ERP-evidence for laryngeal underspecification in English: A mismatch negativity study

In this study, we will show that there is neurobiological evidence in favor of the view that there is laryngeal under-specification in English. The study adds to the growing literature that shows evidence of underspecification in phonological representations (Eulitz & Lahiri, 2004).

Recent research in phonological theory has shown that there are compelling reasons to believe that voiceless stops in English are underlyingly specified for the feature [spread glottis] (1a), while voiced stops in English are underlyingly underspecified for laryngeal features (1b) (Iverson & Salmons, 1995). With respect to all other phonological features, the two sets of sounds have the same specifications at each place of articulation. Thus, the phonological features of the voiceless stop 't' are a super-set of the phonological features of the voiced stop 'd'.

1. a. Voiceless Stops
t
|
[+Spread Glottis]

b. Voiced stops
d

(Eulitz & Lahiri, 2004) show evidence that the Mismatch Negativity (MMN) paradigm can be used to address questions of underspecification of lexical representations, in particular with vowel features. In this paradigm, a "standard" sound stimulus is presented with high frequency, interspersed with a less frequently occurring, "oddball" sound stimulus (e.g., t-t-t-t-t-t-d-t-t-t-t-t-t-d). The "oddball" or "deviant" stimulus, if different, typically elicits a less positive deflection in the P2 auditory component (between 100-300ms after stimulus onset) at fronto-central electrode sites. The difference in amplitude between standards and deviants is typically represented by subtracting the deviant waveform from the standard waveform, resulting in a Mismatch Negativity.

(Eulitz & Lahiri, 2004) argue that a less (featurally-)specified deviant can produce a mismatch to a more (featurally-)specified standard, but a more (featurally-)specified deviant does not produce a mismatch to a less (featurally-)specified standard. Given the laryngeal underspecification theory of stops in English in (1), this predicts that when a set of standard [t]'s is followed by a deviant [d], there will be a mismatch, because the [d] is less specified than a [t]. On the other hand, when a set of standard [d]'s is followed by a deviant [t], there will be no mismatch, because the [t] is more specified than a [d]. We tested this prediction in an MMN study utilizing the modified oddball paradigm of (Phillips *et al.*, 2000), which arguably taps underlying phonological representations rather than just acoustic representations.

Method: 23 subjects (10 males) participated, who all reported normal hearing and English as a first language (mean age 23.5, SD 5.6). 3 subjects were left-handed. The stimuli for the experiment were synthesized on the low level Klatt speech synthesizer with the parameters described for voiced and voiceless alveolar stops in (Phillips *et al.*, 2000). They were all tokens lasting 290 ms and varied only along the VOT dimension (along steps of 5ms VOT increases).

Subjects were presented with two blocks of 700 standards and 100 standards, with each block presenting standards and deviants in pseudo-randomized order. 15 subjects heard [t] as a standard in the first block and 9 subjects heard [d] as a standard in the first block. Standards and deviants were each randomly sampled from four VOT versions, specified so that the VOTs were at most 15ms shorter or longer that each subject's VOT discrimination function for the 10 stimuli (measured before the experiment). The inter-stimulus-interval was varied continuously (mean: 903ms; SD: 80ms). There was an additional distractor task of identifying the gender of the voice of 50 trials of 'ba', interspersed amongst the stimuli to ensure that all subjects were more or less uniform in how they directed their attention to the stimulus stream. The EEG was acquired inside

a soundproof booth with a 128 channel Electrical Geodesics, and experimental control and behavioral response collection was done with E-Prime software. The experiment was a mixed factorial design with 2 (deviant/standard) × 2 (t as standard vs. d as standard) within-subject factors and 2 (t as standard in first block vs. d as standard in first block) between-subject factors.

Results: EEG data were segmented into 800ms epochs with a 200ms baseline period. Trials with artifacts were removed; bad channels were replaced; a single average per cell was computed with baseline correction for each subject, and referenced to the average voltage. Difference waves were computed for all comparisons (deviant T minus standard D, deviant D minus standard T, deviant D minis standard D and deviant T minus standard T). We here present only the descriptive statistics for the results.

We measured the MMN effect at electrode Fcz (fronto-central electrode). When comparing deviant D to standard T, the difference peaks at 236ms, with magnitude -1.4mV. When comparing deviant T to standard D, the difference peaks at 153ms, with magnitude -0.7mV. Thus, the mean mismatch is greater in magnitude at Fcz for D as deviant (although later in time), as predicted by the Eulitz & Lahiri account. We also observed a clear late discriminative negativity (LDN) - often assumed to be triggered when a salient deviant stimulus reaches the level of attention (Shestakova *et al.*, 2003) - to D as deviant, which was absent for T as deviant (Figure 1). This is a large negative going wave at anterior electrode sites to the deviant stimulus, in the 300-500ms range.

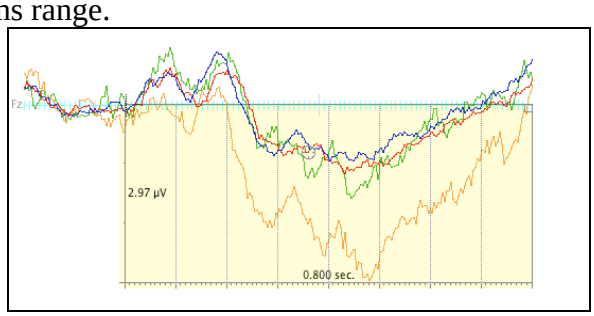

Figure 1: Late Negativity ERP: deviant D=orange; standard D=blue; standard T=red; deviant T=green.

Conclusion: Both the MMN data and the LDN data appear to bear out the prediction that there is an asymmetry between /t/ and /d/ in terms of the magnitude of the brain response when one of these sounds is used as a deviant stimulus in an MMN-experiment. This provides neurophysiological evidence for the (laryngeal) underspecification theory.

References

Ceponien, R., Lepistö, T., Soininen, M., Aronen, E., Alku, P., & Näätänen, R. (2004). Event-related potentials associated with sound discrimination versus novelty detection in children. *Psychophysiology, 41*(1), 130-141.

Eulitz, C., & Lahiri, A. (2004). Neurobiological Evidence for Abstract Phonological Representations in the Mental Lexicon during Speech Recognition. *J. Cogn. Neurosci., 16*(4), 577-583.

Iverson, G. K., & Salmons, J. C. (1995). Aspiration and Laryngeal Representation in Germanic. *Phonology, 12*, 369-396.

Phillips, C., Pellathy, T., Marantz, A., Yellin, E., Wexler, K., Poeppel, D., McGinnis, M., & Roberts, T. (2000). Auditory Cortex Accesses Phonological Categories: An MEG Mismatch Study. *Journal of Cognitive Neuroscience, 12*(6), 1038-1055.

Shestakova, A., Huotilainen, M., Ceponiene, R., & Cheour, M. (2003). Event-related potentials associated with second language learning in children. *Clinical Neurophysiology, 114*(8), 1507-1512.