The Language-Specific Neural Basis of Word Learning from Context

Tengwen Fan (tfan1@lsu.ed)[1] & Julie M. Schneider (julieschneider@g.ucla.edu)[1,2,*]
[1] Department of Communication Sciences and Disorders, Louisiana State University, Baton Rouge, LA, USA
[2] School of Education and Information Studies, University of California, Los Angeles, Los Angeles, CA, USA

BACKGROUND

- Word learning (WL) from context relies on the activation of brain regions typically associated with language processing, like the Inferior Frontal Gyrus (IFG), Super Temporal Gyrus (STG), and Supramarginal Gyrus (SMG; Mestres-Missé et al., 2008).
- The overlapping neural activation between WL and language processing might suggest a level of neural efficiency where the brain repurposes existing circuits for new learning, explaining rapid vocabulary acquisition.
- By examining these overlaps, the current study explores how the brain supports both the acquisition and use of language, aiding both theoretical advancements and practical applications.

RESEARCH QUESTION

Which language-specific brain regions are functionally relevant for word learning from context?

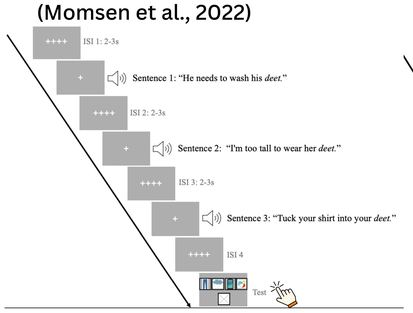
APPROACH

Participants:

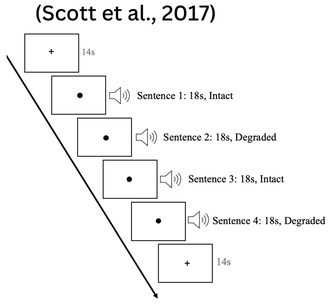
- Eighteen young adults (*M*age = 19.40 years, *SD*age = 1.64)
- All had vocabulary knowledge (NIH Toolbox PVT) within the normal range (*M* = 103.47, *SD* = 8.26, Range: 89-120)

fMRI tasks:

Auditory Word Learning (WL) (Momsen et al., 2022)



Auditory Language Localizer (Scott et al., 2017)



- The WL task had two conditions (50 trials each):
  - Meaning Plus (M+): Meaning should be identified by constraining each novel word's meaning to a single word and increasing cloze probability
  - Meaning Minus (M-): No meaning should be identified due to low cloze probability and inconsistent meanings across sentences

	M+	M-	*t*	*p*
Accuracy	0.87 (0.34)	0.88 (0.32)	-0.64	0.53
RT	1.68 (0.65)	1.73 (0.83)	-0.82	0.42

ANALYSES

Univariate Group-Level Analysis

- Group average activation across tasks & conditions.

Group-Constrained Subject-Specific Analysis

- Individual statistical maps contrasting conditions within tasks were thresholded at p < 0.01 and binarized.
- Binarized maps were overlaid across subjects to create a group-level probability map, smoothed with a 6 mm FWHM Gaussian kernel and thresholded at two subjects.
- A watershed algorithm was used to identify local maxima and assign labels to neighboring voxels, resulting in a 3D parcellation of activation probability.

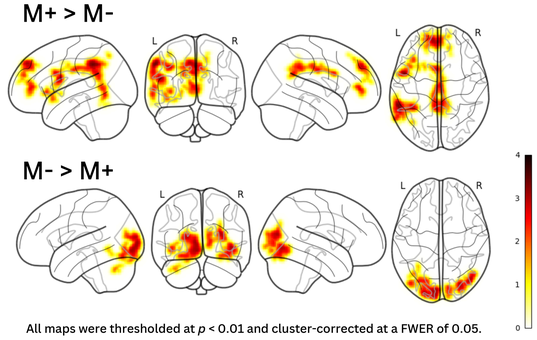
Local-Pattern Similarity Analysis (LPSA) within fROIs

- The top 10% of voxels from each subject's statistical T-map within each parcel were defined as the functional region of interest (fROI).
- Cross-task correlation values were correlated with behavioral measures of vocabulary and accuracy on the WL task.

UNIVARIATE ANALYSES

Word Learning from Context

M+ > M-

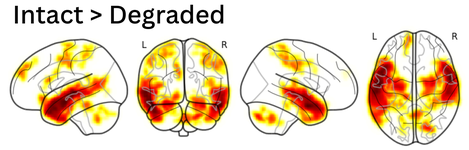


M- > M+

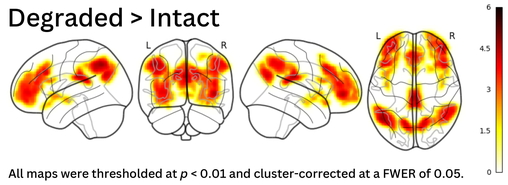
All maps were thresholded at $p < 0.01$ and cluster-corrected at a FWER of 0.05.

Language Localizer

Intact > Degraded



Degraded > Intact



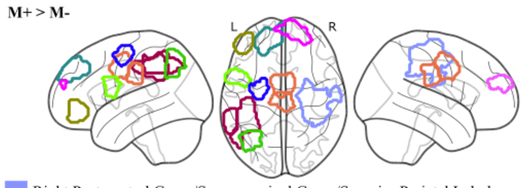
All maps were thresholded at $p < 0.01$ and cluster-corrected at a FWER of 0.05.

Conjunction analyses showed no functional overlap between tasks.

FUNCTIONAL ROIS ENGAGED DURING WORD LEARNING

Group-constrained subject-specific (GCSS; Scott & Perrachione, 2019)

M+ > M-

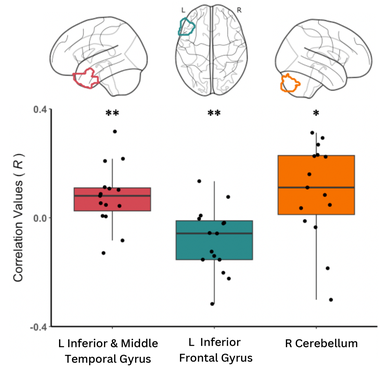


- Right Post-central Gyrus/Supramarginal Gyrus/Superior Parietal Lobule
- Left Supramarginal Gyrus
- Left Precentral Gyrus/Superior Frontal Gyrus
- Left Lateral Occipital Cortex
- Right Frontal Pole
- Left Frontal Pole
- Cingulate Gyrus
- Left Frontal Pole / Frontal Orbital Cortex
- Left Inferior Frontal Gyrus

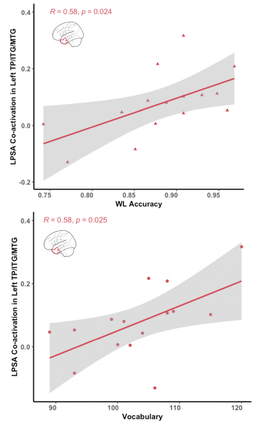
Activation of bilateral frontal regions, including the Frontal Pole, IFG, and SMG, is critical for word learning from context, similar to previous studies (Mestres-Missé et al., 2008).

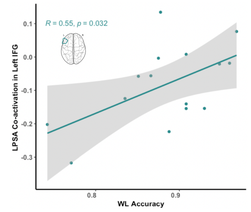
SIMILAR PATTERNS OF ACTIVATION DURING WORD LEARNING & LANGUAGE PROCESSING

Local Pattern Similiarity Analysis (Scott & Perrachione, 2019)



Existing language circuits in the LIFG, LITG/MTG, and R Cerebellum are integral for successful word learning.





Cross-task activation of the LITG/MTG was associated with greater vocabulary knowledge & higher accuracy during WL.

Negative cross-task correlations in the LIFG were positively associated with higher accuracy during WL.

CONCLUSIONS & DISCUSSIONS

- The brain efficiently repurposes key language regions for word learning (including the Left Inferior Frontal and Temporal regions (LIFG, LITG, LMTG), supporting rapid vocabulary acquisition.
  - However, WL does not activate all language-specific brain regions, suggesting a level of neural efficiency where the brain repurposes specific parts of the language network to infer the meaning of new words.
  - This neural efficiency results in higher accuracy during word learning, and is reflected in greater overall vocabulary knowledge.
- The current findings also add to recent theories implicating cerebellar function in non-motor language processing and more general learning (for review, Mariën et al., 2014; Vias & Dick, 2017).
- The negative cross-task correlation in the LIFG, related to higher accuracy on the WL task, might reflect the process of:
  - Suppressing activated competitors to refine the meaning of the novel word (Blomquist & McMurray, 2023)
  - Violation of listeners' semantic prediction resulting in the inhibition of the predicted word (Kim, Wessel & Hendrickson, 2023)

References:
Blomquist, C., & McMurray, B. (2023). The development of lexical inhibition in spoken word recognition. Developmental psychology, 59(1), 186–206. https://doi.org/10.1037/dev0001457
Kim, J., Wessel, J. R., & Hendrickson, K. (2023). Inhibition of lexical representations after violated semantic predictions. Cognition, 240, 105585.Kim, J., Wessel, J. R., & Hendrickson, K. (2023). Inhibition of lexical representations after violated semantic predictions. Cognition, 240, 105585.
Mariën, P. et al. (2014). Consensus paper: Language and the cerebellum: an ongoing enigma. *Cerebellum*, *13*, 386-410.
Mestres-Missé, A., Camara, E., Rodriguez-Fornells, A., Rotte, M., & Münte, T. F. (2008). Functional neuroanatomy of meaning acquisition from context. *Journal of Cognitive Neuroscience*, *20*(12), 2153-2166.
Momsen, J., Schneider, J. M., & Abel, A. D. (2022). Developmental differences in EEG oscillations supporting the identification of novel word meaning from context. *Developmental Cognitive Neuroscience*, *58*, 101185.
Scott, T. L., Gallée, J., & Fedorenko, E. (2017). A new fun and robust version of an fMRI localizer for the frontotemporal language system. *Cognitive neuroscience*, *8*(3), 167-176.
Scott, T. L., & Perrachione, T. K. (2019). Common cortical architectures for phonological working memory identified in individual brains. *Neuroimage*, *202*, 116096.
Vias, C., & Dick, A. S. (2017). Cerebellar contributions to language in typical and atypical development: a review. *Developmental neuropsychology*, *42*(6), 404-421.

Funding: This research was funded by the NSF Directorate for Social, Behavioral & Economic Sciences under Grant 1911462. *: Corresponding author.