Exploring the impact of semantic structure on generalization: a behavioral and fMRI investigation

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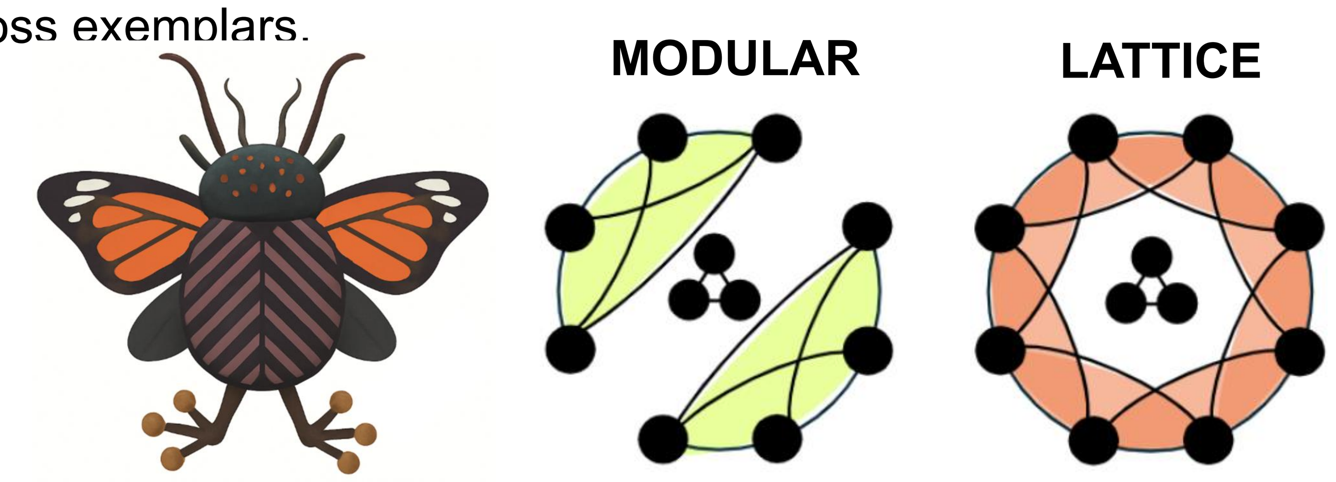
Introduction

- Learning has two goals: to remember specific instances and to generalize knowledge to new situations.
- Prior research identifies factors that support memory retention (e.g., spacing[1,2,3], retrieval[4], depth of processing[5]) and promote generalization (e.g., interleaving[6], comparison[7]), but these studies focus on how we learn, not what we learn.
- When learning a new category, the intrinsic structure (e.g., ring, hierarchy) of that category may shape how easily it is learned, and how easily it is generalized to new examples[8].

Here we integrate behavioral and fMRI data to test how the intrinsic structure of a category influences generalization and to ask whether some category structures are more generalizable than others.

Category Design

Each category has a unique set of 11 discrete features (e.g., wings, tail) which are randomly assigned to the graph nodes below. Categories are defined by one of two structures (i.e., Modular and Lattice): while the core structures are identical, the peripheral structures differ (i.e., green, orange). These structures determine how the category's features covary across exemplars.

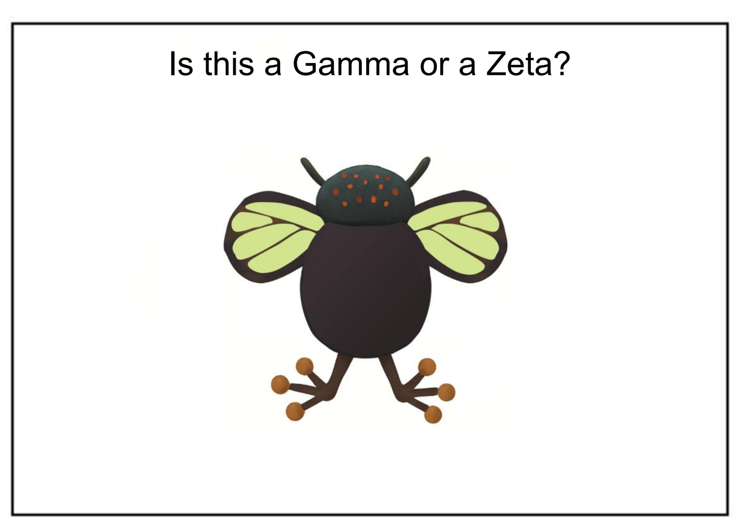


Behavioral Tasks

Learning Task

Participants learned the structure of each category by completing a 2AFC missing feature task. Feedback was provided on each trial to facilitate learning.

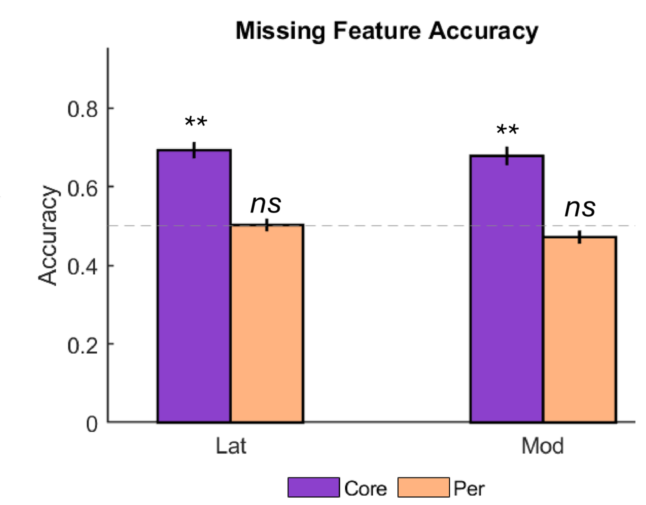
Generalization Task

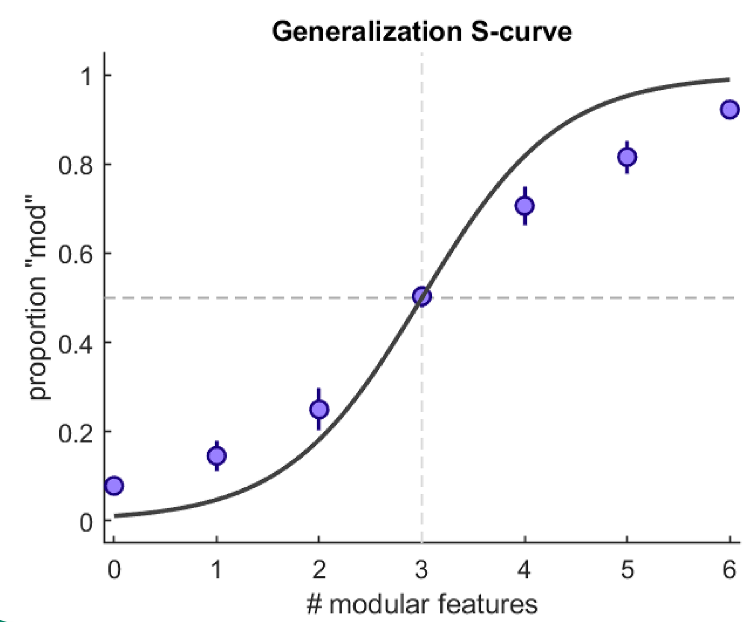


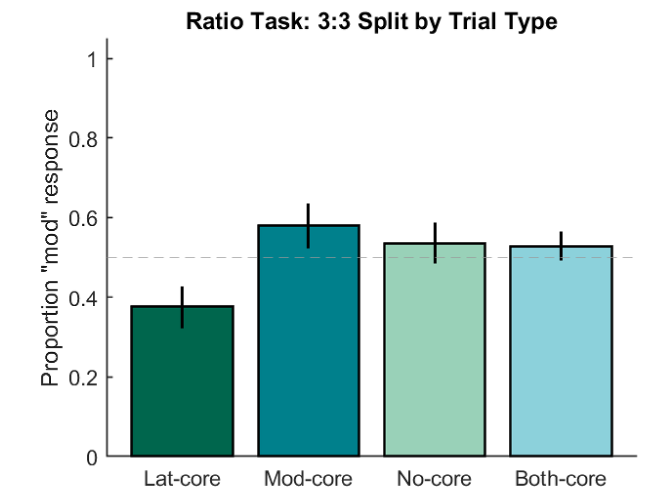
Participants were tested in a generalization task. They classified novel exemplars with varying combinations of features from both categories.

Behavioral Results: Online

Participants on AMT (N = 76), successfully learned the Modular (p<0.001) and Lattice categories (p<0.001) in the MF task. On target trials in the generalization task (3:3 ratio), no influence of intrinsic category structure on generalization was observed (p>0.5).

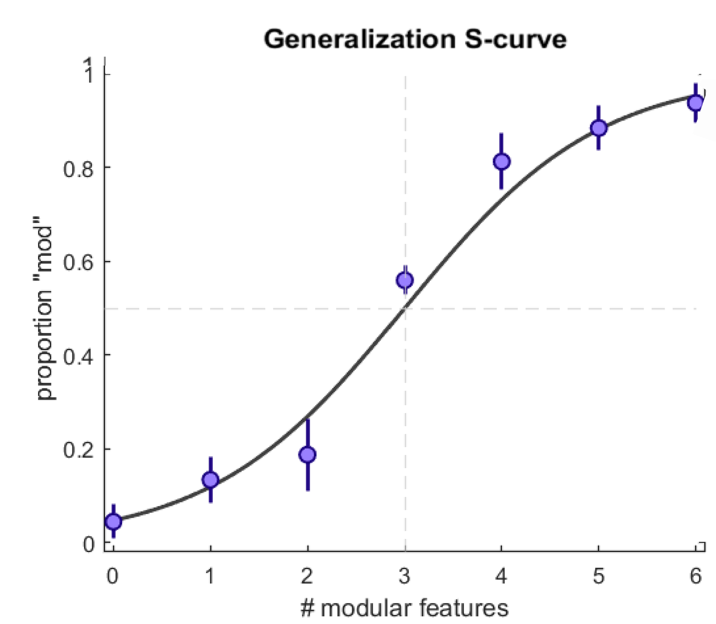


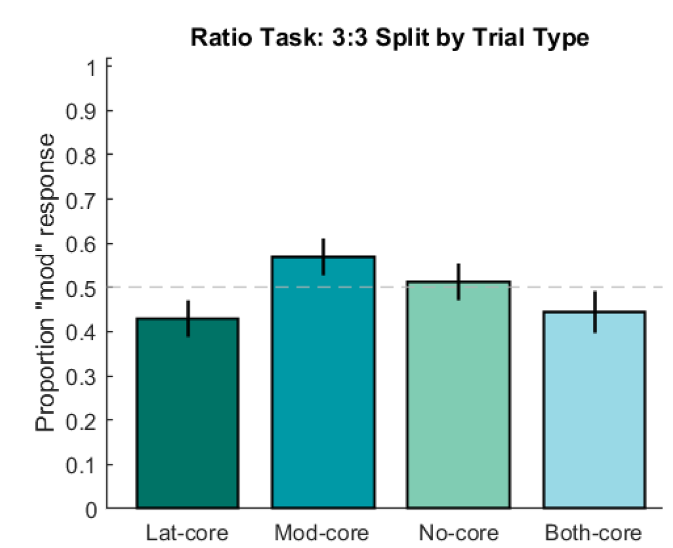




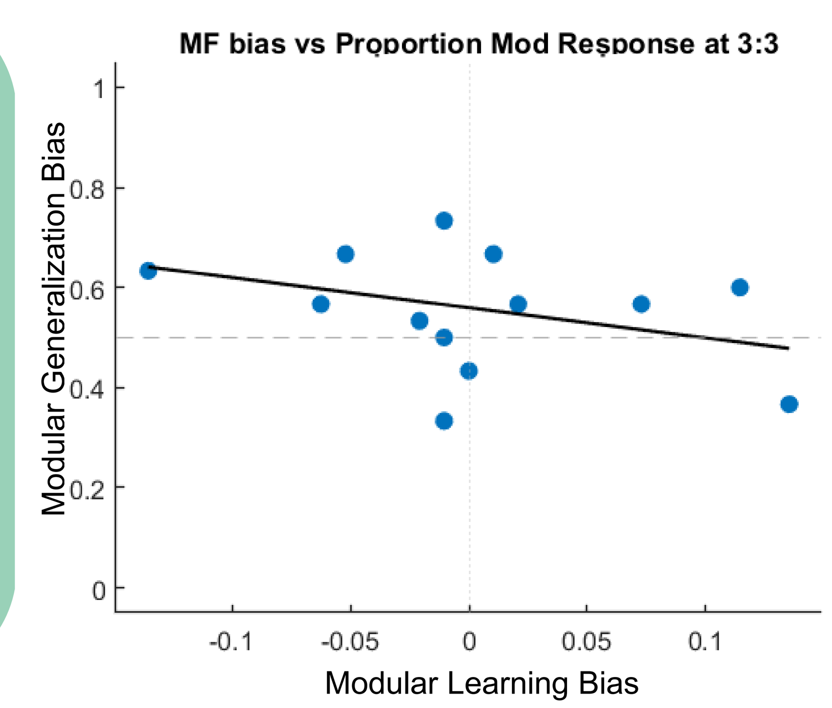
Behavioral Results: In Person

In an ongoing behavioral study (N=25), participants successfully learned the Modular (p<0.001) and Lattice categories (p<0.001) in the MF task. In the generalization task, target trials (3:3 ratio) suggest a potential influence of intrinsic category structure on generalization (p=0.04).



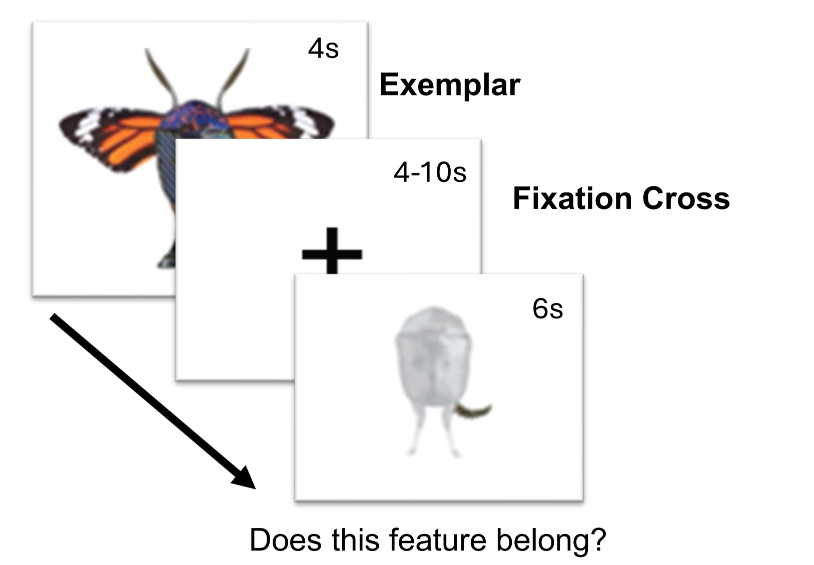


Learning Bias Analysis: Learning behavior was correlated with generalization behavior on target trials to test whether a modular learning bias predicted modular generalization bias when features from both category structures are balanced. The correlation was nonsignificant (r = -.036, p>0.2), suggesting that ease of learning and generalizability might reflect different mechanisms.

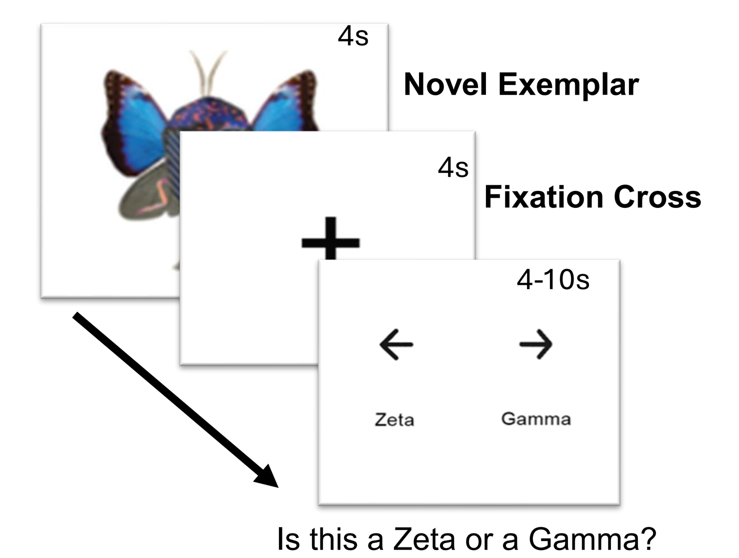


fMRI Design and Analysis

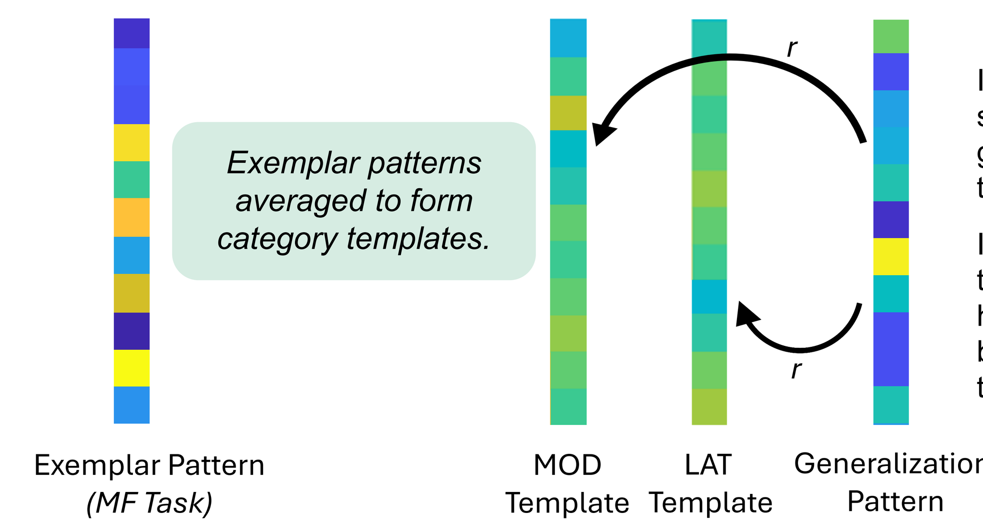
Missing Feature Task



Generalization Task



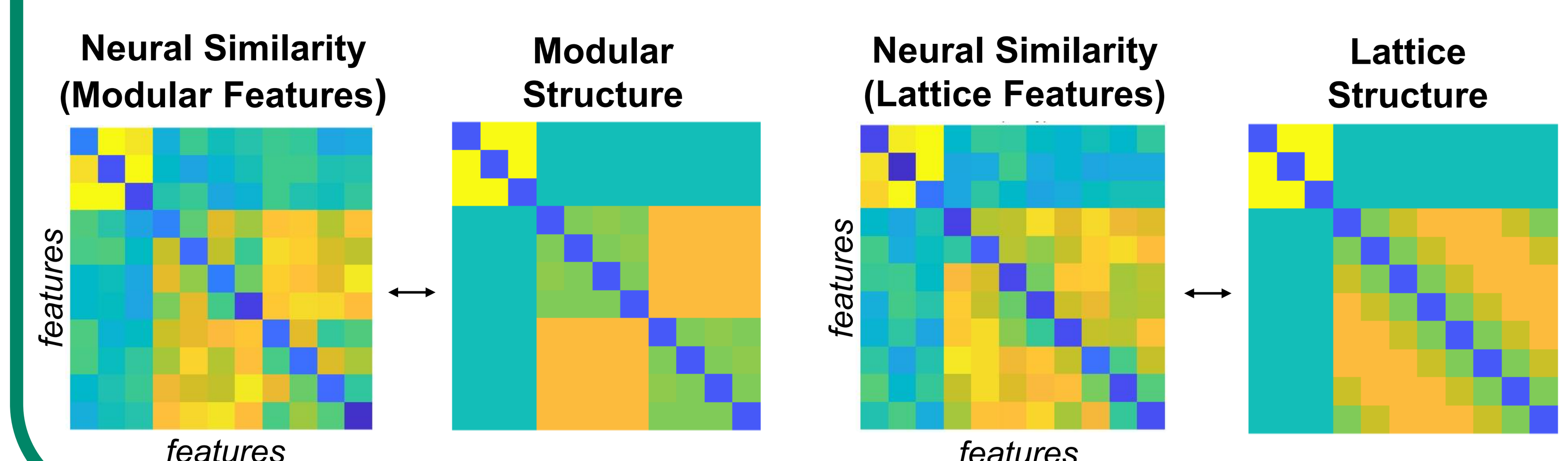
Generalization Analysis: We will compare each generalization pattern to the Modular and Lattice template patterns in individual ROIs (e.g., visual cortex, hippocampus, anterior temporal lobe) and in a searchlight analysis to probe the nature of neural representations across regions.



In regions that contain representations of the stimulus itself (e.g., visual cortex), the generalization pattern will be equally similar to the Modular and Lattice templates.

In regions that contain representations transformed by a generalization process (e.g., hippocampus), the generalization pattern will be equally similar to the Modular and Lattice templates.

Structure Knowledge Analysis: Neural similarity matrices will be compared with category structure matrices *(e.g., correlation, cosine similarity)* to measure alignment between brain representations and true category structure across brain regions in all participants.



Conclusions

- We observed successful learning of both category structures
- Initial behavioral data suggest a potential effect of intrinsic category structure on generalization behavior
- fMRI analyses will reveal neural markers of structure learning and the regions implicated in a structure-based generalization process.

1.Glenberg, 1979, Mem. Cogn. 2.Kornell, 2009, Appl. Cogn. 3.Cepeda et al., 2006, Psychol. Bull. 4. Carrier & Pashler, 1992, Mem. Cogn 5. Craik & Lockhart, 1972, J. Verb. Learn. Verb. Behav. 6. .Rohrer & Taylor, 2006, Appl. Cogn. Psych 7. Gentner, Loewenstein & Thompson, 2003, J. Educ. Psychol.. Psych. 8. Solomon & Schapiro, 2024, J. Exp. Psychol. Learn. Mem. Cogn.

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