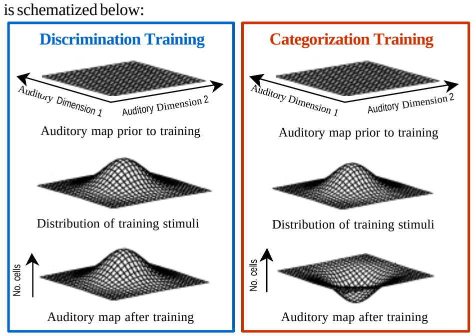
737.14 The Representation of Prototypical and Non-Prototypical Vowels in Peri-Sylvian Cortical Areas

Frank H. Guenther[1,2], Alfonso Nieto-Castanon[1], Jason A. Tourville[1], and Satrajit S. Ghosh[1]

[1]*Department of Cognitive and Neural Systems, Boston University.* [2]*Speech Communication Group, Research Laboratory of Electronics, Massachusetts Institute of Technology.*

INTRODUCTION. It is well known that our ability to discriminate speech-like sounds is not uniform throughout acoustic space. For example, listeners are typically more sensitive to between-category differences than within-category differences, a phenomenon referred to as ***categorical perception***. A heavily discussed example of auditory space warping is the ***perceptual magnet effect*** (Kuhl, 1991), in which prototypical examples of a vowel are more difficult to discriminate from each other than non-prototypical examples. This poster describes the results of an fMRI study investigating the representation of prototypical and non-prototypical examples of the vowel /i/. The study also acts as a test of neural network models of the perceptual magnet effect and of the effects of categorization training on sensory representations in cortex.

EFFECTS OF CATEGORIZATION TRAINING ON CORTICAL REPRESENTATIONS. Previous research has demonstrated that discrimination training with stimuli, including auditory stimuli, leads to an increase in the size of the cortical representation of these stimuli in sensory cortical areas. For example, Recanzone, Schreiner, and Merzenich (1993) performed a single-cell recording experiment in monkeys and reported an increase in the auditory cortical area representing tones that were used in a discrimination task, along with an increase in the monkey's ability to discriminate these tones. In a psychophysical study involving novel auditory stimuli, Guenther, Husain, Cohen, and Shinn-Cunningham (1999) showed that, whereas **discrimination training** with a set of stimuli leads to an *increase* in discriminability of these stimuli in humans, **categorization training** (in which subjects learn to treat several stimuli as members of the same category) leads to a ***decrease*** in discriminability for the trained stimuli. Guenther et al. hypothesized that this decreased discriminability with categorization training was the result of a decrease in the size of the auditory cortical representation for the training stimuli. This hypothesis is schematized below:

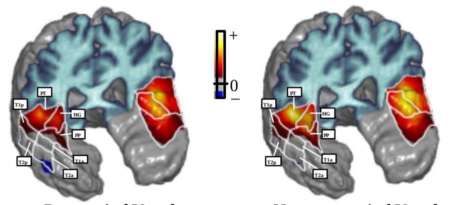


According to Guenther et al. (1999), the perceptual magnet effect for vowels (see Introduction) is the result of vowel category training on these sounds in infancy, leading to a decreased auditory cortical representation for prototypical vowel sounds as in the right half of the figure above. Earlier proposals had attributed the magnet effect to neural map formation properties in auditory cortex (Bauer, Der, and Herrmann, 1996; Guenther and Gjaja, 1996). The hypothesis schematized above (right half) is most similar to the Bauer et al. proposal. The purpose of the current study was to test these hypotheses using functional magnetic resonance imaging (fMRI).

METHODS. Nine subjects ages 18-50 with American English as a first language were scanned while listening to blocks of prototypical examples of the vowel /i/ (**P**) or non-prototypical vowels (**NP**). 4-8 six-minute functional runs were obtained for each subject, together with a whole brain structural image, on a 1.5T GE Signa scanner. **Preprocessing:** Individual functional runs were realigned (motion-corrected) using rigid body transformations to the first image in each scan, then coregistered with a structural T1 scan for each subject. Two runs were rejected for scanner data collection problems not detected during scanning. The remaining runs were visually inspected to meet noise and residual motion criteria, then tested for paradigm-correlated observed motion. Three runs showed excessive correlated motion and were thus removed from the analysis. Structural T1 images were parcellated individually for each subject to define 10 brain regions of interest (ROIs) on the basis of anatomical markers according to the procedure described by Caviness et al. (1996). The use of this parcellation procedure for each individual avoids the need for spatial averaging of the SPMs (and the subsequent loss of spatial resolution). The ROIs were ten peri-sylvian cortical areas, including areas known to become active during perceptual processing of auditory speech stimuli: Heschl's gyrus (H1), parietal operculum (PO), planum polare (PP), planum temporale (PT), anterior and posterior supramarginal gyrus (SGa, SGp), anterior and posterior superior temporal gyrus (T1a, T1p), and anterior and posterior middle temporal gyrus (T2a, T2p). **Preliminary analysis:** Data reduction was applied to each ROI to obtain one temporal activation profile characterizing the response of all voxels within a given region. This was defined for each subject as the first eigenvariate of the response of all voxels inside each ROI. **Hypothesis testing:** Significance of specific contrasts for each ROI activation profile were obtained using the general linear modeling (GLM) framework within the SPM statistical analysis package.

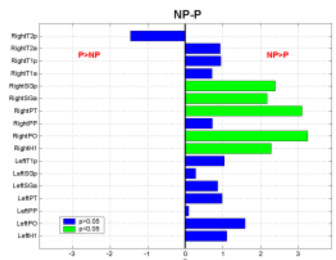
RESULTS.

Prototypical vs. non-prototypical vowels. Significant activation ($p<0.05$) in response to vowel sounds was found in 17 of the 20 ROIs (10 regions x 2 hemispheres = 20 ROIs). Only left T1a, left T2a, and left T2p did not show significant activation for either the P or NP stimulus. The averaged activations for auditory cortical regions on the temporal lobe and supratemporal plane for the P and NP conditions are shown at right. As predicted by the neural models of Guenther et al. (1999) and Bauer et al. (1996), less activation is seen for the prototypical vowel than the non-prototypical vowel in auditory cortical areas, thus supporting a simple explanation for the perceptual magnet effect: prototypical vowels are more difficult to discriminate from each other than non-prototypical vowels because they have a smaller cortical representation. It is commonly believed that, all else equal, stimuli with smaller cortical representations are harder to discriminate from each other than stimuli with larger cortical representations, presumably because representations involving more neurons are less susceptible to noise in the signals of individual neurons.

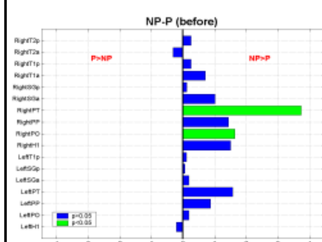


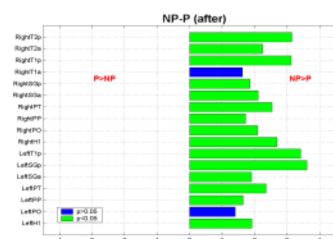
Prototypical Vowel Non-prototypical Vowel

The graph at right shows the difference in activation between the P and NP conditions for all ROIs that were significantly activated by the stimuli. Significant differences ($p<0.05$) were found in five right hemisphere regions: Heschl's gyrus (H1), anterior and posterior supramarginal gyrus (SGa, SGp), planum temporale (PT), and parietal operculum (PO). H1 includes primary auditory cortex and PT is a higher-order auditory cortical area. SG and PO are peri-sylvian parietal areas that have been implicated in phoneme discrimination (Caplan, Gow, and Makris, 1995).



Effects of Categorization Training. As described in the panel at left, the Guenther et al. (1999) model predicts that the reduced activation for prototypical vowels is the result of categorization training early in life. This prediction was supported by the Guenther et al. (1999) psychophysical finding that categorization training with non-speech auditory stimuli (bandpass-filtered acoustic noise) leads to a perceptual-magnet-like effect of reduced discriminability for category-prototypical stimuli. We have preliminary results from an fMRI experiment testing the hypothesis that this reduced discriminability is the result of a smaller cortical representation for prototypical stimuli after training. The preliminary results **from three subjects only** (below) support this hypothesis by showing much more activation for the NP condition vs. the P condition after one week of categorization training training (right) as compared to before training (left).





CONCLUSIONS. An fMRI analysis revealed that listening to prototypical examples of the vowel /i/ leads to less activation in peri-sylvian cortical areas than listening to non-prototypical examples. Preliminary results of a second fMRI study suggest that categorization training leads to a decrease in the relative size of the cortical representation for central members of a category. Taken together, these results support the following assertions of the Guenther et al. (1999) neural model of auditory map formation:

- Categorization training leads to a relative decrease in the size of the cortical representation of prototypical examples of a category.
- Similarly, vowel category training in infancy leads to a decrease in the size of the cortical representation of prototypical examples of a vowel.
- This decreased representation is responsible for the perceptual magnet effect (see also Bauer et al., 1996).

REFERENCES.

Bauer, H.-U., Der, R., and Herrmann, M. (1996). Controlling the magnification factor of self-organizing feature maps. *Neural Computation*, **8**, pp. 757-771.

Caplan, D., Gow, D., and Makris, N. (1995). Analysis of lesions by MRI in stroke patients with acoustic-phonetic processing deficits. *Neurology*, **45**, pp. 293-298.

Caviness, V.S. Jr., Meyer, J., Makris, N., and Kennedy, D.N. (1996). MRI-based topographic parcellation of human neocortex: An anatomically specified method with estimate of reliability. *Journal of Cognitive Neuroscience*, **8**, pp. 566-587.

Guenther, F.H., and Gjaja, M.N. (1996). The perceptual magnet effect as an emergent property of neural map formation. *Journal of the Acoustical Society of America*, **100**, pp. 1111-1121.

Guenther, F.H., Husain, F.T., Cohen, M.A., and Shinn-Cunningham, B.G. (1999). Effects of categorization and discrimination training on auditory perceptual space. *Journal of the Acoustical Society of America*, **106**, pp. 2900-2912.

Kuhl, P.K. (1991). Human adults and human infants show a 'perceptual magnet effect' for the prototypes of speech categories, monkeys do not. *Perception & Psychophysics*, **50**, pp. 93-107.

Recanzone, G.H., Schreiner, C.E., and Merzenich, M.M. (1993). Plasticity in the frequency representation of primary auditory cortex following discrimination training in adult owl monkeys. *Journal of Neuroscience*, **13**, pp. 87-103.

ACKNOWLEDGEMENTS. Supported by the National Institute on Deafness and other Communication Disorders (R29 DC02852 to F. Guenther; R01 DC01925 to J. Perkell). The authors thank the Massachusetts General Hospital NMR Center for the use of their imaging facilities.

Postdoctoral research position available. For more information, contact guenther@cns.bu.edu.