THE REPRESENTATION OF SYLLABIC FRAME STRUCTURES AND PHONOLOGICAL CONTENT IN THE BRAIN

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Background

- The slot/filler theory (Shattuck-Hufnagel, 1979) and the frame/content theory (MacNeilage, 1998) both posit that:
  - The phonological content of a speech utterance is represented in parallel with its structure and timing

Syllabic Frame Structure

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CCVVC
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Phonological Content

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\text{syllable}
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- For instance, Spoonerisms (or exchange errors) occur when two phonemes in different syllables, but in the same syllable position exchange places
  - e.g. “\text{dear old queen}” → “\text{queer old dear}”
  - Suggests that phonemes and their syllable position information are represented separately at some processing stage
- These theories have been implemented in several influential models of speech (GODIVA, WEAVER++, Coupled Oscillator)
- However, a neural basis of the syllabic frame is largely unexplored.
- Previous work (Peeva et al., 2010) showed a syllabic representation in the ventral premotor cortex, but did not differentiate between representations of a syllabic frame and a full syllable (with phonological content)

Methods

- Subjects: 17 American English speaking subjects
- Stimuli & Paradigm
  - FMRI repetition suppression (fMRI-RS) paradigm
  - BOLD response decreases across repeated presentations of stimulus in a region that processes that stimulus

4 speaking conditions varying by how often each type of speech representation – syllabic frame, phoneme, or complete syllable – was repeated between pairs of pseudowords

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- Auditory & orthographic presentations of each target pseudoword (0.7 & 1.5 s)
- Blocks consisted of 6 trials followed by a 3 s pause

**fMRI acquisition**

- Siemens Trio Tim 3T, 32 channel head coil
- TR: 2.5 s, 41 slices, Skip: 25%, 200mm coverage
- Voxel size: 3.1 x 3.1 x 3.0 mm

**fMRI analysis**

- Functional volumes realigned to subject’s anatomical volume, corrected for slice acquisition timing, and first level model estimated with SPM8.
- ROI parcellation: cortical (surface-based speech-focused, Tourville & Guenther, 2003), subcortical (Fischl et al., 2002), and cerebellar (Diedrichsen, 2001)
- Contrast values – 1st half of block vs. baseline (silent fixation) for each speaking condition – extracted and averaged across each ROI using REX (http://web.mit.edu/swg/rex)
  - Normalized by average activity across each ROI

5 hypothesized patterns of across-condition fMRI-RS

**Phoneme** representation for motor execution & auditory stimulus processing

- Loop with superior temporal cortex, M1, SMA

**Phonological Constituent** (SSC) representation for monitoring & modulating feedforward speech motor programs with auditory feedback

- Loop with lateral premotor cortex

Cicero-cerebellar loops

- Functional and anatomical cortico-cerebellar connections (Buckner et al., 2011; O’Reilly et al., 2010)
- Anterior cerebellum, right lobules I-IV & V
  - Sensorimotor processing (e.g. Stoodley & Schmahmann, 2009)
  - Language, articulation, and auditory speech feedback processing (e.g. Stoodley & Schmahmann, 2009; Ackermann et al., 1992; Tourville et al., 2008)

**Phonemic** representation for monitoring & modulating feedforward speech motor programs with auditory feedback

- Loop with lateral cerebellum, right lobule VI & right lobule VIII

- Lateral cerebellum, right lobule VIIB

**Frame** representation for milliseconds range timing and movement synchronization (Hazeltine et al., 1998; Koch et al., 2007) of speech utterances

Discussion

Left lateral prefrontal cortex

- Two representations:
  - Syllable in middle and ventral premotor cortex
  - SSC in posterior inferior frontal gyrus, pars opercularis
- Both areas hypothesized to store feedforward motor commands for speech (Guenther, 2006; Levelt & Wheeldon, 1994)
- Suggests that either:
  - SSC motor programs are used to construct syllable motor programs for execution, or
  - SSC motor programs are used for utterances in which syllable motor programs are not available

Cerebellar representation of speech structure and timing

- Lateral cerebellum, right lobule VIIB

- Lateral cerebellum, right lobule VIII

- Lateral cerebellum, right lobule VI

**Across-condition pattern matching within ROIs**

(Peeva et al., 2010)

- A priori models defined by BOLD activity comparisons across conditions
- Model fit quantified by conjunction test comparing the 4 speaking conditions based on 5 predicted patterns of repetition suppression at each speech production ROI
- Significance threshold of $P_{FWE} < 0.05$
  - Where P is derived from distribution of values from Monte Carlo simulation with 10,000 trials