# Kinematic evidence of centering during vowel production

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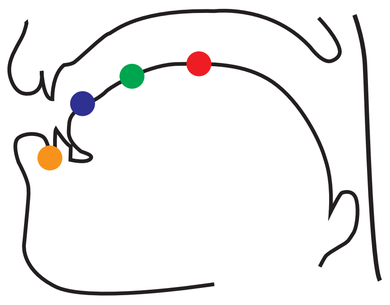
## Background

- Vowel productions which initially fall near the edge of the sound's distribution in F1/F2 space (for a given talker) exhibit movement towards the middle of the distribution over time, a phenomenon known as *centering* [1,2].
- Centering may be driven by auditory feedback, as it is sometimes reduced in masking noise [3].

1. **Is centering visible in speech articulation, as well as speech acoustics?**
2. **Is articulatory centering visible *prior to* acoustic onset, as predicted if centering relies at least partially on somatosensation, internal predictions [4] or increasing restrictions on variability at the planning level [5,6]?**

[1] Niziolek, C. A., Nagarajan, S. S., & Houde, J. F. (2013). What does motor efference copy represent? Evidence from speech production. *Journal of Neuroscience*, *33*(41), 16110–16116.
[2] Niziolek, C. A., & Kiran, S. (2018). Assessing speech correction abilities with acoustic analyses: Evidence of preserved online correction in persons with aphasia. *International Journal of Speech-Language Pathology*, *0*(0), 1–11.
[3] Niziolek, C. A., Nagarajan, S. S., & Houde, J. F. (2015). The contribution of auditory feedback to corrective movements in vowel formant trajectories. In T. S. C. for ICPhS 2015 (Ed.), *Proceedings of the 18th International Congress of Phonetic Sciences*. The University of Glasgow.
[4] Parrell, B., Ramanarayanan, V., Nagarajan, S., & Houde, J. (2019). The FACTS model of speech motor control: Fusing state estimation and task-based control. *PLOS Computational Biology*, *15*(9), e1007321.
[5] Keating, P. A. (1990). The window model of coarticulation: Articulatory evidence. In J. Kingston & M. E. Beckman (Eds.), *Papers in Laboratory Phonology I* (pp. 451–470). Cambridge University Press.
[6] Guenther, F. H. (2016). *Neural control of speech*. The MIT Press.

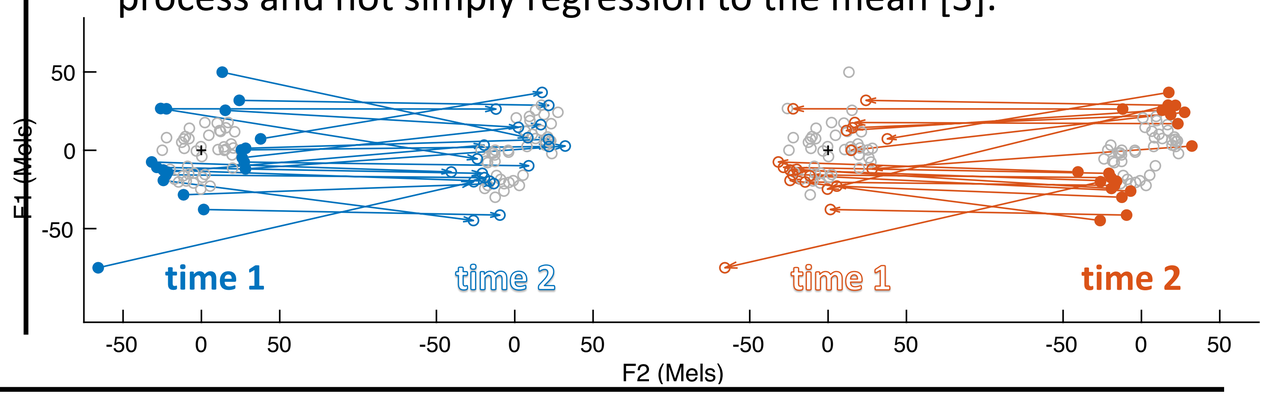
## Methods



- 2 participants (S1, S2)
- Sensors placed on **tongue tip**, **tongue body**, **tongue dorsum**, and jaw (lower incisors) and tracked with EMA (NDI WAVE).
- 60 repetitions each of *Edd*, *ebb*, *ad*, *abb*, and *shed* to test for effects of vowel, coda place of articulation, and onset.

## Centering

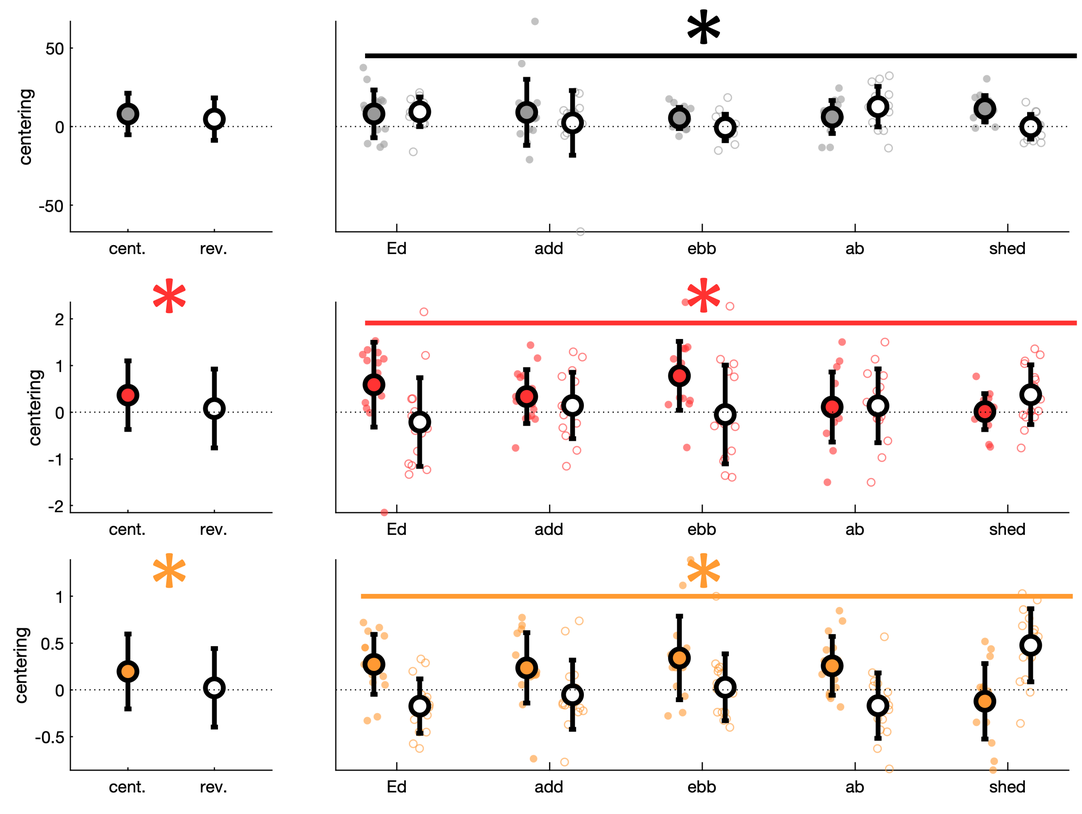
- **Centering**: the change in F1/F2 distance to overall median values from **time 1** (e.g., onset) to time 2 (e.g., midpoint) in *peripheral trials* (1/3 most distant from median at time 1).
- ***Reverse centering:*** the change in variability from **time 2** to time 1 for peripheral trials defined at time 2.
- Higher centering than reverse centering suggests an active process and not simply regression to the mean [3].




# S1

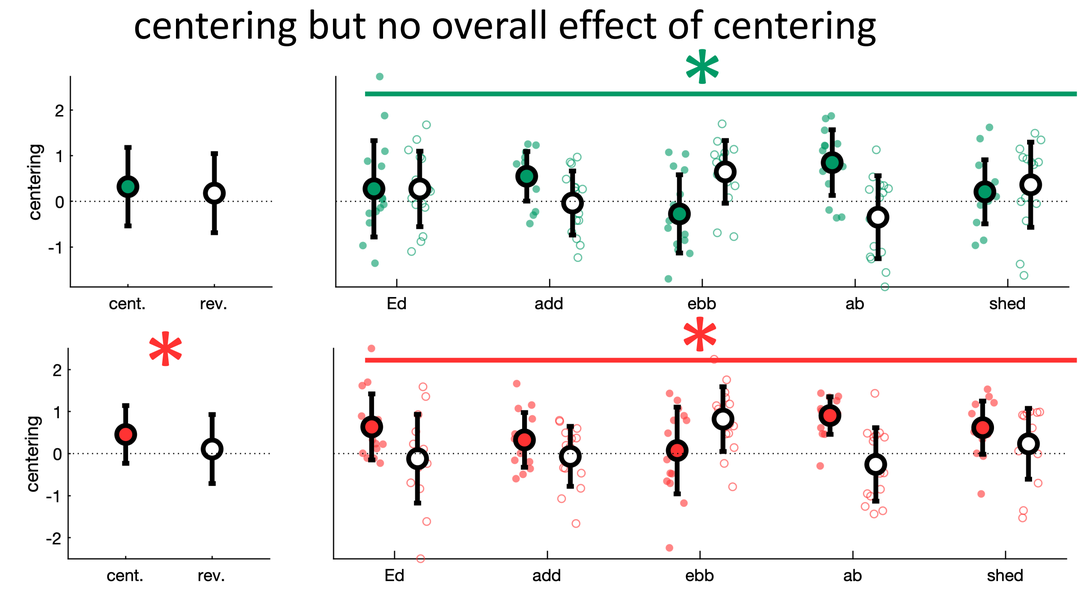
## Vowel onset (first 50 ms) to midpoint (middle 50%)

- No overall **acoustic centering**, but a significant interaction with word.
- Centering occurred in **tongue dorsum** and **jaw**, though variably across words.




## Pre-onset to post-onset

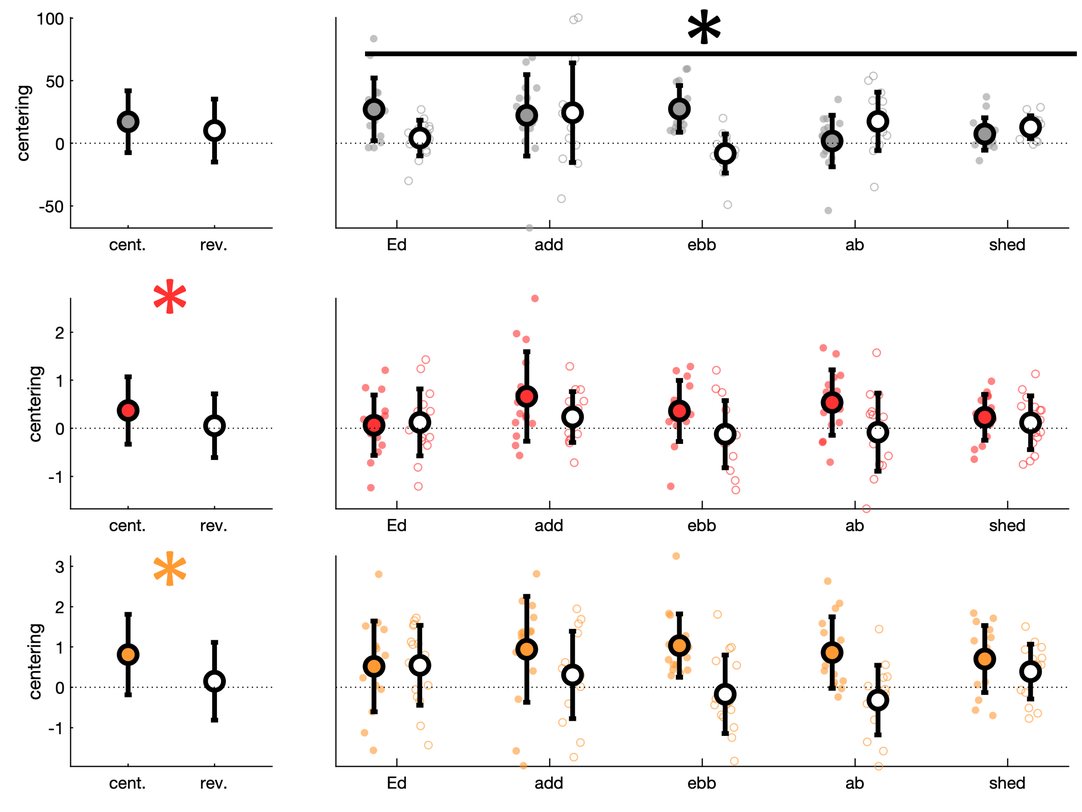
- Centering occurred in **tongue tip** and **tongue dorsum**, though variably across words.
- For the **tongue body**, there was a significant interaction between word and centering vs anti-centering but no overall effect of centering




# S2

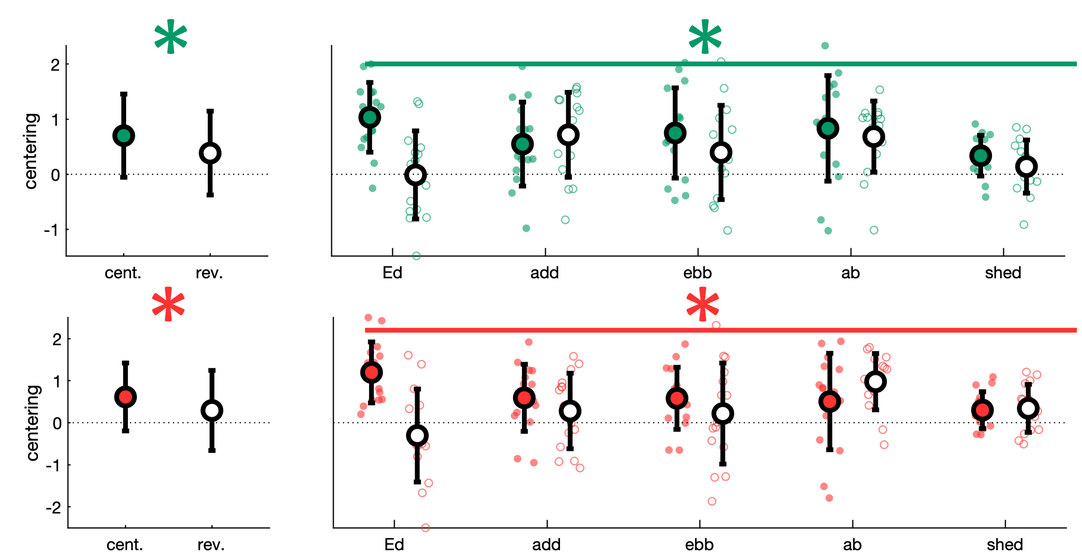
## Vowel onset (first 50 ms) to midpoint (middle 50%)

- No overall **acoustic centering**, but a significant interaction with word
- Consistent centering was found for the **tongue dorsum**, **jaw**, **tongue tip** and **tongue body**.




## Pre-onset to post-onset

- Centering occurred in **tongue body** and **tongue dorsum**, though variably across words.




## Conclusions

- We found limited evidence for centering in vowel formants, suggesting these speakers may be on the lower range of centering behavior.
- Despite this, we found significant evidence of centering in speech kinematics for both participants, most consistently in the tongue dorsum and jaw.
- We additionally found kinematic evidence for centering **prior** to vowel onset.
- This suggests that centering is driven, at least partly, by factors other than auditory feedback (e.g., somatosensory feedback, internal predictions, increasing restrictions on the permitted variability at vowel midpoint compared to vowel onset)