

**Title:** Behavioral and Neural Responses to External Alterations of Speech Variability (Exp 5)

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## Study Protocol

This study consists of three related behavioral paradigms aiming to test sensorimotor adaptation, a correlative analysis investigating the relationship between the outcome measurements from these three experiments, and several experiments seeking to modulate these outcome measures. Here we describe Experiment 5, which used magnetoencephalographic (MEG) imaging to will noninvasively measure auditory cortical activity evoked during speech production and playback.

Experiment 5 specific Methods: In each of 3 separate sessions (order counterbalanced across participants), participants produce and listen to playback of the stimulus words *ease*, *add*, *odd*, and *ooze* (these contain the same four vowels as in Aim 1, but start without a consonant to avoid movement artifacts in MEG). We compare behavioral and neural responses induced by exposure to the perturbation field.

- *Baseline phase:* 60 productions of each word to determine each vowel's target (center of distribution in F1/F2 space) and to measure baseline variability and centering. These 240 production trials will be interleaved with 240 perception trials where participants passively listen to speech audio recorded from production trials.
- *Exposure phase, Session A:* inward-pushing perturbation field. A perturbation pushes each trial toward the vowel target measured in the baseline phase. The perturbation magnitude is 50% of the distance between the current production and the target. This effectively reduces the perceived error.
- *Exposure phase, Session B:* outward-pushing perturbation field. A perturbation pushes each trial away from the vowel target measured in the baseline phase. The perturbation magnitude is 50% of the distance between the current production and the target. This effectively increases the perceived error.
- *Exposure phase, Session C:* no perturbation is given.
- *Test phase:* Identical to baseline phase.

  

- MEG procedure: MEG data will be collected using a 306-channel, whole-head Elekta VectorView MEG system (Elekta Neuromag, Helsinki, Finland) located at the Medical College of Wisconsin, where Prof. Niziolek maintains an ongoing collaboration for MEG data collection. Participants will wear insert headphones and perform the speaking tasks described above.
- Data analysis and outcome measurements: Behavioral outcome variables include 1) variability across trials in F1/F2 space (Fig 2C) and 2) centering, the reduction in variability from vowel onset to vowel midpoint. The MEG analysis measures participants' auditory sensitivity to self-produced variability, as well as how this sensitivity is modulated by external manipulations to variability during the exposure phase. As in our past work, MEG sensor data from passive listening trials will be localized to its auditory cortical sources, yielding a peak source voxel in each hemisphere. From these peak voxels, the "virtual source" time-course will be estimated from the MEG sensor data in both speaking and listening trials constrained by each subject's MRI. The dependent measure is the speaking-induced suppression (SIS), defined as the z-score reduction in average M100 amplitude in the speak condition compared with the listen condition. The M100 peak is defined as the peak activity between 75 and 150 ms after stimulus onset; peaks will be confirmed by visual inspection.
- Sample size with power analysis: We planned to test 35 participants across the 3 conditions; moving to a within-subjects design, we tested 15 participants in each of our 3 conditions for a total of 45 scanning sessions. This provides a power of slightly over 0.80

at  $\alpha = 0.05$  for detecting changes in variability (0.82,  $d = 0.44$ ) and centering (0.81,  $d = 0.43$ ) observed in our behavioral data. Our previous MEG data investigating differences in within-participant SIS magnitude between different speaking conditions showed larger effects of  $d = 1.2$  (mean z-score difference of 2.8).

## Statistical Analysis Plan

Experiment 5: Behavioral outcome variables include 1) variability across trials in F1/F2 space and 2) centering, the reduction in variability from vowel onset to vowel midpoint. The MEG analysis measures participants' auditory sensitivity to self-produced variability, as well as how this sensitivity is modulated by external manipulations to variability during the exposure phase. The dependent measure for sensitivity is the **speaking-induced suppression (SIS)**, defined as the z-score reduction in average M100 amplitude in the speak condition compared with the listen condition. The M100 peak is defined as the peak activity between 75 and 150 ms after stimulus onset; peaks will be confirmed by visual inspection. We planned to test 35 participants across the 3 conditions; moving to a within-subjects design, we tested 15 participants in each of our 3 conditions for a total of 45 scanning sessions. Given our preliminary data, this provides a power of 0.82 at  $\alpha = 0.05$  ( $d = 0.44$ ) for detecting differences in variability and a power of 0.81 at  $\alpha = 0.05$  ( $d = 0.43$ ) for detecting differences in centering. Our previous MEG data investigating differences in within-participant SIS magnitude between different speaking conditions showed larger effects of  $d = 1.2$  (mean z-score difference of 2.8).