Overlapping semantic representations of sign and speech in novice sign language learners

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Introduction

Background:

- Multivariate patterns of neural activity have been used to measure knowledge and learning in many conceptual domains[1-2]
- Homologous words in two different languages have been shown to evoke partially overlapping neural patterns associated with semantic meaning[3].
- In individuals who are fluent in both languages, this shared representation can be detected even when the languages in question are of different modalities (e.g. spoken British English and British Sign Language) [4]

Central Question:

- Can we detect evidence of shared semantic representations between sign and speech very early in the learning process (<2 hours of training)?

Neural Analyses:

- Support vector machine classification of semantic categories in clusters identified through whole-brain searchlight RSA[5]

Methods

Study Procedure

Training Sessions (30 min)

- Day 1: Twelve vocabulary words in ASL or Russian, recall quiz
- Day 2: Twelve additional words, recall quiz
- Day 3 (prior to scan): Review all 24 words, final quiz

fMRI Session

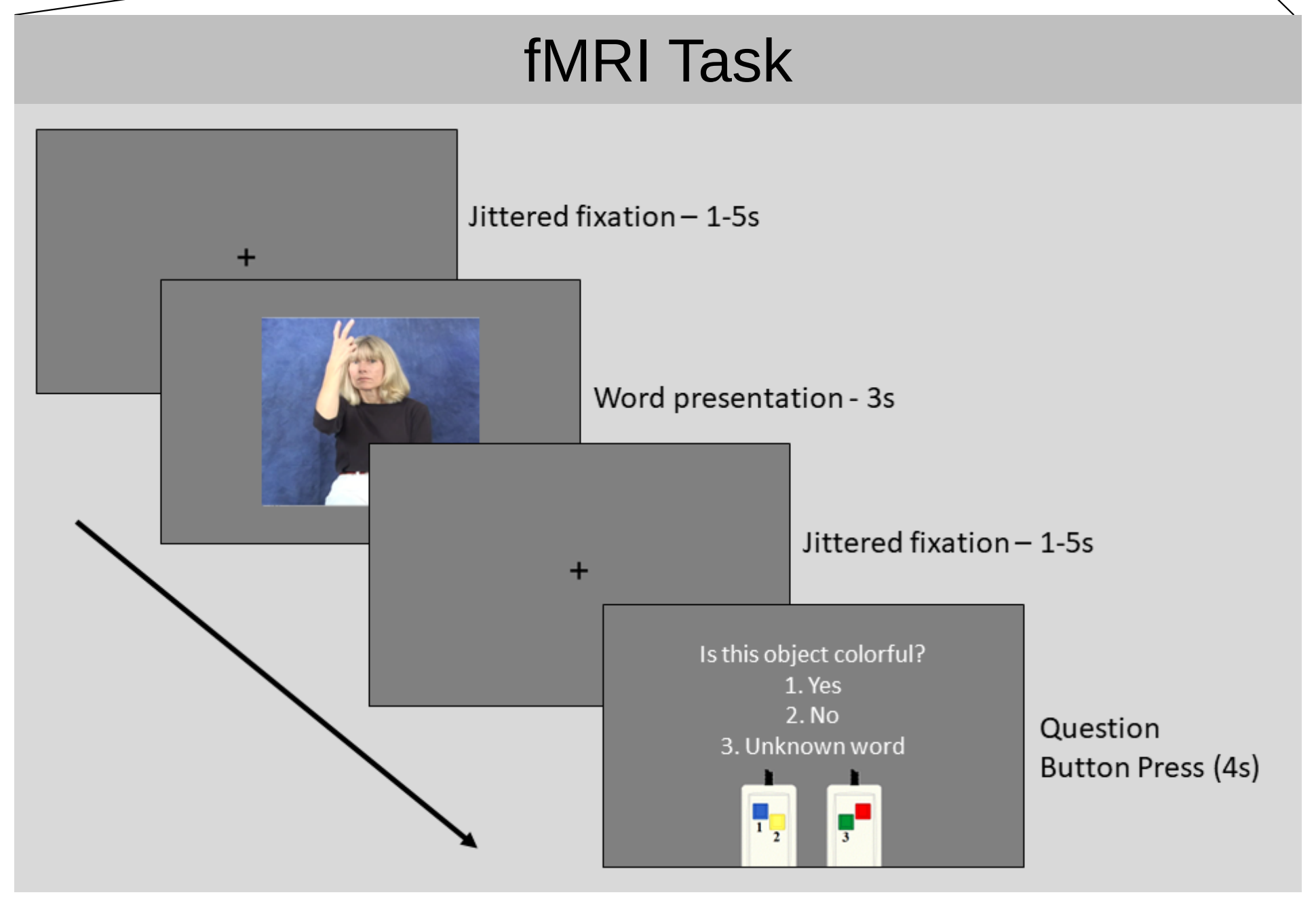
- Alternating blocks of ASL and Russian word clips
- Answer semantic and nonsemantic questions with button press
- In the final run, participants complete the same task with clips of the same 24 words in English

Semantic Trials	Nonsemantic Trials
Is this object colorful? Would it be easy to cause this object to move?	Have you seen this word already in this block?

- Semantic questions were designed to encourage subjects to think about the semantic meaning of the word without specifically priming the target categories (animal, fruit, and vehicle). Nonsemantic trials were included to promote attention even during blocks of the unstudied language.

Overview

Day 1: Online Lesson (30 min) → Day 2: Online Lesson (30 min) → Day 3: Online review (30 min), fMRI Scan



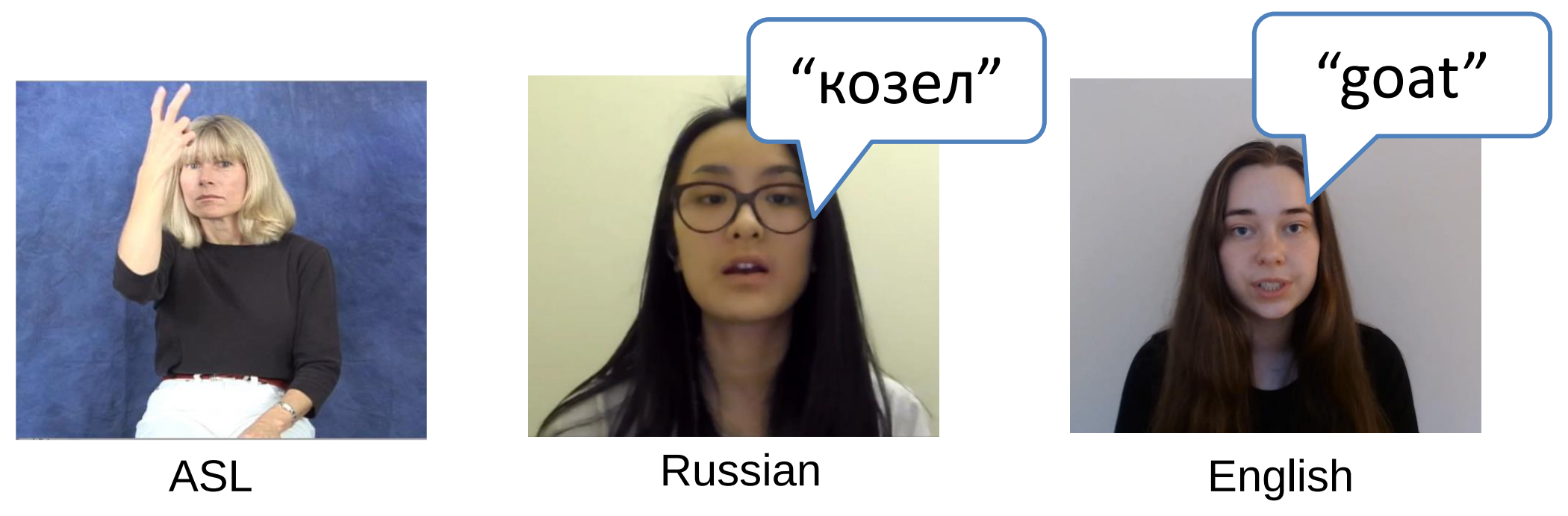
Stimuli

- Participants learned 24 concrete nouns in either ASL or Russian. Twelve of these (A) were members of target semantic categories.
- Single-word clips containing one noun each in each language. (B)
- ASL videos were provided courtesy of ASL-LEX[6] while English and Russian videos were created by lab volunteers.
- Piloting ensured nonsigners' ratings of the visual and auditory similarity between words did not correlate with the categorical structure (C).

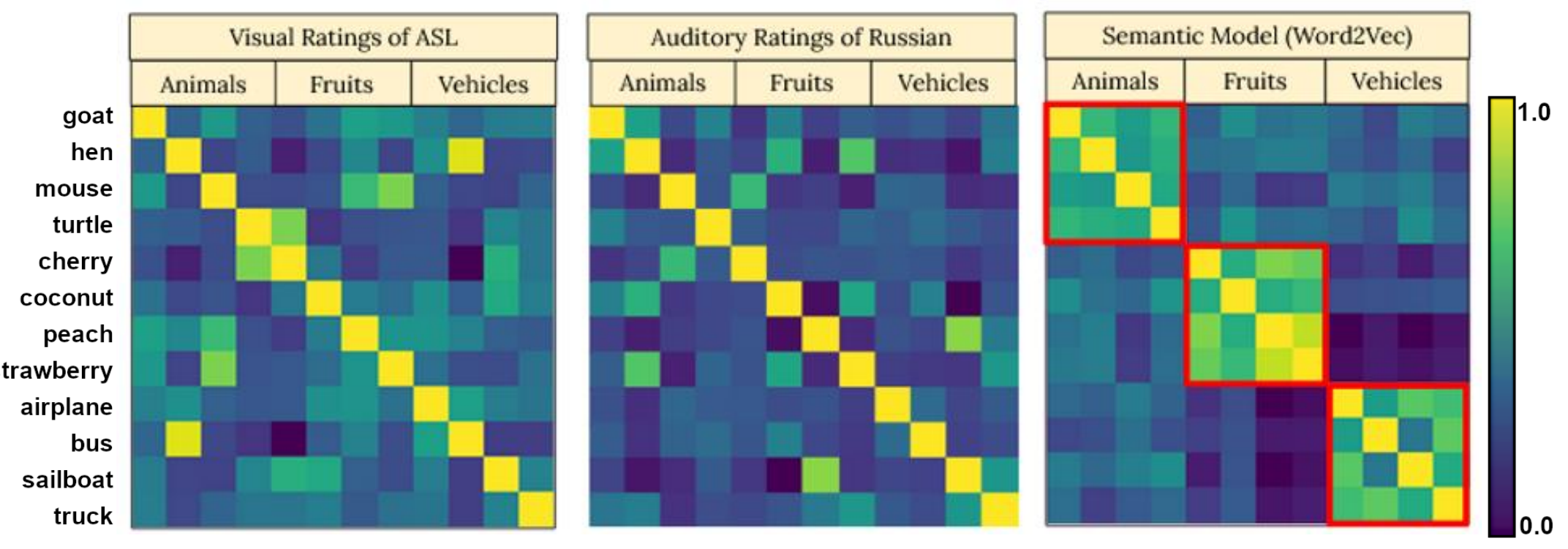
A.

Animals	Fruits	Vehicles
goat hen mouse turtle	cherry coconut peach strawberry	airplane bus sailboat truck

B.

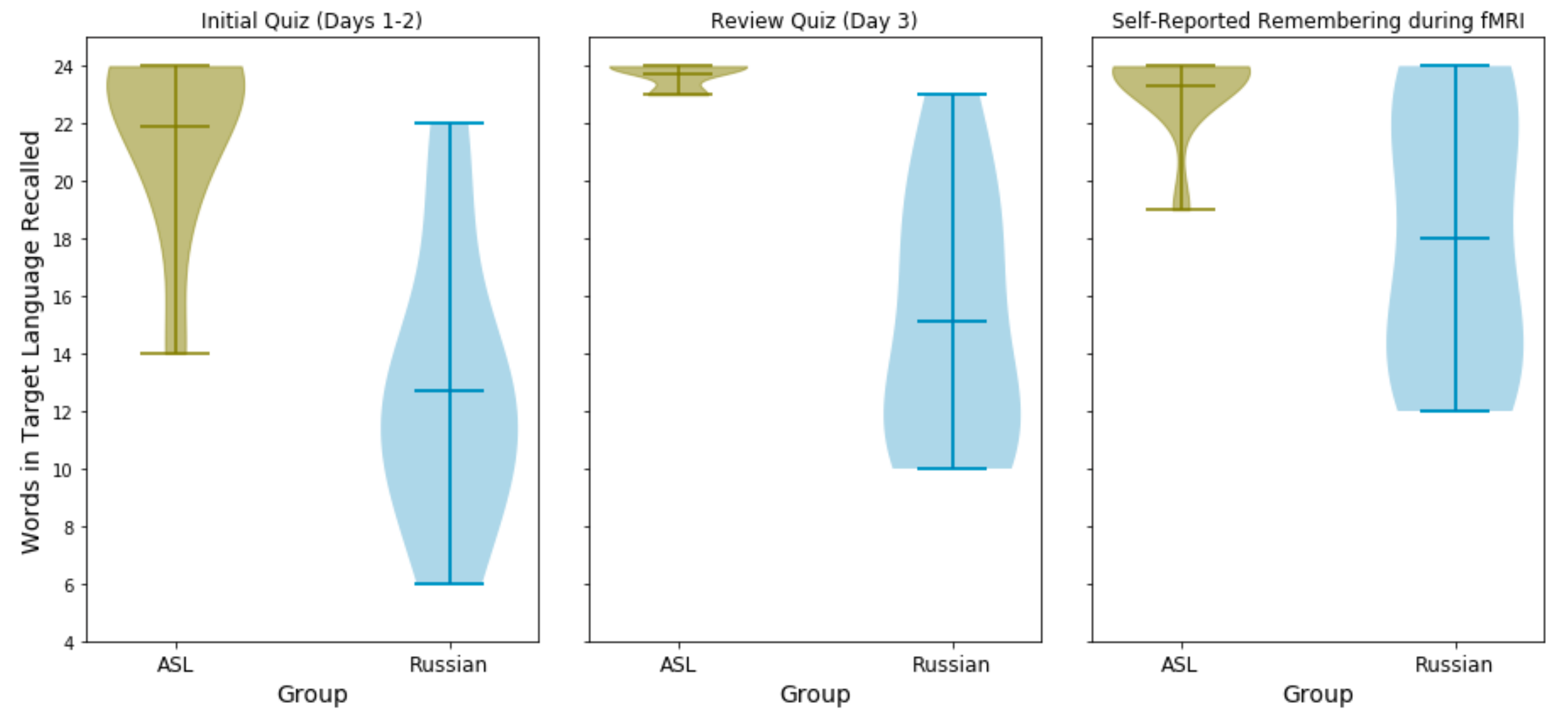


C.



Results

Behavioral Results: Recall Performance



- $M_{ASL} = 91.25\%$, $SD_{ASL} = 3.08\%$
- $M_{RUS} = 52.92\%$, $SD_{RUS} = 4.56\%$

- $M_{ASL} = 98.75\%$, $SD_{ASL} = 2.01\%$
- $M_{RUS} = 62.92\%$, $SD_{RUS} = 18.89\%$

- $M_{ASL} = 97.08\%$, $SD_{ASL} = 1.49\%$
- $M_{RUS} = 75\%$, $SD_{RUS} = 4.52\%$

Summary of Behavioral Results

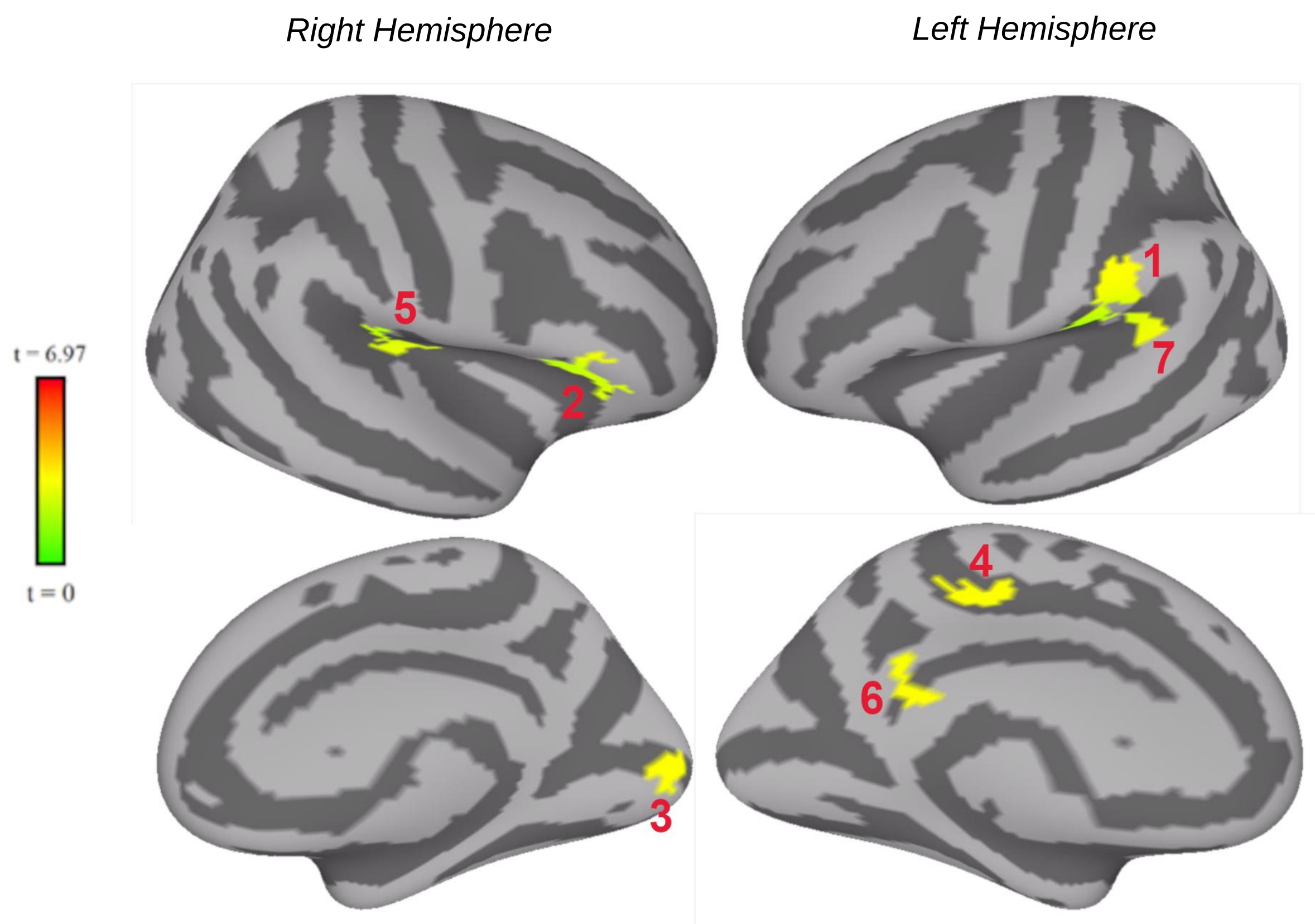
- ASL and Russian groups performed differently on the recall quizzes and scanner task
- ASL group scored at ceiling on review quiz, indicating mastery of the 24 words they had studied. For this reason, all subsequent analyses focus solely on the ASL group.

Neural Results: English RSA

Using data from **English trials only,** whole brain searchlight RSA was used to identify **7 clusters** where patterns of activity were significantly correlated with item-level dissimilarities in the semantic (word2vec) model.

We then probed these clusters for evidence of semantic category representation during the **foreign language (ASL and Russian) trials.**

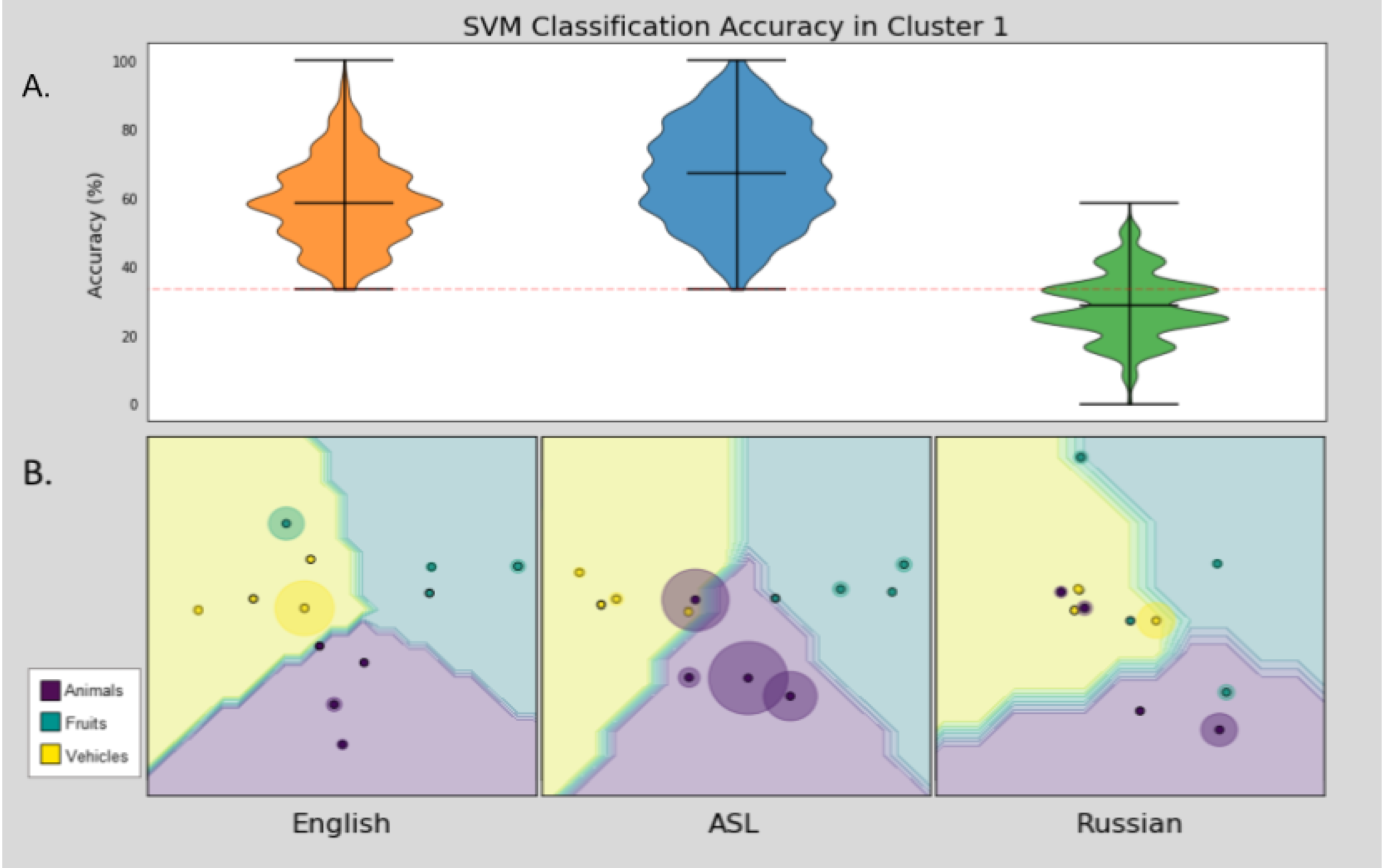
Above-chance classification of semantic categories in these clusters would provide evidence of semantic representation of words in the newly-learned language in these areas.



English RSA Results (ASL group) after cluster correction (α = .05, FDR corrected),

Neural Results: Support Vector Classification

- In each of the 7 neural clusters defined by English trials, we performed 1,000 iterations of leave-one-item-out cross-validated SVM classification for each language. (Train: 5 Ss x 9 items, Test: 5 Ss x 3 items)
- Results are shown here from the strongest cluster to emerge from the English RSA results – Cluster 1 in the left supramarginal gyrus. SVM accuracy in English is also shown as a comparison.



(A) SVM accuracies across 1000 iterations of half-sample leave-one-item-per-category-out SVM in left SMG ($M_{ENG} = 58.58\%$***, $SD_{ENG} = 12.45\%$, $M_{ASL} = 67.03\%$***, $SD_{ASL} = 14.47\%$, $M_{RUS} = 28.79\%$, $SD_{RUS} = 9.43\%$)

(B) Averaged MDS plots of target words in each language. SVM decision boundaries are also shown.

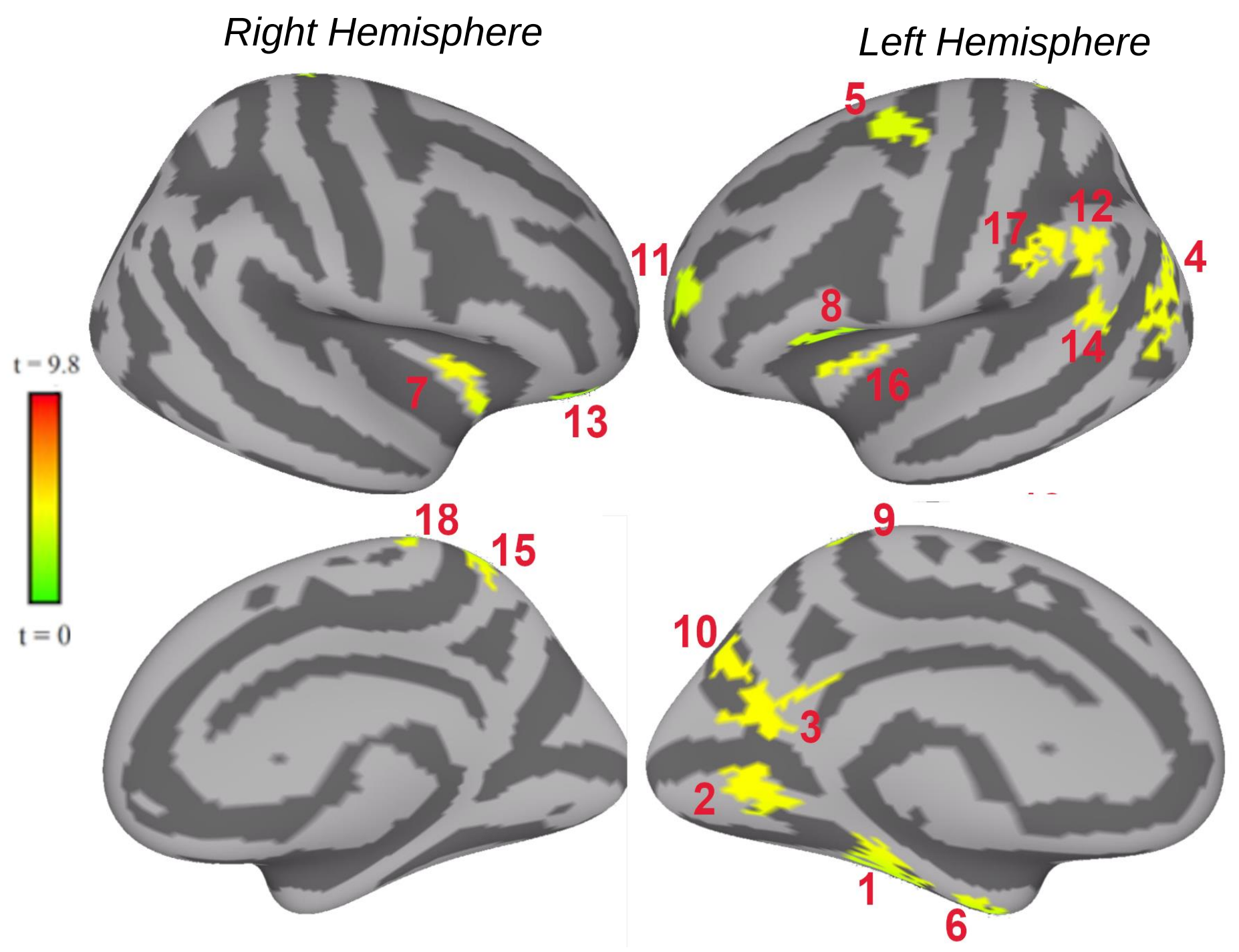
Summary of Neural Results

- All seven clusters which significantly correlated with item-level semantic information in the English RSA showed **above-chance classification of the ASL trials**, indicating the presence of semantic information for ASL.
- Similarly, several significant clusters from the ASL RSA exhibited above-chance classification of English trials.
- The best-performing cluster in both English and ASL was located in the **left SMG**, an area which has previously been associated with word recognition and phonological processing[7].
- As a negative control, evidence of semantic representation **was not observed for the unstudied language, Russian**.

Neural Results: ASL RSA

We also find **above-chance category classification of English items in several clusters identified using RSA of the ASL trials only** (18 significant clusters, α = .05, FDR corrected).

Left SMG (Cluster #17) and **left Planum Temporale** (Cluster #12) appeared in both English-only and ASL-only RSA results, and scored significantly above chance in both languages.



Conclusions and Future Directions

Conclusions:

- Ten novice ASL learners showed evidence of **item-level semantic representations** which were shared between a well-known (English) and newly-learned (ASL) language, but not an unstudied language (Russian).
- This preliminary finding provides a proof of concept for the study of shared semantic representations across language modalities (sign and speech) and suggests that these representations can be detected **even for novice learners** after a very brief training.

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Next Steps:

- In a larger-scale study, use this and similar multivariate neuroimaging approaches to not only detect, but differentiate the extent of learning in individual students.
- → ASL learners in this study learned all 24 target nouns to ceiling. Future work may encompass more complex and difficult aspects of language learning.
- Use previously developed **informational network analysis**[1] to determine whether **neural scores** predict other indicators of real-world knowledge (such as pencil and paper tests).

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