Neural encoding of talker-specific phonetic variation

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Background

The same acoustic cues of the speech signal carry information about phonetic identity (/g/ or /k/) and talker identity (Joanne or Sheila)

- The acoustic parameter voice-onset-time (VOT) cues the voicing distinction (/g/ or /k/) in word-initial English stop consonants
- Talkers show systematic variation in their production of some speech sounds, including VOT variants for voiceless stops (e.g. /k/, Theodore et al., 2009)
- Listeners are sensitive to talker-specific phonetic variation (Theodore & Miller, 2010; Goldinger, 1996)
- Listeners use talker-specific phonetic variation to guide processing:
  - Ambiguous tokens during exposure will produce shifts in the **category boundary** (e.g. Norris, et al., 2003; Kraljic & Samuel, 2008) and unambiguous tokens will produce shifts in **internal category structure** (Theodore et al., 2015)
  - In accented speech, exposure to ambiguous or shifted tokens produces speeded lexical decisions to consistent words, shifts in the category boundary, and shifts in 'goodness' judgments for non-standard tokens (e.g. Eisner et al., 2013; Xie et al., under review)

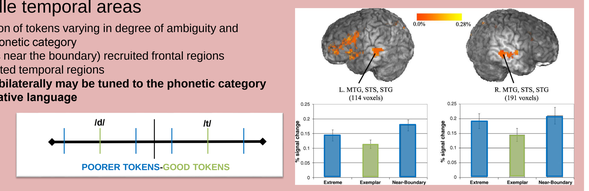
Does the neural system separate processing of VOT for phonetic identity and talker identity?

- Left and right temporal regions tune to the phonetic category structure (e.g. Myers, 2007, see inset, above)
- Right middle temporal & frontal regions respond to the shifted category boundary that results from exposure to an ambiguous token (see inset, right)

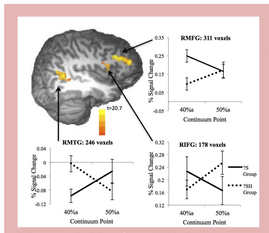
→ Will listeners recruit the same right hemisphere regions for perception of VOT variants that are unambiguous (that is, do not require or result in a shift in phonetic category boundary)?
→ Is there a core neural system for processing talker-specific phonetic variation?

Sensitivity to phonetic category variability (i.e. "goodness of fit") in bilateral superior temporal / middle temporal areas

- Phonetic categorization of tokens varying in degree of ambiguity and 'goodness of fit' to phonetic category
- Ambiguity (i.e. tokens near the boundary) recruited frontal regions
- Goodness of fit recruited temporal regions
- **Posterior MTG/STS bilaterally may be tuned to the phonetic category structure of one's native language**

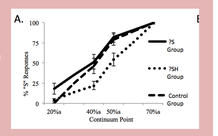


Myers, 2007



Sensitivity to ambiguous talker-specific variants encoded in right hemisphere temporal/frontal areas

- Perceptual learning for speech (e.g. Norris, et al., 2003, Kraljic & Samuel, 2008)
- Listeners hear an ambiguous s/sh blend inserted in either an s-biasing (e.g. 'epi?ode') or sh-biasing (e.g. 'flouri?ing') context
- Later interpret that ambiguous token according to the exposure (i.e. shift in the phonetic category boundary)
- **Modulation in right-hemisphere regions also involved in processing talker identity** (e.g. von Kriegstein, et al., 2003)



Myers & Mesite, 2014

Methods

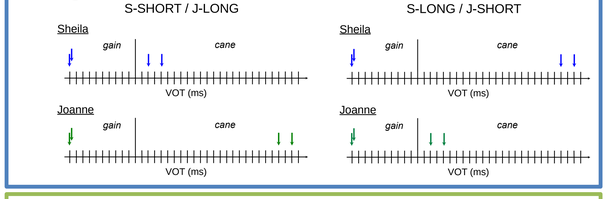
Participants

- 15 Monolingual English listeners, assigned to one of two training groups:
  - S-SHORT/J-LONG (n = 7)
  - S-LONG/J-SHORT (n = 8)

Stimuli

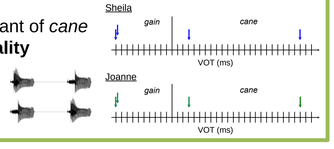
- Two synthesized VOT continua ranging from *gain* to *cane*
- Continua were based on the speech of two female talkers, fictitiously named "Joanne" and "Sheila"
- Continua were created using naturally-produced *gain* tokens; word duration and VOT were equated across talkers
- Subsets of tokens were used during **training** and **test** phases

Training stimuli



Test stimuli

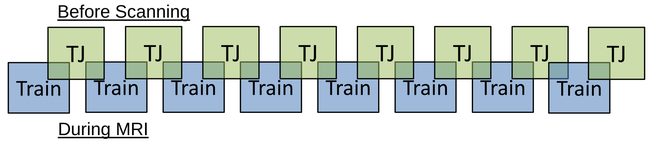
- Short-VOT and long-VOT variant of *cane* used to create pairs for **typicality judgement** task
- All variants used in **phonetic categorization** tests



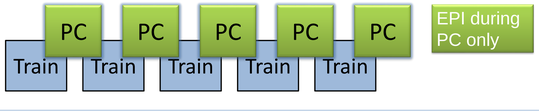
Procedure

- **Talker Training** (out-of-scanner and alternating with scanning):
  - Heard *gain* or *cane* on a given trial
  - Asked to identify the initial sound and the talker
  - Feedback was provided for the talker choice only
- **Typicality Judgement** (**TJ**, out-of-scanner test): Presented with short-VOT and long-VOT pair and asked to choose which is most like each talker (2AFC)
- **Phonetic Categorization** (**PC**, in-scanner task): Presented *gain*, short-VOT *cane*, and long-VOT *cane* for both talkers and asked to categorize as 'GAIN' or 'CANE'

Before Scanning



During MRI

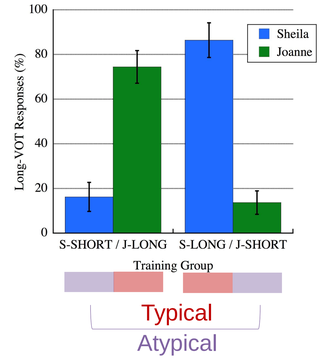


MRI Methods

- EPI and structural images acquired with a Siemens 3T Tim Trio
- EPI: Sparse design, 2x2x2.5 mm voxels, 27 slices
- Functional preprocessed according to standard processing stream
- Beta estimates of each condition submitted to two ANOVAs (Voice X Typicality) and (Voice X VOT)

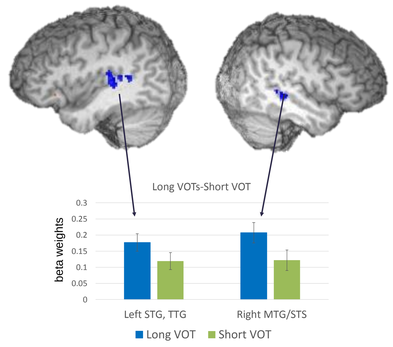
Results

Listeners are behaviorally sensitive to the "typicality" of VOT variants as representative of a talker's voice.

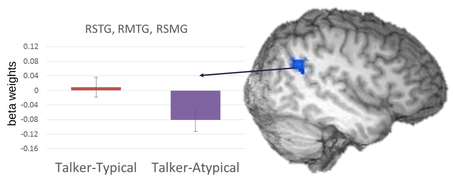


During pre-scanning typicality judgment (TJ): percentage of Long-VOT responses that are judged to be most typical of that talker's voice.

Right and Left posterior temporal regions sensitive to phonetic category structure (Long>Short variant, see Myers, 2007)



Typicality of a token as a member of a talker's voice modulates activity in right temporo-parietal regions also implicated in adaptation to ambiguous tokens (see Myers & Mesite, 2014)



All clusters significant at whole-brain level, p<0.05, cluster-corrected for multiple comparisons, voxel-level p<0.025, 112 contiguous voxels

Atypical - Typical

Voxels	Peak x	Peak y	Peak z	Region	t-value at maximum
323	-42.9	55.2	24.9	RSTG, RMTG, RSMG	-4.46
192	0.9	44.8	26.6	L Post Cingulate, L Cingulate	-4.39

Joanne-Sheila

Voxels	Peak x	Peak y	Peak z	Region	t-value at maximum
254	-25.4	46.5	31.9	R IPL	-6.57
161	-11.4	55.2	35.4	R Precuneus	-3.65
142	44.6	-6	-10.1	LSTG LIFG	-4.77
136	41.1	-41	-1.4	L MFG	-5
135	49.9	4.5	-13.6	LMTG LSTG	-5.56

Long-Short

Voxels	Peak x	Peak y	Peak z	Region	t-value at Maximum
359	-2.6	-18.2	12.6	Right subcortical	-5.56
268	-56.9	36	-6.6	Right MTG/STG	-3.48
227	39.4	25.5	17.9	Left MTG/STG	-4.78
222	2.6	-34	21.4	Anterior Cingulate	-5.21

Discussion

- A core region for linking talker identity to phonetic variation may occupy the right temporoparietal region:
  - Modulates as a function of typicality of a token as representative of a talker's voice
  - These regions overlap with areas involved in perceiving ambiguous stimuli following lexically-conditioned phonetic category boundary shifts (Myers & Mesite, 2014).
- This system is adjacent to, but does not overlap with, regions responsible for processing phonetic category structure.
  - Left and right superior temporal gyrus/sulcus are sensitive to within-category differences more generally, decoupled from talker information (see also Myers, 2007).
- Suggests that adaptation to talker-specific variation, while resulting in widespread perceptual/processing adjustments, does not fundamentally retune temporal lobe sensitivities, at least over short exposures
- Longer-term adaptation may ultimately result in temporal lobe retuning

References

1. Eisner, F., Melinger, A., & Weber, A. (2013). Constraints on the transfer of perceptual learning in accented speech. *Frontiers in Psychology, 4*,148.
2. Goldinger, S. D. (1996). Words and voices: Episodic traces in spoken word identification and recognition memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*(5), 1166-1183.
3. Kraljic, T., & Samuel, A. G. (2007). Perceptual adjustments to multiple speakers. *Journal of Memory and Language, 56*, 1-15.
4. Myers, E. B. (2007). Dissociable effects of phonetic competition and category typicality in a phonetic categorization task: An fMRI investigation. *Neuropsychologia, 45*(7), 1463-1473.
5. Myers, E. B., & Mesite, L. M. (2014). Neural systems underlying perceptual adjustment to non-standard speech tokens. *Journal of Memory and Language, 76*, 80-93.
6. Norris, D., McQueen, J. M., & Cutler, A. (2003). Perceptual learning in speech. Cognitive Psychology, 47(2), 204-238.
7. Theodore, R. M., & Miller, J. L. (2010). Characteristics of listener sensitivity to talker-specific phonetic detailia). *The Journal of the Acoustical Society of America, 128*(4), 2090-2099.
8. Theodore, R. M., Miller, J. L., & DeSteno, D. (2009). Individual talker differences in voice-onset-time: Contextual influences. *The Journal of the Acoustical Society of America, 125*(6), 3974-3982.
9. Theodore, R.M., Myers, E. B., Lomibao, J.A. (2015). Talker-specific influences on phonetic category structure. *Journal of the Acoustical Society of America, 138*(2), 1068-1078.
10. von Kriegstein, K., Eger, E., Kleinschmidt, A., & Giraud, A. L. (2003). Modulation of neural responses to speech by directing attention to voices or verbal content. *Cognitive Brain Research, 17*(1), 48-55.
11. Xin, X., Theodore, R. M., & Myers, E. B. (Under review). More than a boundary shift: Perceptual adaptation to foreign-accented speech reshapes the internal structure of phonetic categories.

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