion” that restores balance.
  - Usually in the subthalamic nucleus (STN)
- Increasingly common treatment for general motor symptoms in refractory PD.
  (Atkinson-Clement et al., 2015)
- Variable outcomes on speech symptoms.
  (Skodda et al., 2013)



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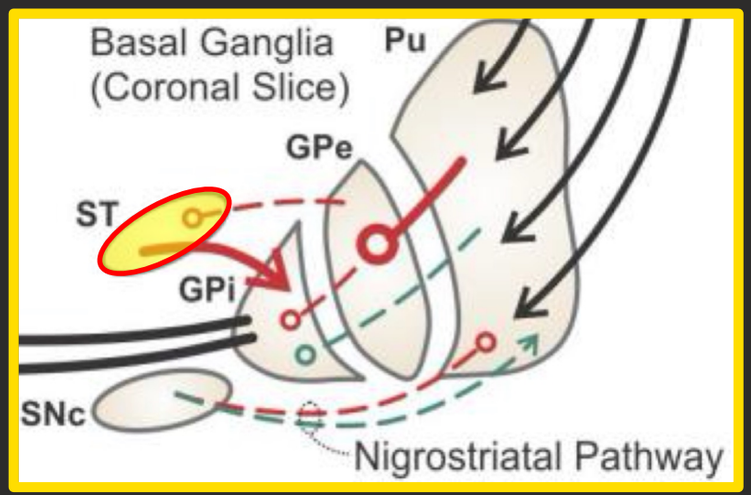


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# Hypokinetic dysarthria in PD

- 90% of those with PD develop hypokinetic dysarthria. (Duffy, 2020)
- Reduced respiratory, phonatory, and articulatory precision leads to slow, effortful, and slurred speech. (Darley et al., 1969; Duffy, 2020)
  - Reduced intelligibility (Müller et al., 2001; Hartelius & Svensson, 1994)
  - Vocal instability (Behroozmand et al., 2019)
  - Low pitch variability (Skodda et al., 2013)
  - Small vowel (articulatory) space (Bang et al., 2013; Skodda et al., 2011)
- Although 33% report speech as a major challenge, only 3% seek speech therapy. (Hartelius & Svensson, 1994)
- Most therapies target vocal effort (intensity) and require intensive schedules and clinician input. (Atkinson-Clement et al., 2015)
- Limited evidence supporting speech therapy for patients with DBS:
  - Variable maintenance (Spielman et al., 2011)
  - Reduced cognitive capacity for speech rehabilitation (Atkinson-Clement et al., 2015)



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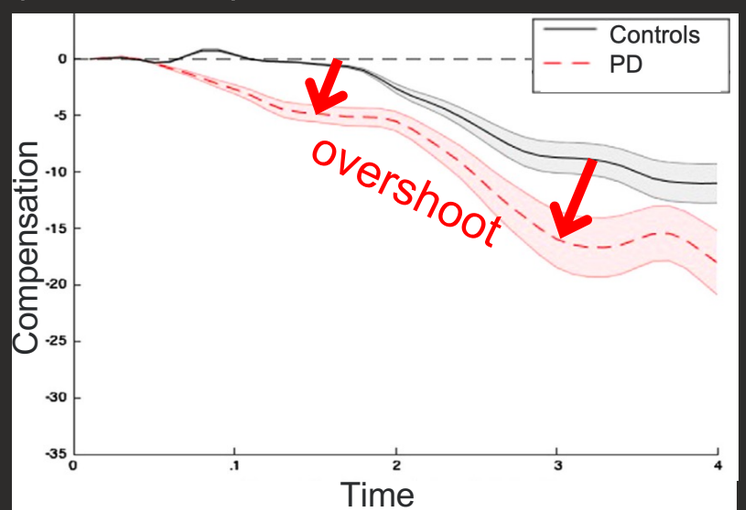
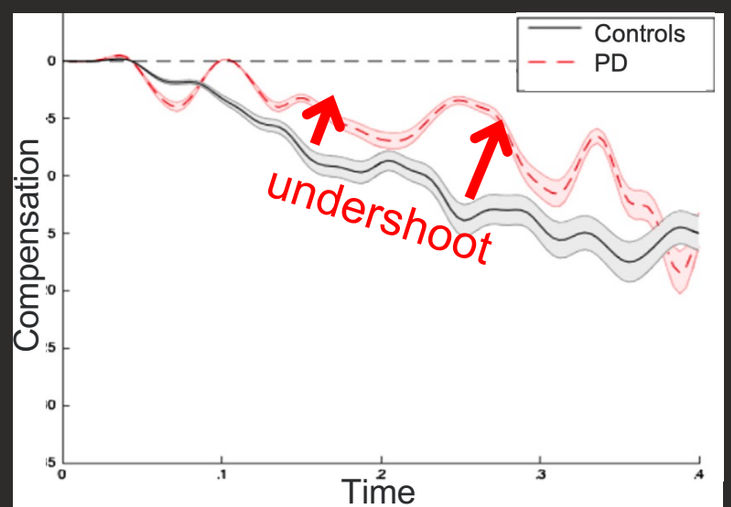
# Atypical sensorimotor control of speech in PD

- Speakers typically compensate for pitch/formant perturbations by shifting frequencies in the opposite direction to the perturbation. (Houde & Jordan, 1998; Jones & Munhall, 2005)
- Responses to online perturbations for patients with PD compared to controls:
  - ***Pitch*** *compensation (phonation): Larger (overshoot)* *(Chen et al., 2013; Huang et al., 2016; Liu et al., 2012)*
  - **Formant** compensation (*articulation*): Smaller (*undershoot*) (Mollaei et al., 2013)




Mollaei et al., 2016




Mollaei et al., 2016



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# Effects of DBS on sensorimotor control in PD

- **Pitch** compensation (*phonation*):
  With ***brief*** (200ms) pitch perturbations, DBS turned ON has a *regulatory* effect, reversing previously observed *overshoot.*
  (Behroozmand et al., 2019)
  - Correlated with reductions in vocal instability

- **Formant** compensation (*articulation*):
  No study has investigated whether DBS regulates atypically small response (*undershoot*) to formant perturbations.
- Inconsistent reports on vowel space:
  - ↓ when DBS turned on (Sidtis et al., 2016)
  - ↑ when DBS turned on (Martel-Sauvageau et al., 2014)

# Effects of DBS on sensorimotor control in PD

- Leverage increasing occurrence of DBS as a novel window into sensorimotor control.
- Within-subject comparison of response to *sustained* perturbations affecting voice (pitch) versus articulation (formants) with DBS-STN off and on.
- ***Is sensorimotor control within the cortico-basal ganglia motor loop pitch-sensitive?***

**yes**

DBS regulates pitch but not formants

**no**

DBS regulates both pitch and formants

- Development of passive perturbation-based treatment tool?



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# Methods

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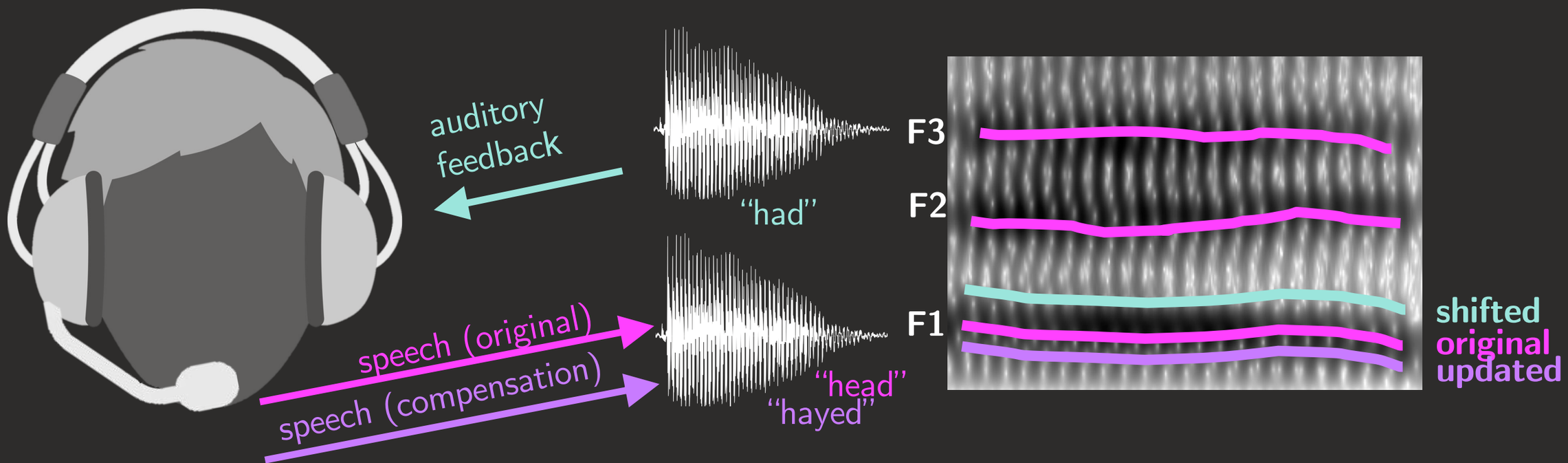
# Perturbation task

- Patients sustained /ɛ/ with interleaved F0 (±100 cents) or F1 (±125 mels) perturbations.
  (Behroozmand et al., 2019; Niziolek & Guenther, 2013)



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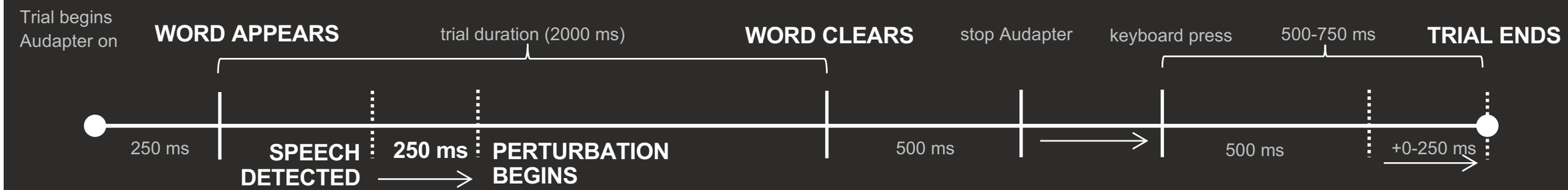
# Perturbation task

- 150 trials:  condition, word, and direction randomized within each block of 10.


- Within-block randomization and within-trial jitter maximize unpredictability of perturbation.
- Pink noise on throughout task to maximize reliance on air-conducted feedback.

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# PD and control groups

- 23 patients with PD and bilateral DBS-STN
- 9 healthy controls of comparable age
- Significantly higher VHI *(p < 0.001)* in PD compared to control group.

| | PD (n = 23) | Control (n = 9) |
|---|---|---|
| **Age** | m = 62.8<br>sd = 9.2 | m = 61.7<br>sd = 12.9 |
| **Gender** | 3 (13.0%)<br>female | 5 (66.7%)<br>female |
| **Voice Handicap Index (VHI)** | m = 46.7<br>sd = *23.3* | m = 9.3<br>sd = *6.6* |



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# Results

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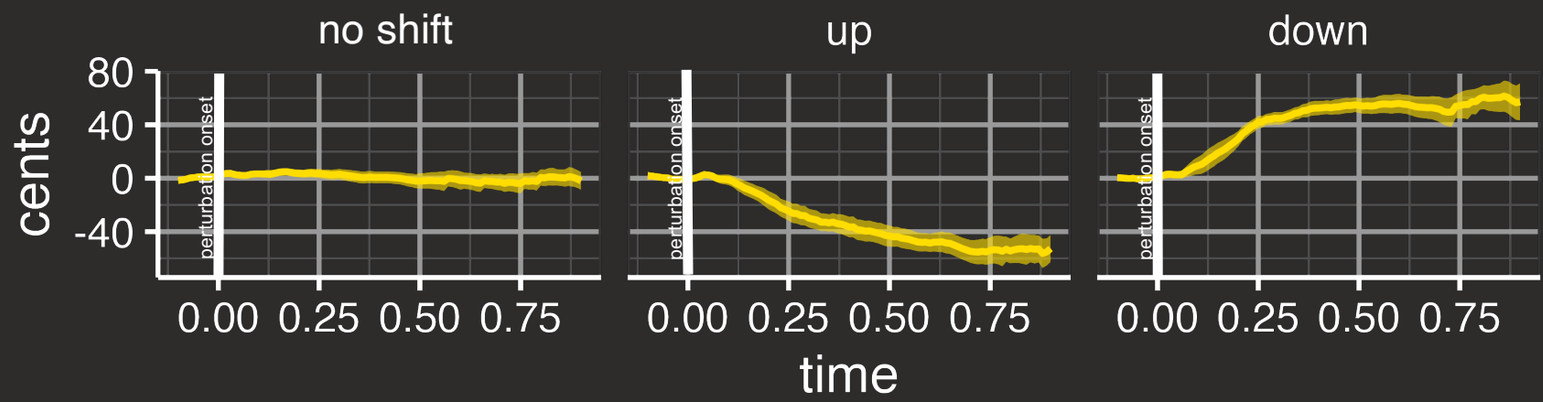
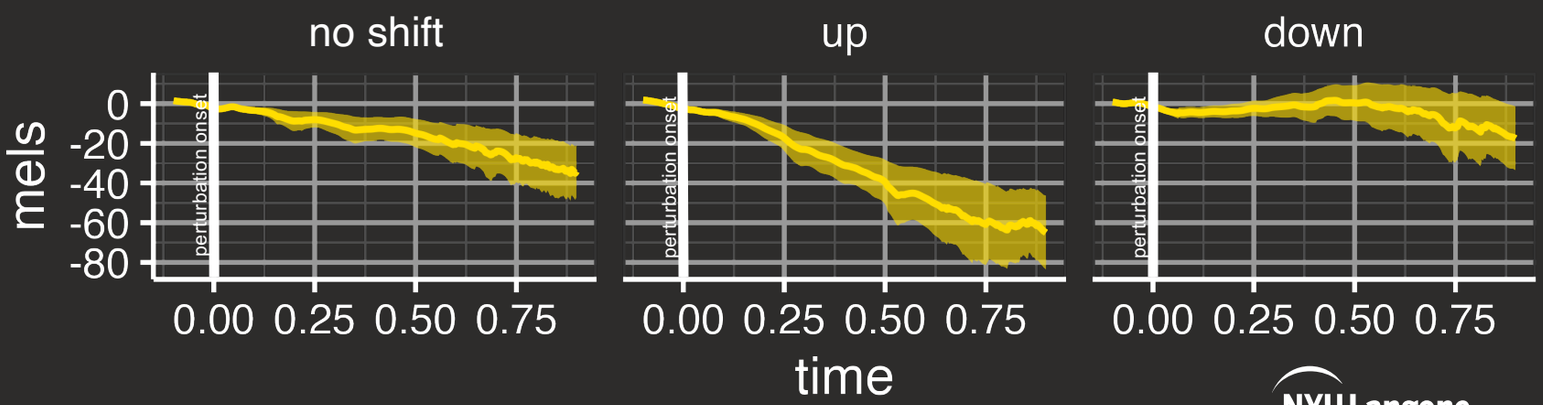
# Data visualization

- From raw Hz signal, we:
  - Convert to cents (pitch) & mels (formant).
  - Calculate compensation relative to 100 ms pre-perturbation.
- Compensation trends:
  - Pitch
  - Formant
- Subtract noshift condition from up/down conditions to show *relative* compensation patterns.

## Control group compensation to pitch shift




## Control group compensation to formant shift



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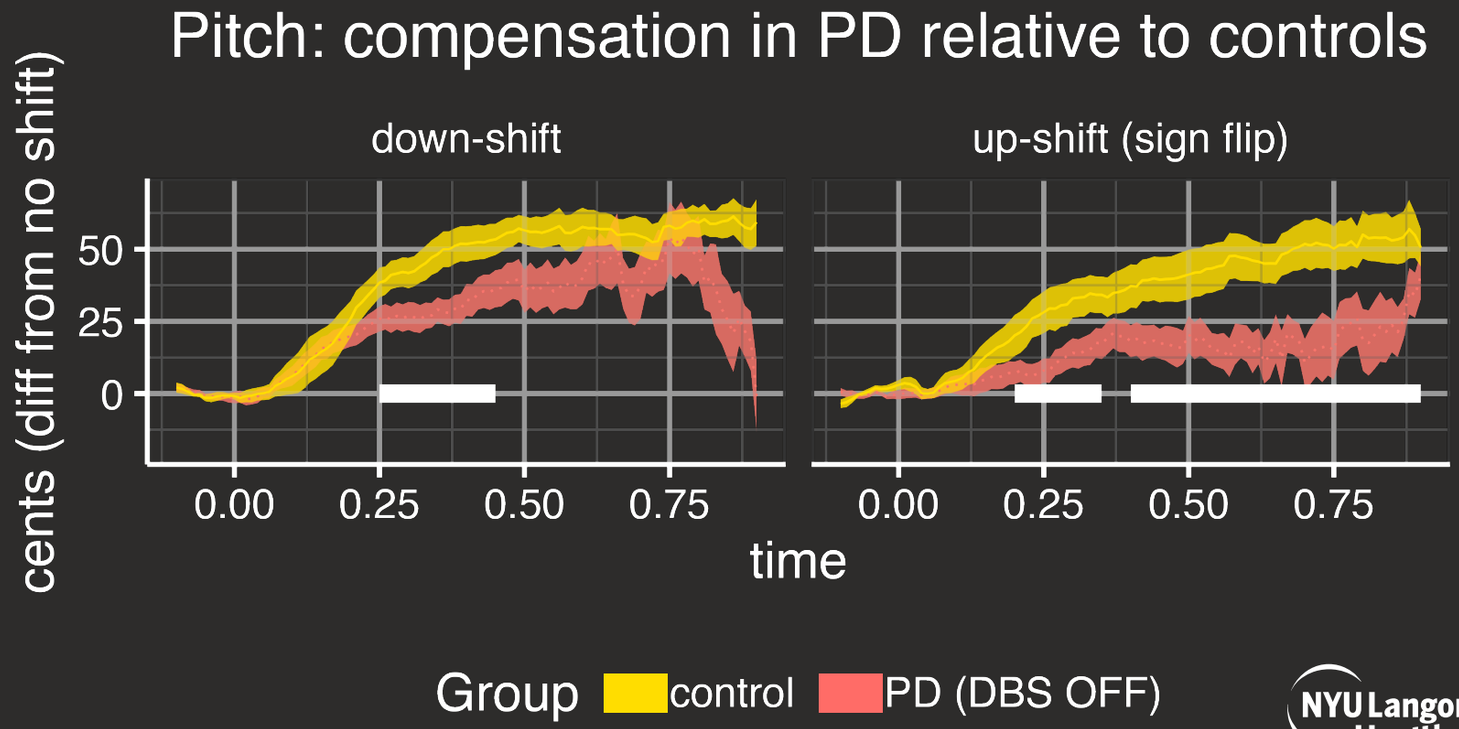
# Pitch

- Controls:
  - More likely to be compensators.
- Comparison with PD (DBS OFF):
  - Down:
    - **Specific window: 250-450 ms**
  - Up:
    - **Specific window: 200-350 ms; 400-900ms**

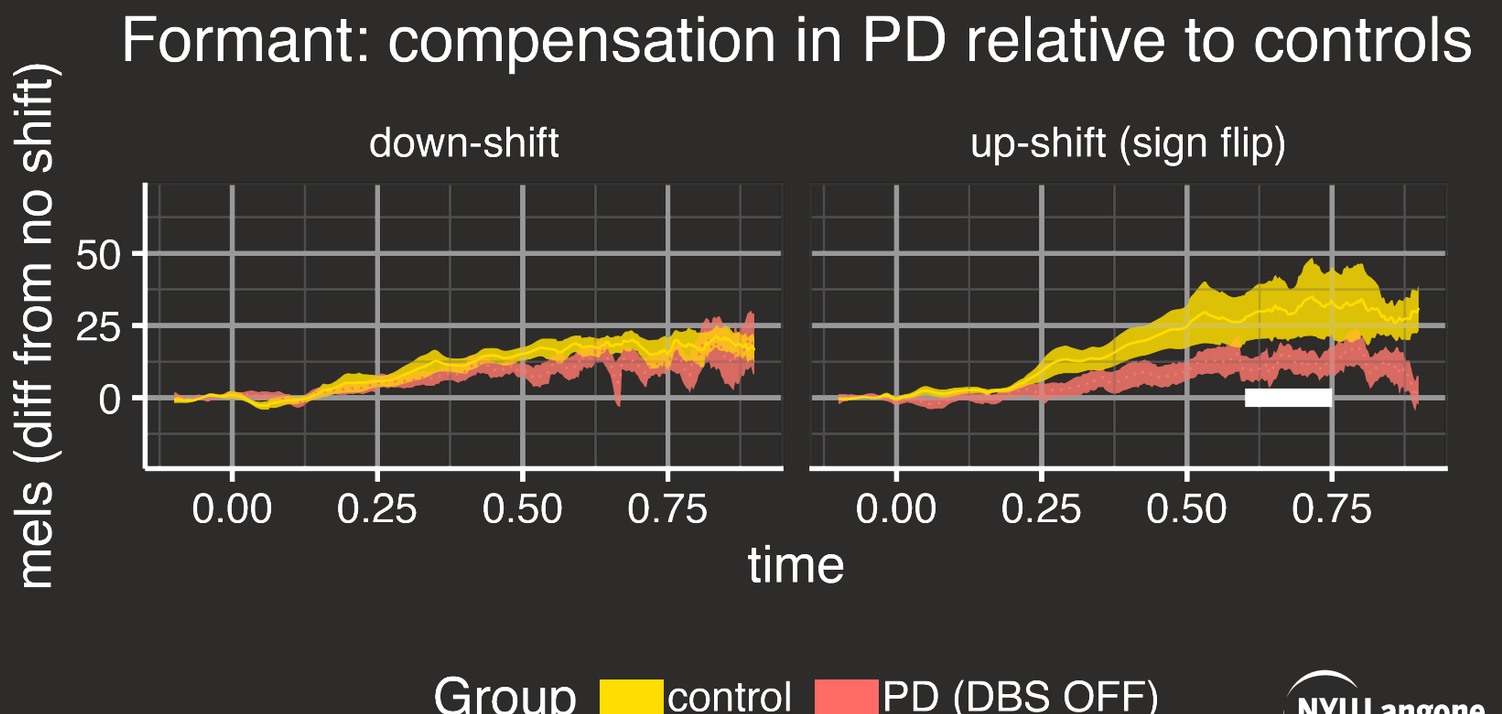
| group | direction | compensators |
|---|---|---|
| **control** | down | 100% (9/9) |
| **PD** | down | 82.6% (38/46) |
| **control** | up | 100% (9/9) |
| **PD** | up | 69.6% (32/46) |



# Formant

- Controls:
  - More likely to be compensators.
- Comparison with PD (DBS OFF):
  - Down:
    - No difference
  - Up:
    - **Specific window: 600-750 ms**

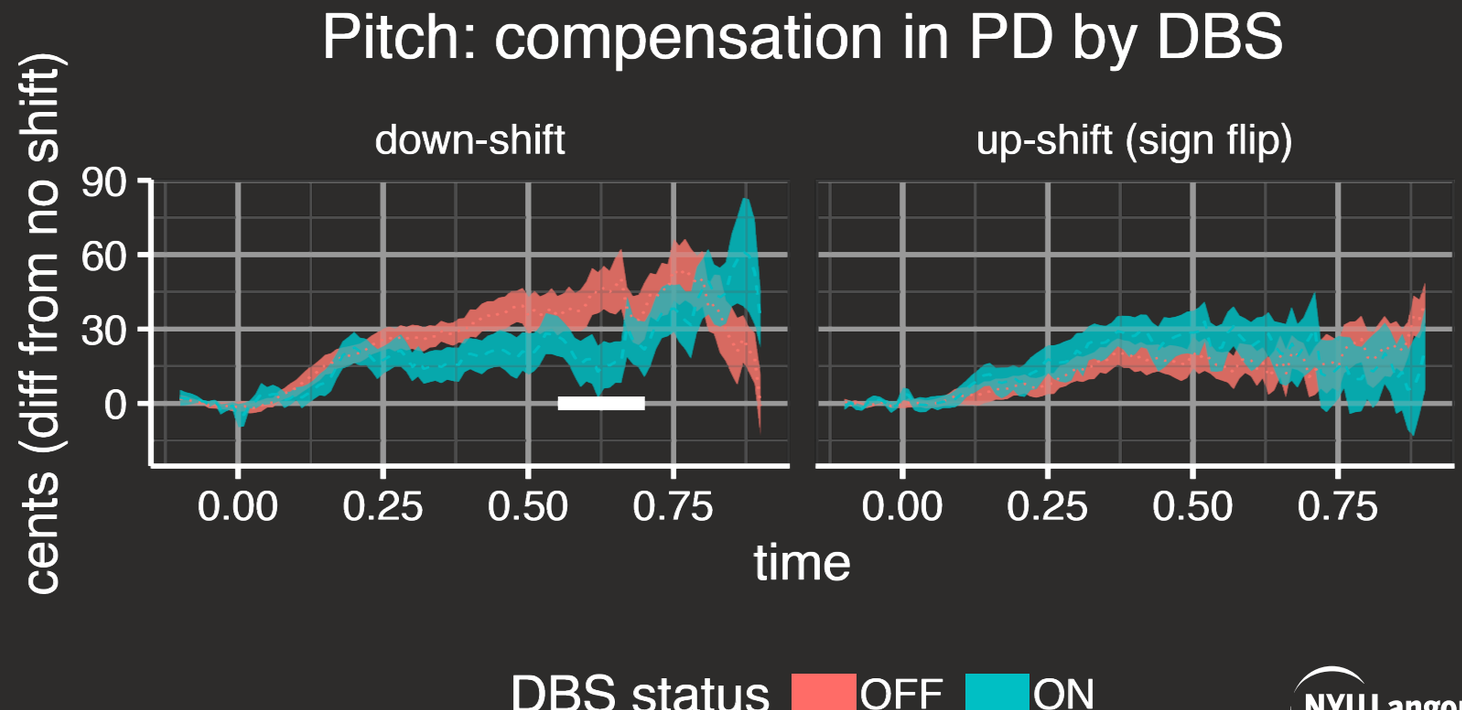
| group | direction | compensators |
|---|---|---|
| control | down | 88.9% (8/9) |
| PD | down | 69.6% (32/46) |
| control | up | 88.9% (8/9) |
| PD | up | 76.1% (35/46) |



# Pitch

- DBS ON vs OFF:
  - No clear pattern of compensators
- Comparison within PD (ON vs OFF):
  - Down:
    - **Specific window: 550-700 ms**
  - Up:
    - No difference

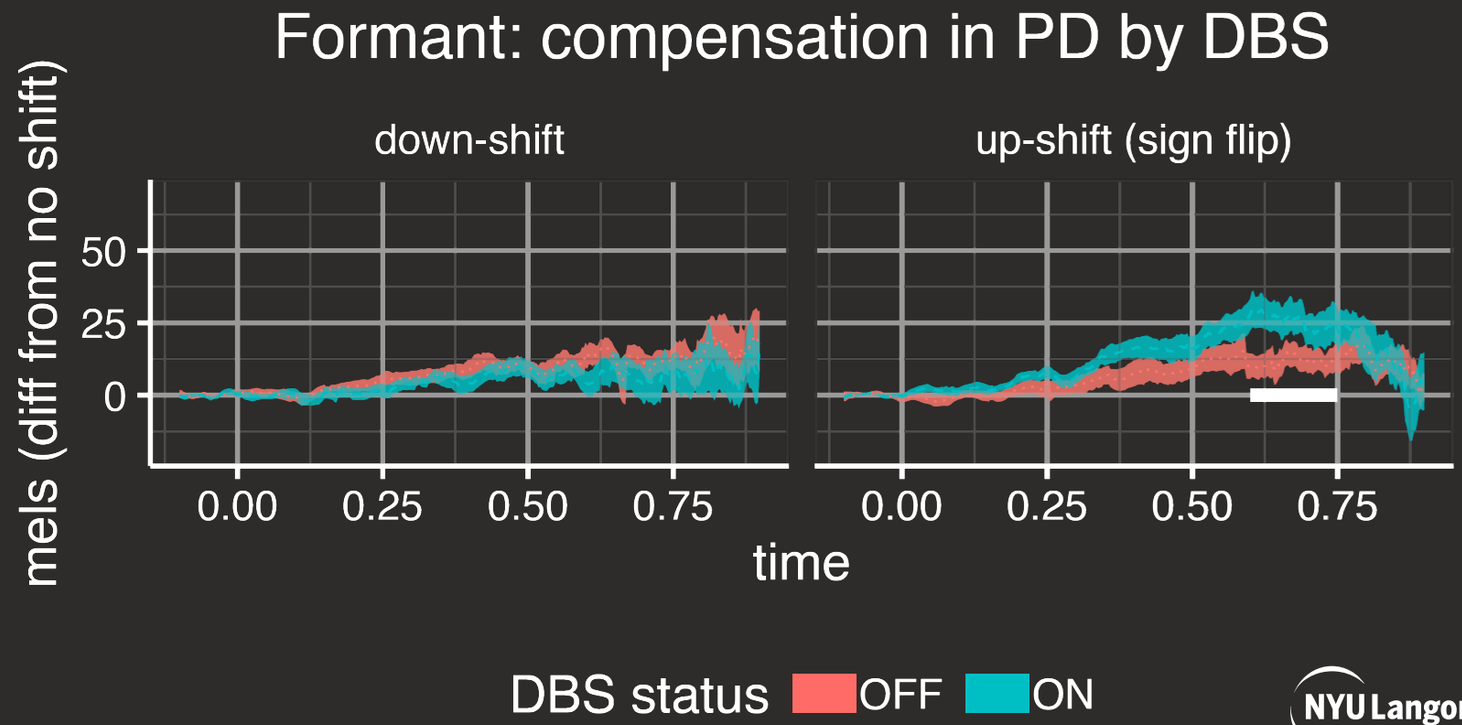
| DBS | direction | compensators |
|---|---|---|
| OFF | down | 91.3% (21/23) |
| ON | down | 73.9% (17/23) |
| OFF | up | 65.2% (15/23) |
| ON | up | 73.9% (17/23) |



# Formant

- DBS ON vs OFF:
  - No clear pattern of compensators.
- Comparison within PD (ON vs OFF):
  - Down:
    - No difference
  - Up:
    - **Specific window: 600-750 ms**

| DBS | direction | compensators |
|---|---|---|
| OFF | down | 73.9% (17/23) |
| ON | down | 65.2% (15/23) |
| OFF | up | 69.6% (16/23) |
| ON | up | 82.6% (19/23) |



# Discussion

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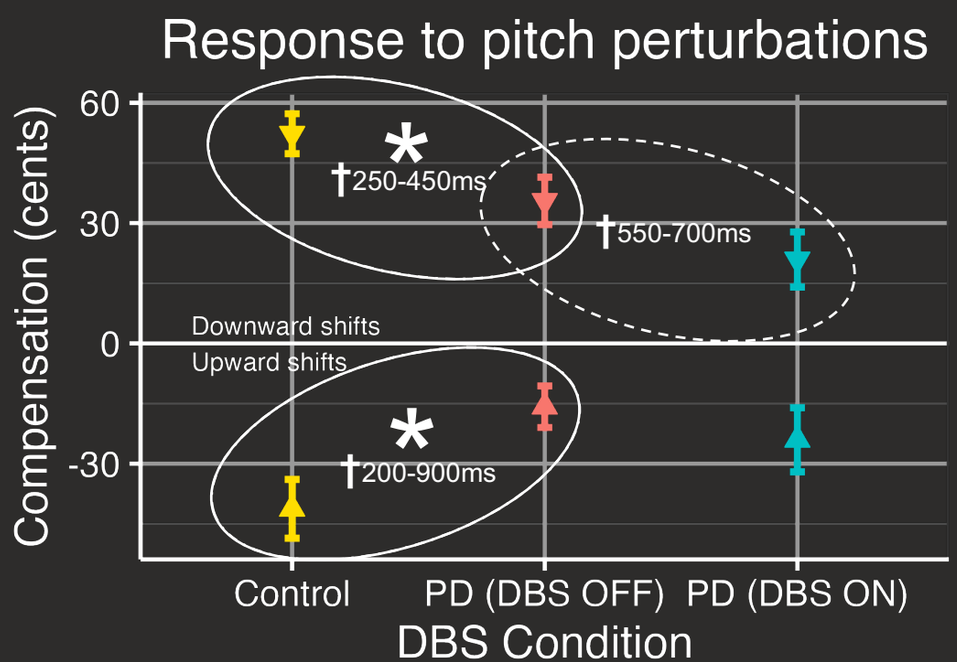
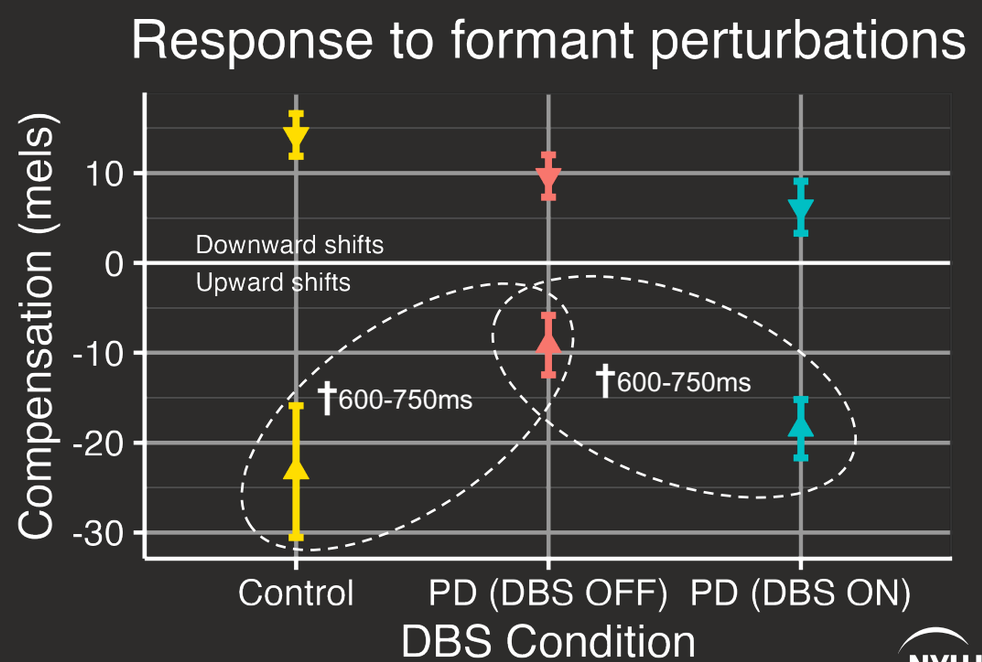
# Summary of patterns

- Plots show window from 250-750 ms post-stimulation onset.
  - Significance based on small-window tests (†)
  - Significance based on large-window tests (*)



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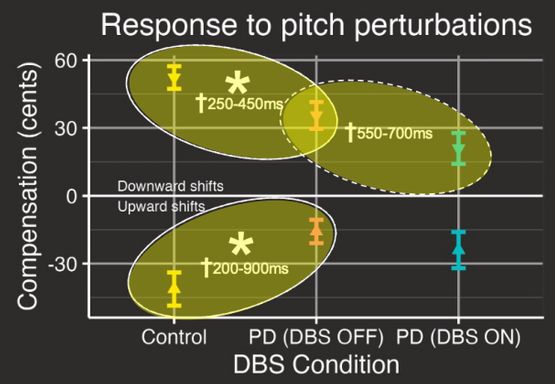
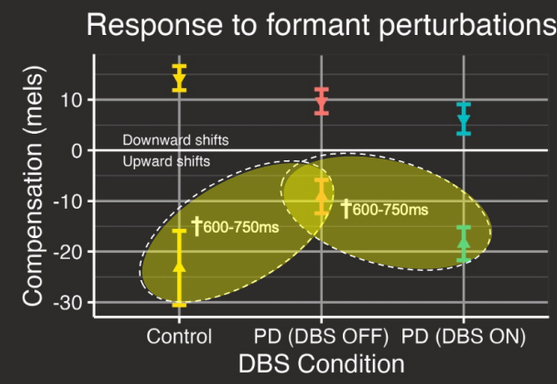
# Conclusion




- Patients with PD showed lower compensation than controls, suggesting compensatory *undershoot*.
  - **Pitch**: Robust difference for up- and down-shifts
  - **Formant**: Difference for up-shifts
- For patients with PD, turning DBS on leads to divergent changes for pitch vs. formants.
  - **Pitch**: already low compensation *reduced* more with DBS on [down-shift]
  - **Formant**: already low compensation *increased* closer to control levels with DBS on [up-shift]
- This pattern suggests that the cortical-basal ganglia motor circuit also regulates formant modulation, providing novel evidence for shared pathways for online modulation of laryngeal structures controlling pitch and articulatory structures controlling formants.



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# Clinical impact

- **Perioperative care**: Associate compensation patterns with individual patient characteristics, including disease factors, stimulation settings, and neural target.
  - Predicting which speech subsystems are likely to weaken will improve perioperative counseling.
- **Functional outcomes**: Compare compensation patterns with functional voice/articulation (voice quality, intelligibility) measures.
  - Identify real-world impact of sensorimotor challenges on communication.
- **Therapy tool**: *sustained* formant perturbation as a method of increasing vowel space
  - Applications toward a range of motor speech disorders:  apraxia, stuttering, and other dysarthrias

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# Thank you Flinker Lab!

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