Noninvasive brain stimulation to facilitate foreign language speech-sound learning in low-aptitude learners

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Summary

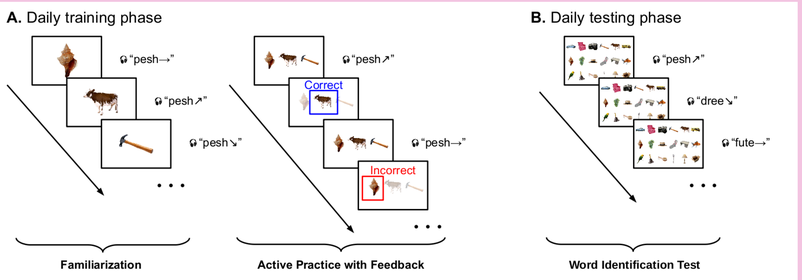
- Pitch-contour perception predicts the ability to learn to use lexical tones.
- English-speakers with low pitch-contour perception abilities learned a vocabulary incorporating lexical tone minimal contrasts.
- Participants received either anodal transcranial direct current stimulation (tDCS) or sham stimulation during training.
- Active brain stimulation improved learning for some low-aptitude learners, who performed as well as high-aptitude learners do.
- Sham stimulation did not improve learning in low-aptitude learners.
- Noninvasive brain stimulation may help recover speech-sound learning abilities in listeners with low pre-training perceptual aptitudes.

Lexical Tone Vocabulary Training

Pitch Contour Perception Test
The PCPT is a strong predictor of how well adults can learn words with lexical tones like those in Mandarin Chinese (Wong & Perrachione, 2007; Perrachione et al. 2011). Listeners hear isolated vowels with a superimposed pitch contour and, in a 2AFC task, match the pitch they hear to a representative arrow indicating the pitch contour direction (rising, falling, or level). Participants who score >75% on this test successfully learn a tone language vocabulary; those who score lower do not learn the vocabulary.

Participants
Young adults scoring ≤ 70% on the PCPT (N = 16) with normal speech, language, hearing, and cognitive abilities were assigned to undergo tone-language vocabulary training while receiving anodal tDCS (n = 8) or sham tDCS (n = 8).

Lexical tone vocabulary training design

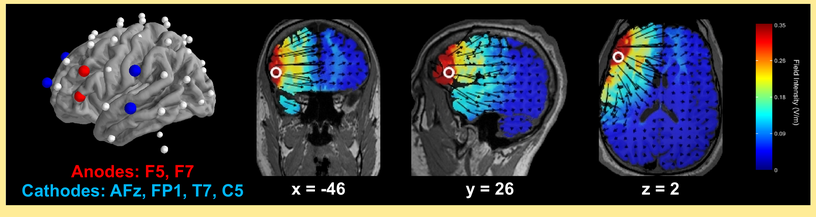


Stimuli
Participants learned a vocabulary of 18 words: 6 syllables each superimposed with 3 Mandarin lexical tones (level, rising, falling) spoken by 4 different talkers (2 male, 2 female). Each word (syllable + tone contour) was uniquely associated with a photograph of an object.

Procedure
Training took place in 15-20 minute sessions on 4 consecutive days. **(A)** Participants were familiarized with the words by hearing each spoken in isolation while the corresponding picture was on the screen. Stimuli were familiarized in minimal triplets by tone. All talkers were intermixed during training in a high-variability design. Participants then practiced identifying the words in each minimal triplet with corrective feedback. **(B)** Learning progress was measured on a daily word identification test with all 72 tokens (6 syllables × 3 tones × 4 talkers). After the word identification test on day 4, listeners also completed a generalization test, comprised of the same 18 words spoken by 2 new, untrained talkers.

Noninvasive Brain Stimulation

HD-tDCS stimulation location and current flow maps



Noninvasive brain stimulation (high-definition transcranial direct current stimulation, HD-tDCS; Datta et al. 2009; Villamar et al., 2013) was applied over left IFG with anodal polarity at 2mA. Participants were randomly assigned to anodal or "sham" stimulation conditions. Anodal stimulation lasted the full course of each training and testing session (~15-20 min). Sham stimulation had the same setup as anodal stimulation, but no electric current was delivered during training. Participants were blind to their stimulation condition. Locations of stimulating (anodal) and return (cathodal) electrodes and maps of cerebral current flow are shown above. These locations were determined based on neuroimaging work suggesting the importance of left IFG in foreign language learning (Wong, Perrachione, & Parrish, 2007; Myers, 2014; Dayan et al., 838).

Results

Learning with Low Aptitude for Pitch Perception
Extensive work has shown that pitch perception abilities constrain the ability to learn a tone language as a second language (Wong & Perrachione, 2007; Bowles et al., 2016).

(A) Individual traces for high-aptitude learners (>75% on PCPT) are shown vs. low-aptitude learners (<75%) on a high-variability training task (Perrachione et al., 2011). No low-aptitude learners attain more than 60%.

Low-Aptitude Learning with Brain Stimulation
Nearly half of the low-aptitude learners who received active tDCS performed better than expected based on their PCPT score; they have similar learning rates and outcomes to those of high-aptitude learners.

(B) Individual traces for low-aptitude learners (all <70% on PCPT) receiving anodal or sham brain stimulation. Several low-aptitude learners display marked improvement compared to no stimulation; however, stimulation does not appear to improve performance for some low-aptitude learners. All of the low-aptitude learners who received sham stimulation learned the vocabulary poorly, as expected.

(C) Average learning trajectories of high- and low-aptitude learners from Perrachione et al. (2011) juxtaposed with low-aptitude learners receiving anodal or sham stimulation from the present study. On average, low-aptitude learners receiving brain stimulation exceed learning expectations based on their pre-training pitch perception abilities.

Learning by Group and Session:
(generalized linear mixed model with df = 15)
- **Group:** t = -0.06, p = 0.95
- **Session:** t = 8.67, p < 0.0001 **
- **Group × Session:** t = 2.25, p < 0.04 *

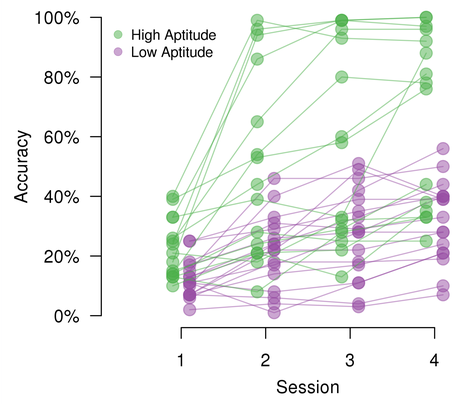
(D) Points and distributions showing how vocabulary knowledge generalizes to novel talkers. Learners with anodal brain stimulation show better generalization abilities than those with sham stimulation.

Generalization, Anodal vs. Sham:
- **Anodal Group:** 34.3% - 85.2% (mean = 48.2%)
- **Sham Group:** 23.1% - 39.8% (mean = 34.1%)
- two-sample t_{14} = 2.21, p < 0.05 *
- Cohen's d = 1.18

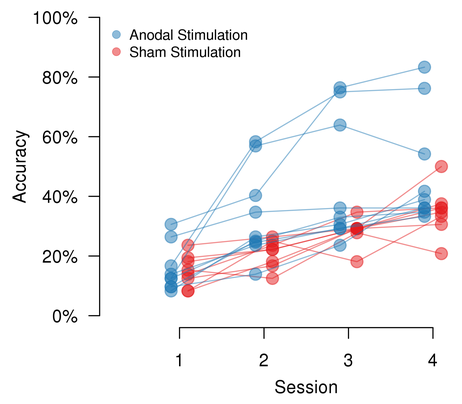
No group difference in pre-training PCPT scores.
- **Anodal Group:** 58% - 70% (mean = 64.8%)
- **Sham Group:** 58% - 69% (mean = 65.1%)
- two-sample t_{15} = 0.18, p = 0.86

Correlation between Accuracy and PCPT scores:
- **Anodal Group:** Spearman's rho = -0.18, p = 0.64
- **Sham Group:** Spearman's rho = 0.69, p = 0.06

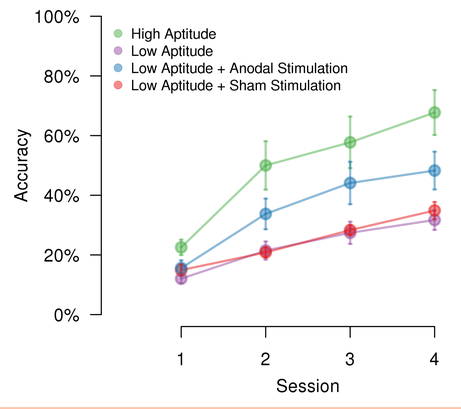
A. Learners with high pitch-contour perception abilities have better aptitude for learning lexical tones in words



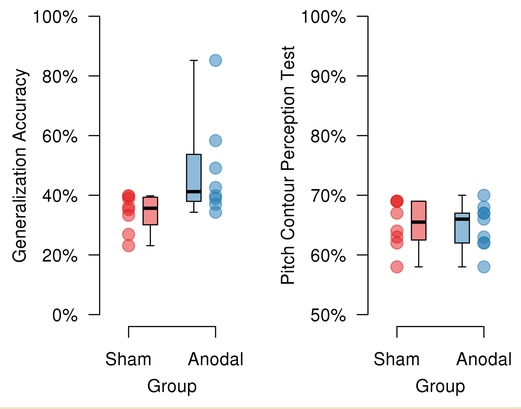
B. Anodal tDCS stimulation improves lexical tone vocabulary learning in a number of low-aptitude learners



C. Low-aptitude learners receiving anodal stimulation show greater than expected learning; sham stimulation has no effect



D. Better generalization to novel talkers after training with anodal stimulation; no group difference in pre-training aptitude



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The Pitch Contour Perception Test is available online as free, open-source: http://hdl.handle.net/2144/16461

Acknowledgments

We thank Emily Thurston, Terri Scott, Lauren Gustainis, Jennifer Golditch, and Deirdre McLaughlin for their assistance

This work was supported in part by NIH (NIDCD) grant R03 DC014045 and Brain and Behavior Research Foundation grant 23503 to TP. EH was supported in part by an award from the BU Undergraduate Research Opportunities Program.

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