The role of language-specific vs. domain-general systems in phonological working memory

Terri L. Scott[1], Sara Dougherty[2], Ja Young Choi[2,3], Tyler K. Perrachione[2]

[1]Graduate Program for Neuroscience, Boston University, [2]Department of Speech, Language & Hearing Sciences, Boston University, [3]Program in Speech and Hearing Bioscience and Technology, Harvard University

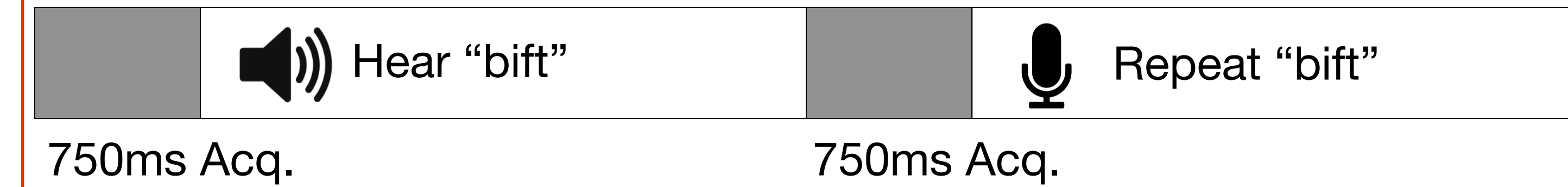**BOSTON UNIVERSITY**

Summary

Phonological working memory is the process of maintaining sounds important for **speech** and **language** in short term memory. This process is believed to be crucial for successfully acquiring **reading proficiency** and is often assessed using **nonword repetition** tasks, in which a student is asked to repeat progressively longer nonwords. In this work, we compare regions that become more active when longer nonwords are repeated to regions that are active during passive listening to speech, a verbal working memory task, or a spatial working memory task. We found that **nonword repetition most consistently recruits temporal lobe speech/language regions**, however, **nonword repetition-responsive regions L-PT and L-PreCG show domain-general properties** as evidenced by significant increases in activation with working memory load in both verbal and spatial working memory tasks.
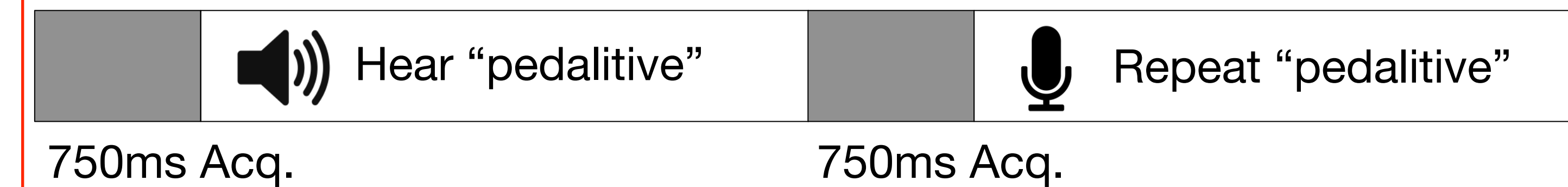
Methods

Participants: 20 fluent English-speaking adults

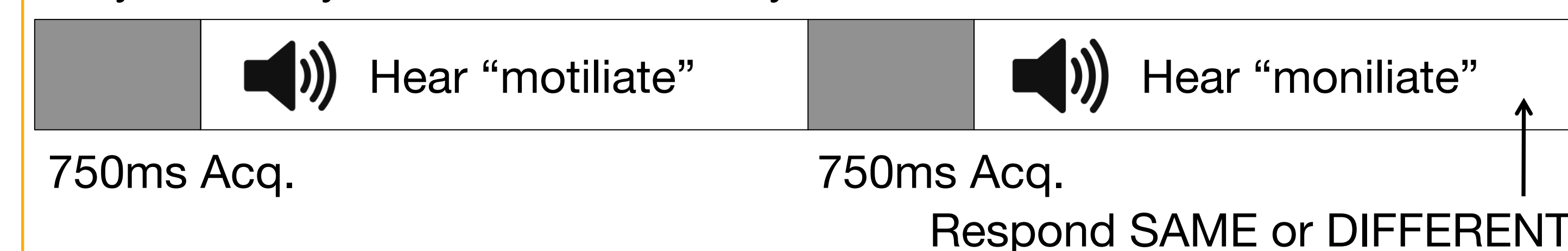### Nonword Repetition

Easy – One Syllable

| | 🔊 Hear "bift" | | 🎤 Repeat "bift" |

750ms Acq. ... 750ms Acq.

Hard – Four Syllables

| | 🔊 Hear "pedalitive" | | 🎤 Repeat "pedalitive" |

750ms Acq. ... 750ms Acq.

Real Words – One and four syllables long included as a control.

Nonword Discrimination

Easy – One Syllable, Hard – Four Syllables

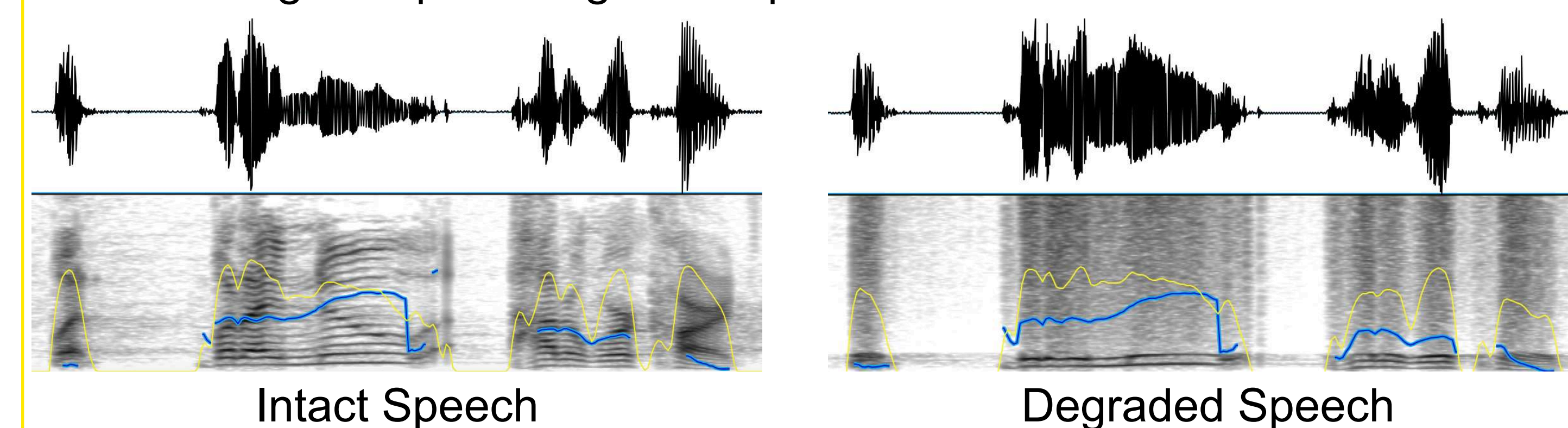| | 🔊 Hear "motiliate" | | 🔊 Hear "moniliate" |

750ms Acq. ... 750ms Acq.
Respond SAME or DIFFERENT

fMRI Data Acquisition:
- Sparse-sampling block design, using simultaneous multislice imaging
- TR=2.25s, TA=0.75s, 3mm isotropic, 45 slices, 5 simultaneous slices
- Nonword Repetition: 3 runs, 360s each, containing 16 trials per each of the 4 conditions plus fixation, with 4.5s trials.
- Nonword Distrimination: 2 runs, 324s each, containing 24 trials per each of the 2 conditions plus fixation, with 4.5s trials.

Speech/Language: Passive listening to intact clips of speech contrasted with listening to clips of degraded speech

Intact Speech | Degraded Speech
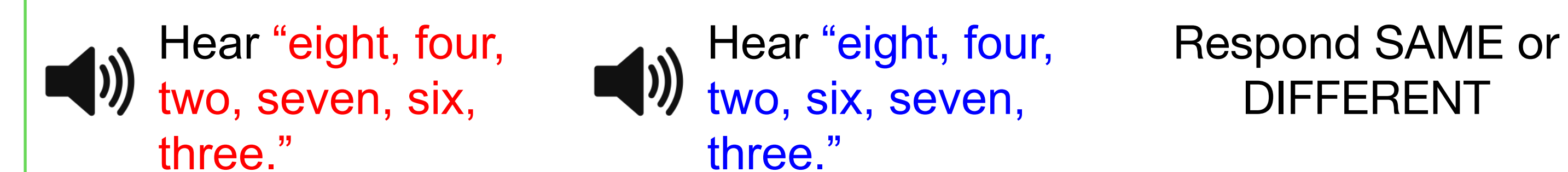
fMRI Data Acquisition:
- Continuous-sampling block design, using simultaneous multislice imaging
- TR=0.75s, TA=0.75s, 3mm isotropic, 45 slices, 5 simultaneous slices
- 2 runs, 358s each, containing eight 18-second audio clips per each of 2 conditions plus fixation.

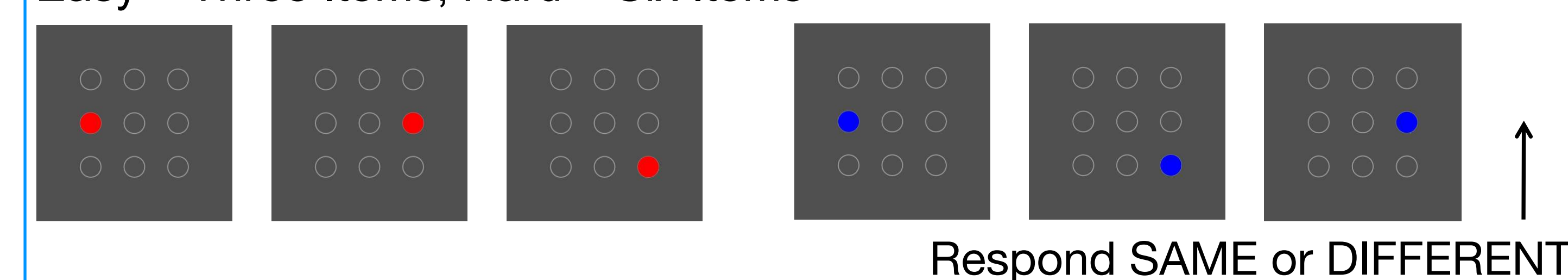### Verbal Working Memory: Digit Span

Easy – Three Items

| 🔊 Hear "six, one, two." | 🔊 Hear "six, two, one." | Respond SAME or DIFFERENT |

Hard – Six Items

| 🔊 Hear "eight, four, two, seven, six, three." | 🔊 Hear "eight, four, two, six, seven, three." | Respond SAME or DIFFERENT |

Spatial Working Memory: Corsi Blocks

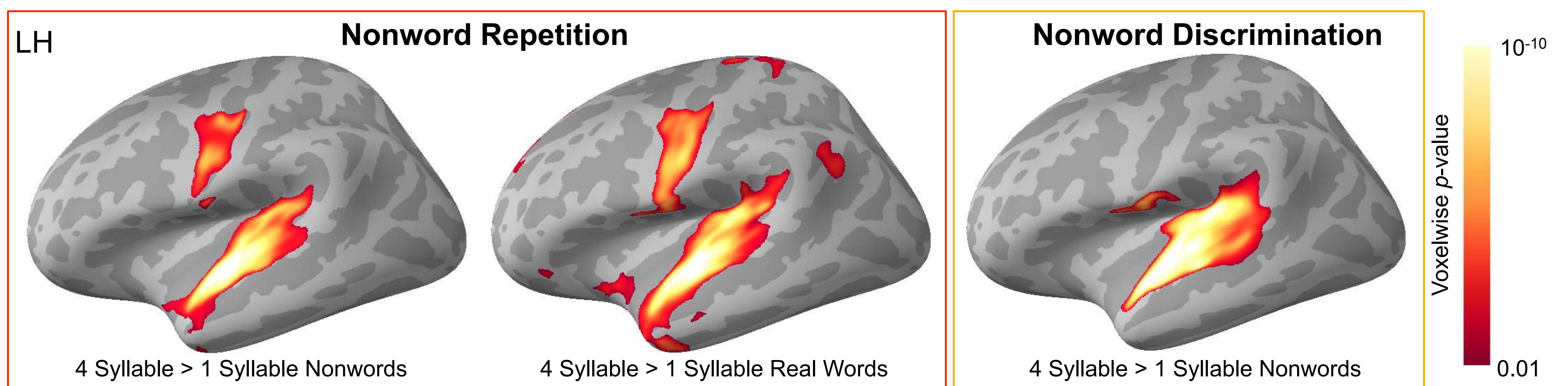Easy – Three Items, Hard – Six Items

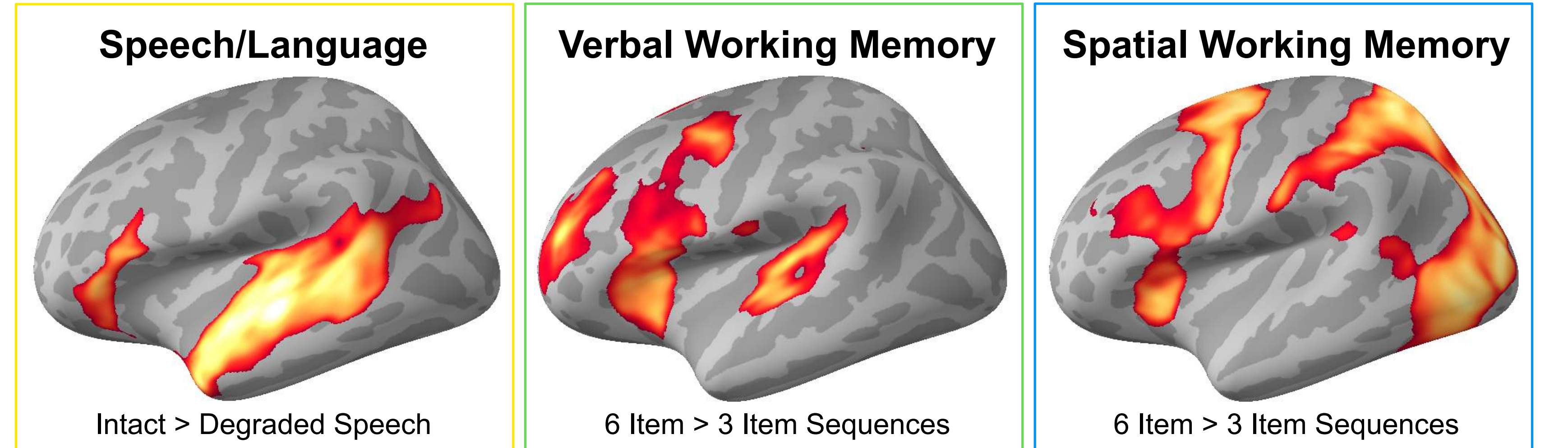Respond SAME or DIFFERENT

fMRI Data Acquisition:
- Continuous-sampling block design, using simultaneous multislice imaging
- TR=0.75s, TA=0.75s, 3mm isotropic, 45 slices, 5 simultaneous slices
- 2 runs, 375s each, containing 20 trials per each of 2 conditions plus fixation, with Easy trials lasting 18s each and Hard trials lasting 27s each.
- All items were presented for 0.5s with 1.5s fixation between the two sequences and 1.5s after the second sequence for the subject's response.
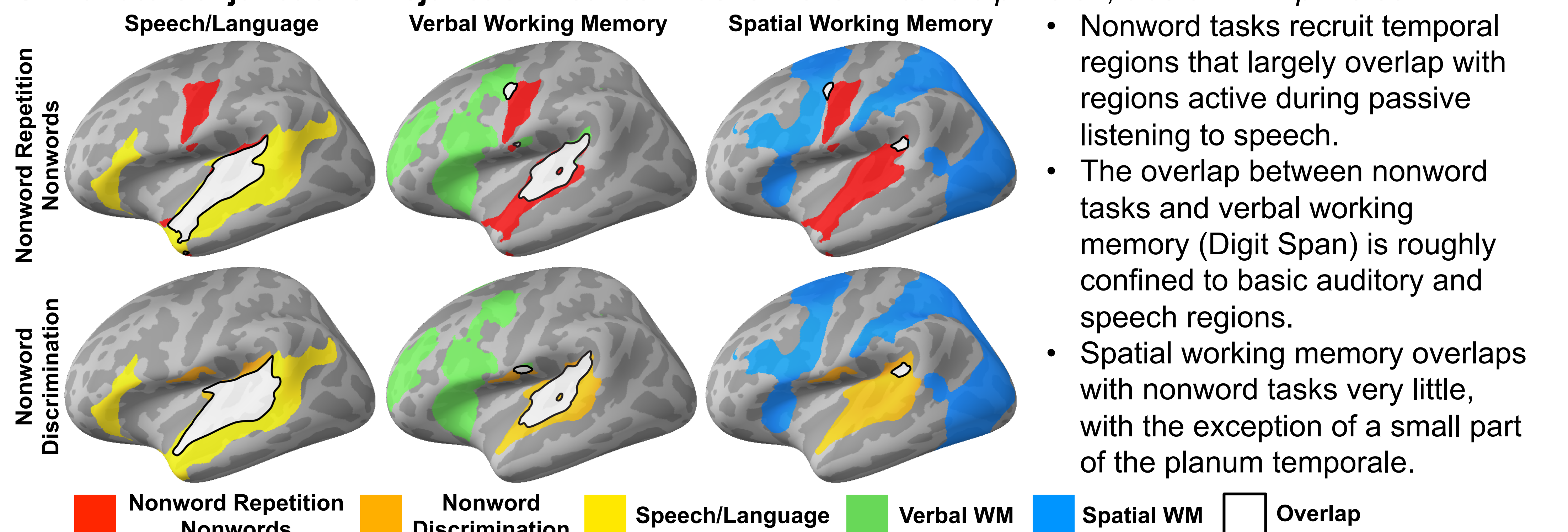
Results

Univariate Group Maps: Voxel threshold $p < 0.01$, cluster FWE $p < 0.05$

Nonword Repetition (LH): 4 Syllable > 1 Syllable Nonwords; 4 Syllable > 1 Syllable Real Words
Nonword Discrimination: 4 Syllable > 1 Syllable Nonwords

Voxelwise p-value 10^{-10} to 0.01

Univariate group maps reveal recruitment of temporal lobe regions during both nonword tasks, and the addition of LH speech/motor regions during repetition.

Speech/Language: Intact > Degraded Speech
Verbal Working Memory: 6 Item > 3 Item Sequences
Spatial Working Memory: 6 Item > 3 Item Sequences

Univariate Conjunction / Disjunction Between Tasks: Voxel threshold $p < 0.01$, cluster FWE $p < 0.05$
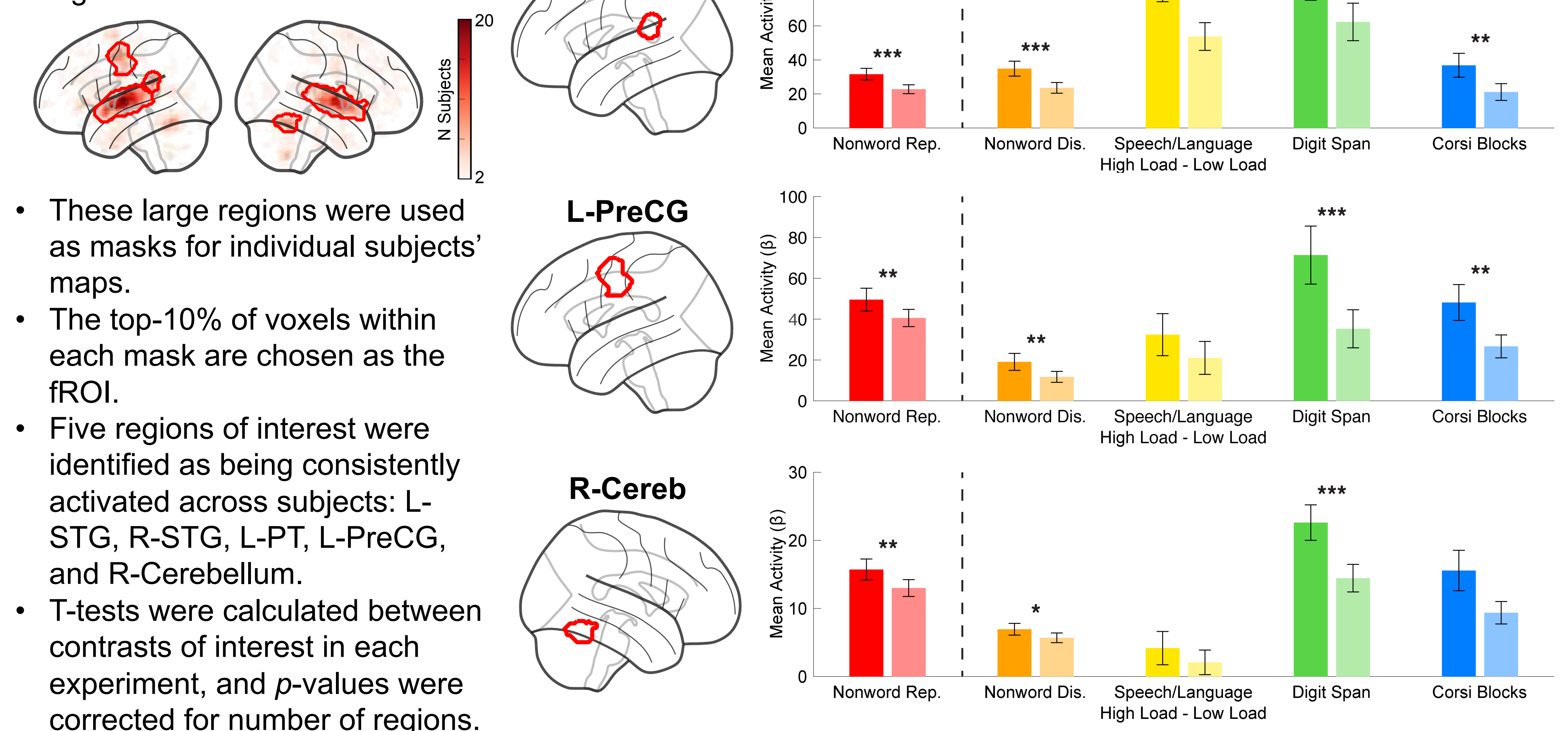

- Nonword tasks recruit temporal regions that largely overlap with regions active during passive listening to speech.
- The overlap between nonword tasks and verbal working memory (Digit Span) is roughly confined to basic auditory and speech regions.
- Spatial working memory overlaps with nonword tasks very little, with the exception of a small part of the planum temporale.

Legend: ■ Nonword Repetition Nonwords ■ Nonword Discrimination ■ Speech/Language ■ Verbal WM ■ Spatial WM □ Overlap

Individual Subject Analyses: Group-constrained Subject Specific (GSS) analysis to define regions of interest.

Functional regions of interest were defined on the nonword repetition contrast of four > one syllable nonwords.
- Collect each individual's statistical map
- Threshold at $p < 0.01$ uncorrected
- Binarize each thresholded map
- Overlay each subject's map to create a probability map
- Use a watershed algorithm to "fill in" regions around peaks in the probability map.
- Identify regions with high degrees of overlap and in which most subjects (≥ 80%) have significant voxels

- These large regions were used as masks for individual subjects' maps.
- The top-10% of voxels within each mask are chosen as the fROI.
- Five regions of interest were identified as being consistently activated across subjects: L-STG, R-STG, L-PT, L-PreCG, and R-Cerebellum.
- T-tests were calculated between contrasts of interest in each experiment, and p-values were corrected for number of regions.

*** $p < 0.001$
** $p < 0.01$
* $p < 0.05$

L-STG, R-STG, L-PT, L-PreCG, R-Cereb charts showing Mean Activity (β) for Nonword Rep., Nonword Dis., Speech/Language High Load - Low Load, Digit Span, Corsi Blocks

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BU

tlscott@bu.edu
http://sites.bu.edu/cnrlab/