Phonological contrasts are maintained despite neutralization: an intracranial EEG study

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Introduction

In English, alveolar stops **d** and **t** neutralize to alveolar tap **r** (=dx) when they occur intervocalically following a stressed syllable.

(Kahn 1980, Warner et al. 2009, Warner & Tucker 2011, Braver 2014)

$$\{\,\mathbf{d, t}\,\} \rightarrow \mathbf{r} \,/\, \mathbf{\acute{V}\_V}$$

Although the acoustic difference is neutralized, phonological theory posits that taps derived from phonemic t, (**dx_t**) remain *phonologically distinct* from taps derived from phonemic d (**dx_d**). (Kenstowicz & Kisseberth 1979)

Hypothesis

Chang et al. (2010), Mesgarani et al. (2014), and others have shown that high gamma activity (HG: ~70-150Hz) reflects both categorical and gradient properties of sounds during speech perception.

Does HG activity also reflect language-specific phonological contrast?

Predictions.
HG activity will support the existence of both "phonetic sites" and "phonological sites".

HG activity	surface similarity	underlying similarity
dx_t & **dx_d**	same	different
dx_t & **t**	different	same

Comparisons

Speech comparison.
- Epochs of speech vs. epochs of silence.
- Establishes which electrodes are speech-selective.

Phonetic & phonological comparisons.
- **t** epochs vs. **dx_t** epochs vs. **dx_d** epochs.
- Establishes which electrodes are "phonetic sites" and which electrodes are "phonological sites".

Stimuli

Excerpts from Buckeye Corpus of conversational US English speech.
- 27 different speakers.
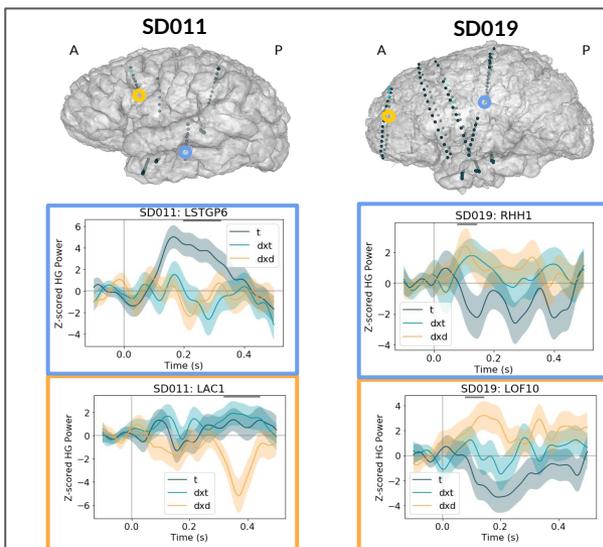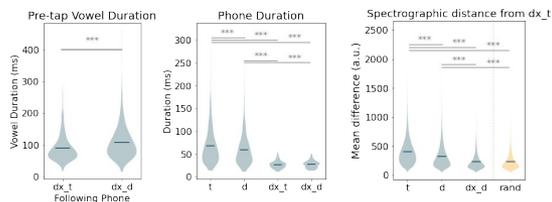- on average 23 of each target type {**t**, **dx_t**, **dx_d**} per excerpt

Acoustics.

t has longer duration and higher center of gravity than **dx_t** & **dx_d**.
(Derrick & Schultz 2013)

Acoustically, **dx_t** & **dx_d** are more similar to one another than to **t**.
Horizontal grey lines indicate significant differences (p<0.05).

SD011   SD019

A   P   A   P

Top row. Non-selective electrodes in **dark green**; electrodes with significant phonetic comparison in **blue**; electrodes with significant phonological comparison in **orange**. Circle colors corresponds to box outline colors of plots below.

Bottom rows. Example electrodes showing significant phonetic and phonological comparisons. Mean z-scored HGP plotted in solid lines with ±SEM shaded. Time points with significant comparisons indicated by horizontal grey line at the top of each plot (p<0.01).
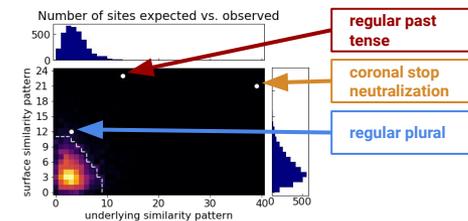
Methods

Participants.
10 have been recorded to date
1235 electrodes total
- 89 speech selective
  - 21 with phonetic-t pattern
  - 39 with phonological-t pattern

A   P

6 participants warped to template
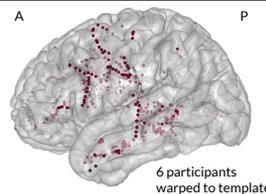
Task. Patients listen to excerpts from the Buckeye Corpus
Each participant listened to at least 14 excerpts

Data Pre-processing.
High gamma power (HGP: 70-150Hz) extracted with Hilbert transform
Segmented into peri-stimulus epochs (-100ms, 500ms) aligned to the onset of the target phone
z-scored relative to 100ms baseline

Analysis. Significance assessed for each comparison using sliding-window one-way ANOVA (100ms window size, 50ms step) followed by Tukey's HSD.

Results

- More sites sensitive to **surface similarity** than expected by chance
- More sites sensitive to **underlying similarity** than expected by chance
- Similar results also observed for morphophonological comparisons:
  - regular past tense: word-final d vs. past tense d vs. past tense t
  - regular plural: word-final z vs. plural z vs. plural s

Statistical Control

Expected Distribution:
- 3,500 arbitrary pairs (A, B)
- arbitrary split of one phone (A, B_x, B_y)
- ANOVA to test for underlying similarity vs. surface similarity pattern


- Heat map represents expected distribution of sites that exhibit surface vs. underlying similarity
- Dotted white line indicates values that have 5% probability of occurring
- Phonologically principled comparisons lie outside of the expected distribution

Discussion

- Both acoustic and phonological contrast are maintained during passive listening to natural speech.
- Timing of contrast maintenance varies across sites.
- Posterior phonetic sites are consistent with previous work (Mesgarani et al. 2014, Hullett et al. 2016).
- Phonological sites may be consistent with work showing engagement of frontal areas during phonological tasks involving segmentation (Burton 2001) and phonetic competition (Xie & Myers 2018).

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