Nonword repetition recruits distinct and overlapping nodes of language and working memory networks

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Summary

- **Phonological working memory (PWM)** is the process of maintaining sounds important for **speech** and **language** in short term memory. This process is believed to be a crucial component for typical language development.
- Here **we examined the functional responses within regions sensitive to PWM load during nonword repetition**, in order to better understand what types of computations these brain areas support.
- Participants completed three tasks during neuroimaging: (1) nonword repetition (including control conditions with real words), (2) passive listening to language/speech, and a (3) verbal working memory task (digit span).
- We localized functional regions of interest (fROIs) responsive to PWM load in **within individual subjects**, and tested their responses during language and verbal working memory tasks.
- By describing the functional profiles of PWM brain regions, we have uncovered evidence for the involvement of canonical speech regions (superior temporal gyri; STG) and dual language/working memory convergent regions in the dorsal stream.

Analysis Methods

In order to provide a detailed description of the functional properties of PWM regions within individual subjects, we employed *group constrained subject-specific* (GCSS) analysis (Fedorenko et al., 2010; Julian et al., 2012; Scott et al., 2018). With this technique, we addressed the following questions:

What are the functional profiles of PWM brain regions in individuals?

Subject 1   Subject 2   Subject 3   Ind. Task Response
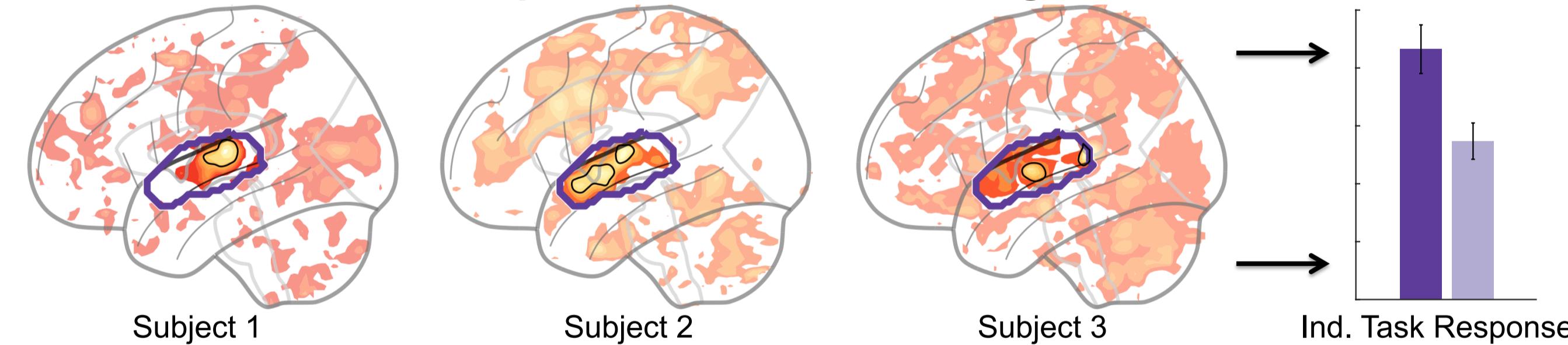
Broad search areas – "parcels" – are used to mask individual subjects' activation maps, and then fROIs are defined as the top 10% of voxels inside the mask. In *independent data*, responses are measured in these fROIs.

**Are the patterns of activity similar between two tasks?**

Even if a region is sensitive to a separate contrast, the pattern of activity is not necessarily the same. We correlated voxels from two tasks across the entire parcel to assess the similarity in patterns of activation.
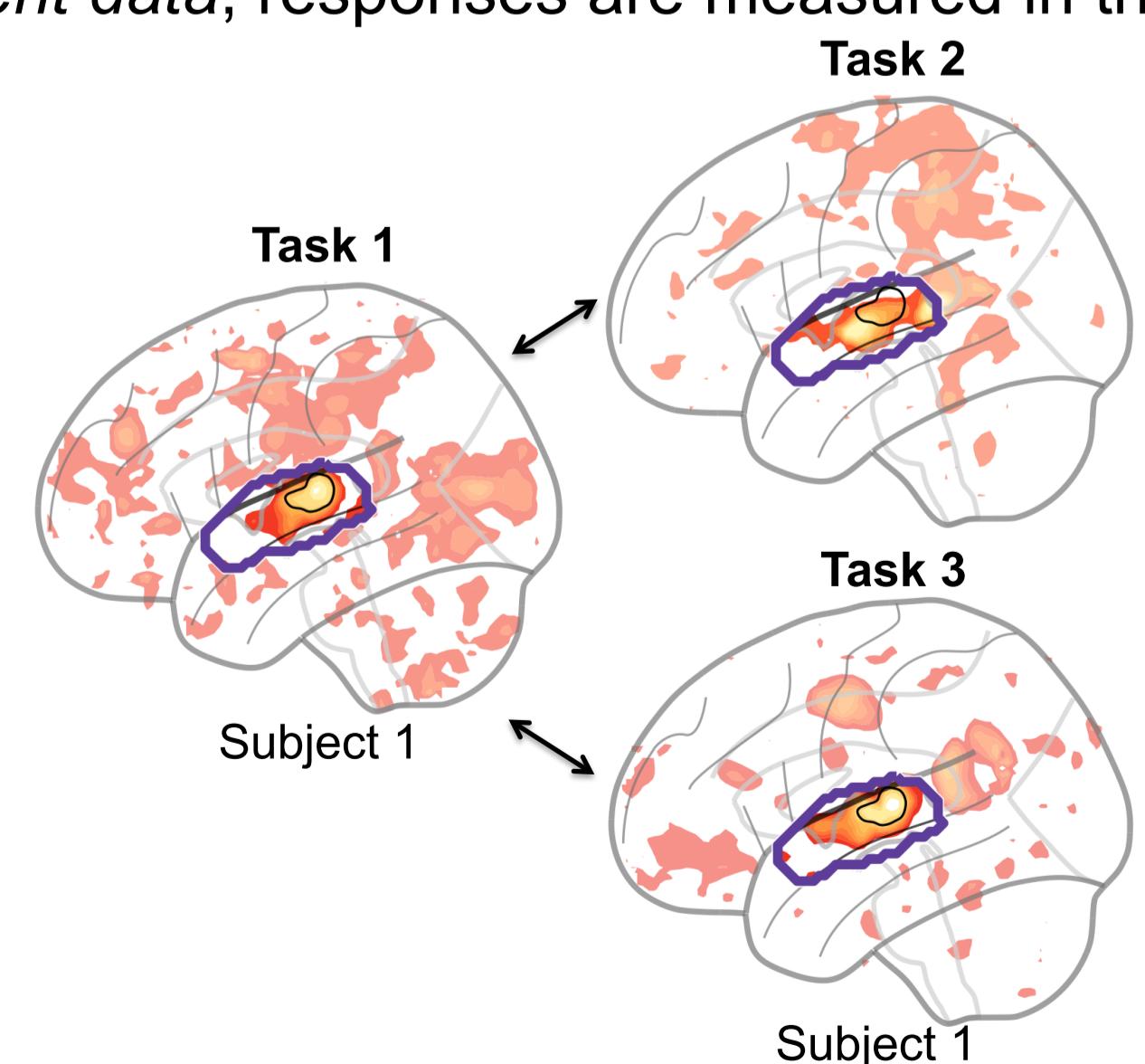
- Sensitivity to both tasks
- **Different** patterns of activation
- Sensitivity to both tasks
- **Similar** patterns of activation

fMRI Tasks

**Participants**: 20 fluent English-speaking adults (12 female; age 19-32 years, *M* = 24.1 years)

Nonword Repetition Design
fMRI Runs: 3 per session

| 1-Syllable Nonwords | 4-Syllable Real Words | 1-Syllable Real Words | (Rest) | 4-Syllable Nonwords | ... |

18 s / block
Trials: 4 per block

TA 🔊 Hear "pedalitive"   TA   🎤 Repeat "pedalitive"   TA

2.25 s / TR   0.75 s / TA; 1.5 s / response window
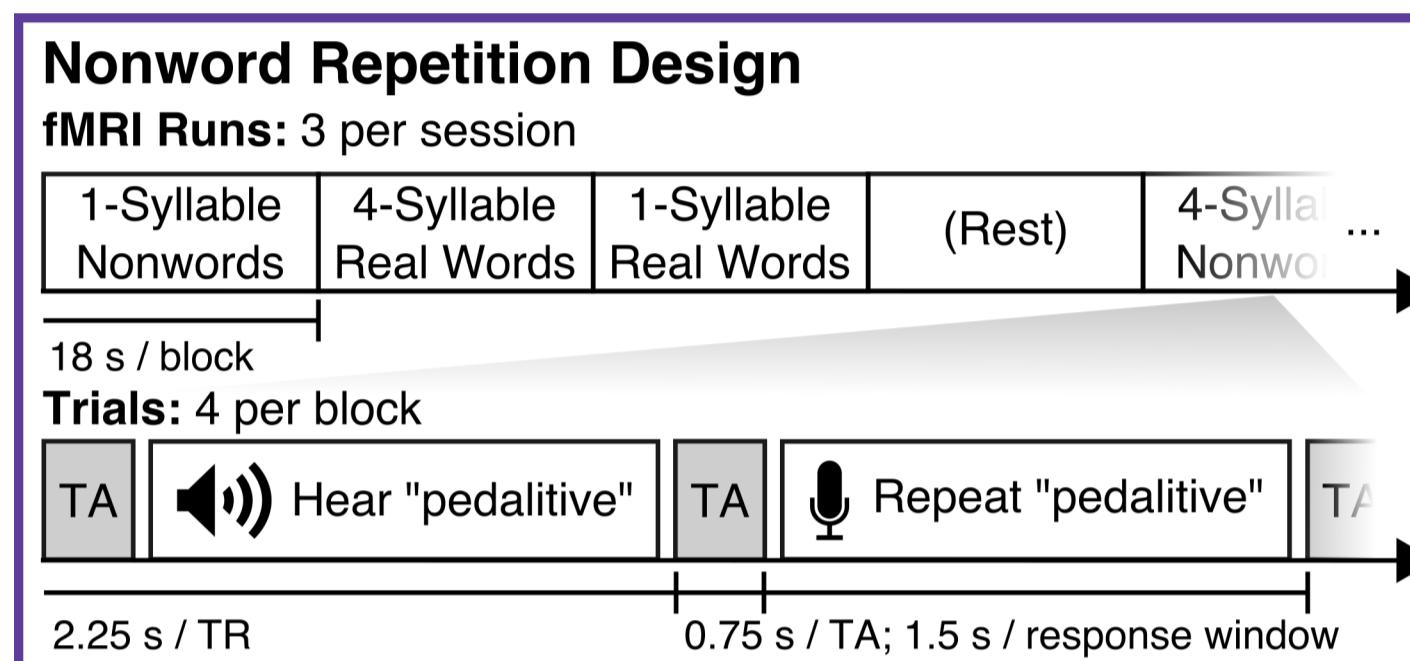
Acquisition: Sparse-sampling block design, using simultaneous multislice imaging.

Language/Speech Task Design
fMRI Runs: 2 per session, 16 passive listening blocks per run + rest, one 18-second audio clip per block
Intact Speech   **Degraded Speech**
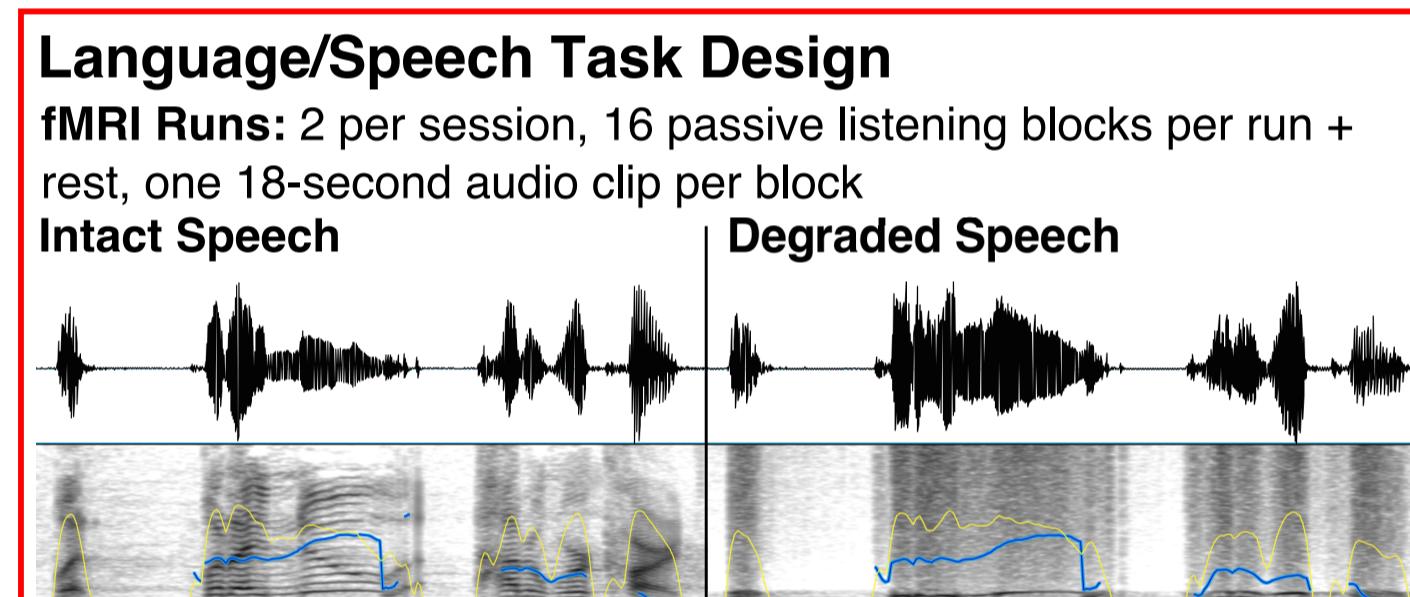
Verbal Working Memory: Digit Span
fMRI Runs: 2 per session, 8 blocks per run + rest, 4 trials per block, Easy blocks lasted 18 seconds, Hard blocks lasted 27 seconds
Easy - Three Item Sequences
🔊 Hear "six, one, two."   🔊 Hear "six, two, one."
Hard - Six Item Sequences
🔊 Hear "eight, four two, seven, six, three."   🔊 Hear "eight, four two, six, seven, three."   👆 Respond SAME or DIFFERENT
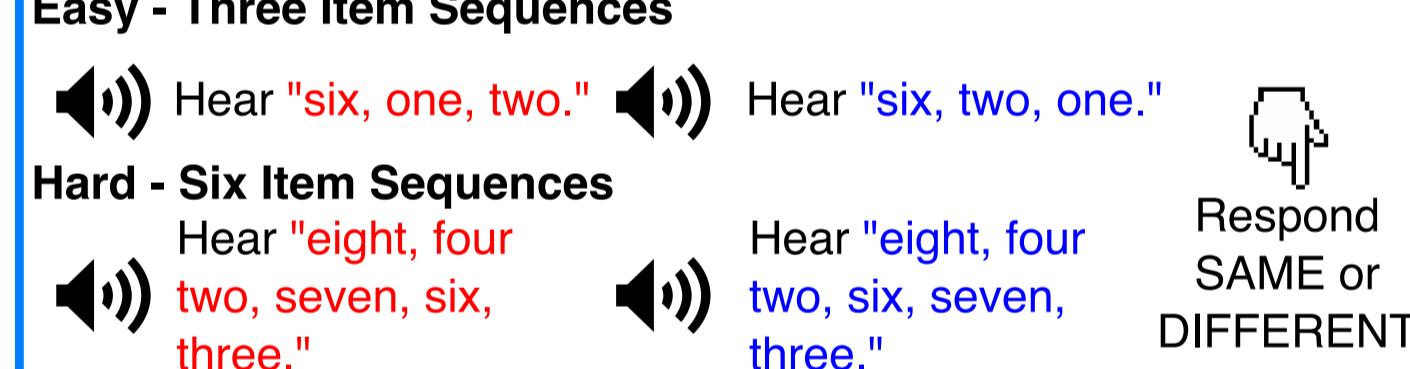
Acquisition: Continuous-sampling block design, using simultaneous multislice imaging (TR=0.75s).

Figure Legend

Significance was evaluated after correcting for repetitions of each test across regions: *n.s.*: p > 0.001, *: p < 0.01, **: p < 0.002, ***: p < 0.0002.

1. ☐ Boundary of parcel
2. ■ 4 syl., 1 syl., Nonwords
   ■ 4 syl., 1 syl., Real Words
3. ■ Intact, Degraded Speech
   ■ 6, 3, Digit Sequences
4. ■ Language, VWM, corr. to PWM

Results

1. Which brain regions show significant activation during PWM (4 syl. > 1 syl. nonwords)?

LSTG   RSTG   LPT   LPreCG   RCereb
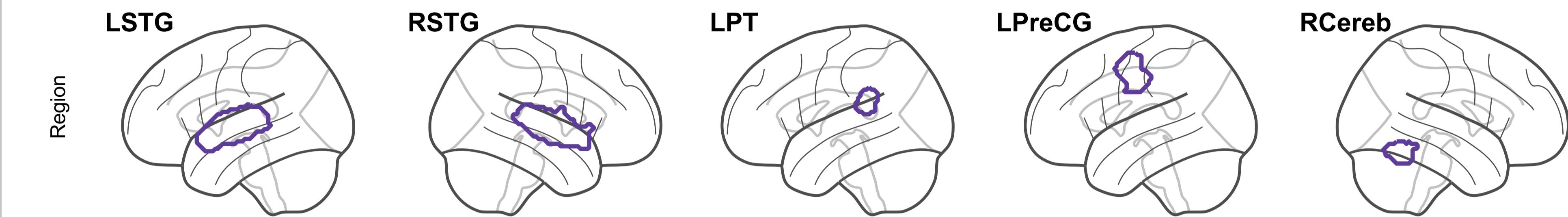
2. Are these brain regions modulated during repetition of real words?

|	LSTG	RSTG	LPT	LPreCG	RCereb
Main Effect of Word Type?	***	***	***	***	*
Main Effect of Syllable Load?	***	***	***	***	***
Interaction?	n.s.	n.s.	n.s.	n.s.	n.s.
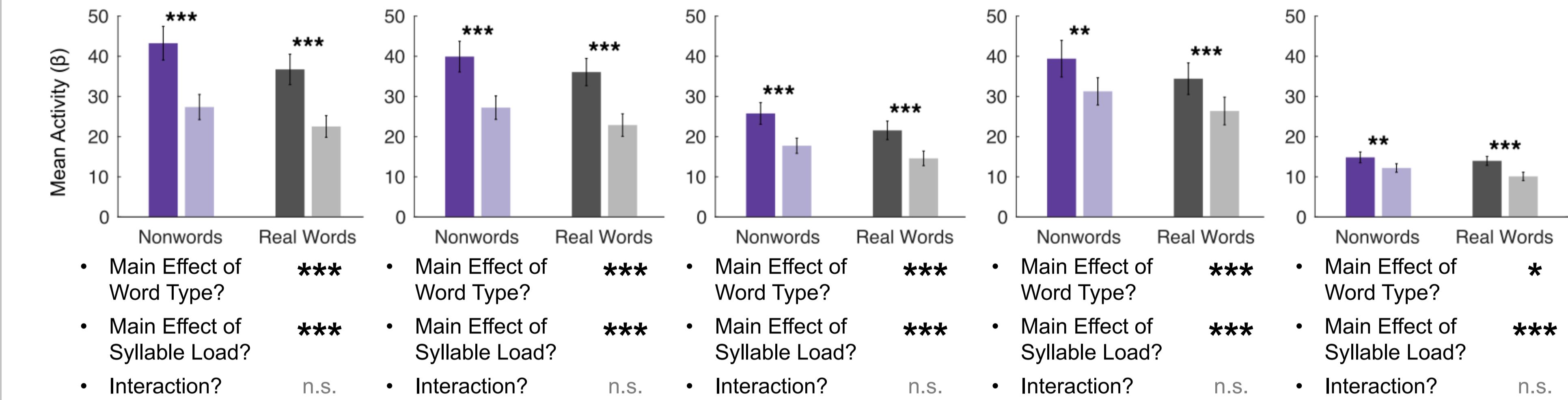
In every region we tested, we found similar parametric modulation of activation for repeating real words and nonwords. This suggests that the computations these regions support do not rely upon access to learned words.

3. Do these brain areas respond significantly to language or verbal working memory?

	LSTG	RSTG	LPT	LPreCG	RCereb
Main Effect of Task?	***	***	***	***	***
Main Effect of Load?	***	***	***	***	***
Interaction?	***	***	n.s.	n.s.	n.s.
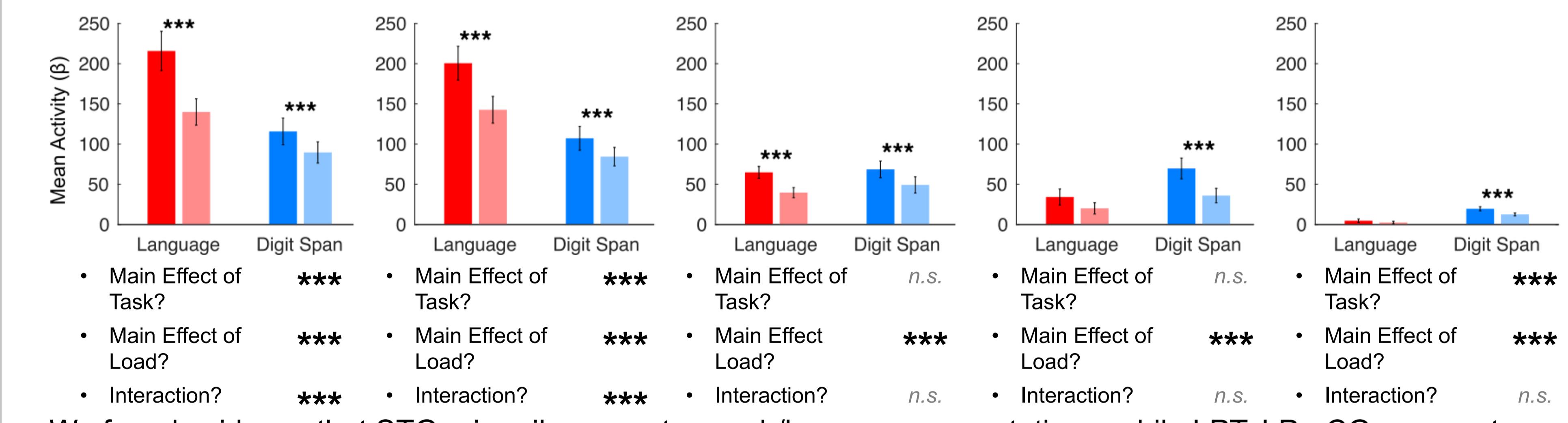
We found evidence that STG primarily support speech/language computations, while LPT, LPreCG, appear to support computations that play a dual role in language and verbal working memory.

4. How similar are the patterns of activation between nonword repetition and language or verbal working memory?
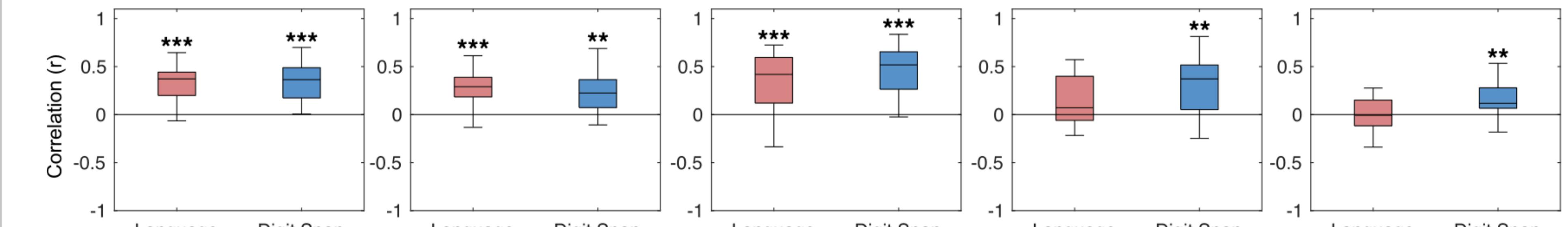
Both language and verbal working memory evoked significantly correlated patterns of activation when compared to PWM. Future work will investigate the nature of these overlapping patterns of activity.

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