Noninvasive neurostimulation of sensorimotor adaptation in speech production
Laura Haenchen, Ayoub Daliri, Sara Dougherty, Emily Thurston, Julia Chartrove, Frank Guenther, & Tyler Perrachione
Department of Speech, Language, & Hearing Sciences, Boston University

**tDCS Methods**

High-definition transcranial direct current stimulation (HD-tDCS): 6 electrodes (2 anodes, 4 cathodes) were placed at designated locations on the scalp targeting left ventral premotor / motor cortex. Participants received 2 mA of anodal stimulation during the task (≤ 20 minutes). Resistance at each channel was < 10 Ω.

**Procedure**

Stimuli: The words bed, dead, and head – presented in a random order.
Dependent measure: Participants read the target words aloud; their speech was recorded for acoustic analysis of F1 and F2.
Baseline phase: Participants heard unaltered auditory feedback.
Ramp phase: Participants heard a real-time resynthesized version of their speech using Audapter, with F1 shift increasing linearly from +0% to +30%.
Shift phase: Auditory feedback of speech with F1 always shifted by +30% of participants’ productions.
Return phase: Participants heard unaltered feedback.

**Design**

A. Overview

![Flowchart of experimental design](image)

B. Adaptation paradigm

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<tr>
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<th>Baseline (5 Trials)</th>
<th>Ramp (5 Trials)</th>
<th>Shift (5 Trials)</th>
<th>Return (5 Trials)</th>
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<td>F1 +0%</td>
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C. Perturbation setup

![Diagram of perturbation setup](image)

**Adaptation Screening**

Participants: N = 18 right-handed, native speakers of American English, age 18-29 years and without speech, language, or hearing deficits completed the tDCS study.
Exclusion: (i) Participants who did not demonstrate an adaptation effect in response to auditory feedback perturbation of at least 5% during the second half of the “stay” phase of the screening visit; (ii) Participants who did not complete all sessions; (iii) Participants who declined to undergo tDCS.

**Results**

▲ Mixed-effects linear models revealed that Anodal stimulation resulted in significantly greater F1 adaptation magnitude compared to Sham during the perturbation phase \([t = -6.53, p < 0.001]\), and a greater increase in adaptation over time \([t = -2.48, p = 0.013]\).
▲ There was no effect of stimulation on F1 recovery or recovery time \([both p ≥ 0.22]\).
▼ There was no effect of stimulation on F2 during perturbation \([both p ≥ 0.50]\), but withdrawal of perturbation resulted in instabilities in F2 during sham, but not anodal stimulation: \([t = -3.55, p < 0.001]\).

**Acknowledgments**

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**Summary**

Repetitive exposure to disparity between motor plans and auditory feedback during speech production results in auditory-motor adaptation. Perturbing F1 in auditory feedback during speech production results in a concomitant and proportional change in the produced F1. Transcranial direct-current stimulation (tDCS) can be used to alter neural excitability in focal areas of the brain. Participants read target words aloud as their auditory feedback was perturbed in real time by raising F1 by 30%. Participants’ speech showed an increasing magnitude of adaptation of F1 over time during anodal tDCS compared to sham. tDCS affects the behavioral response during auditory-motor adaptation, which may have implications for sensorimotor training in speech disorders.