

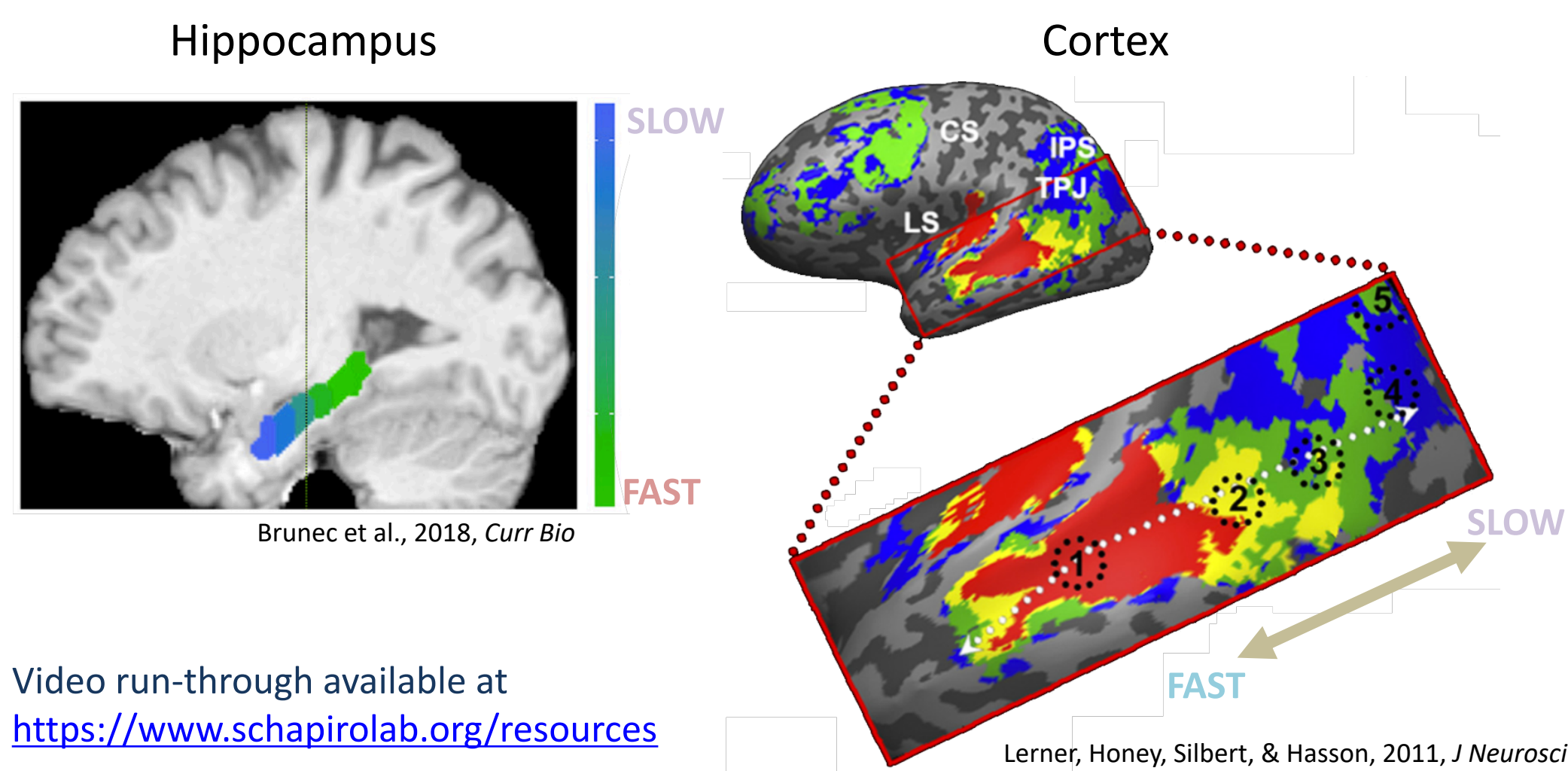
Hierarchical statistical learning: Behavioral, neuroimaging, and neural network modeling investigations

Cybelle M. Smith, Anna C. Schapiro, and Sharon L. Thompson-Schill

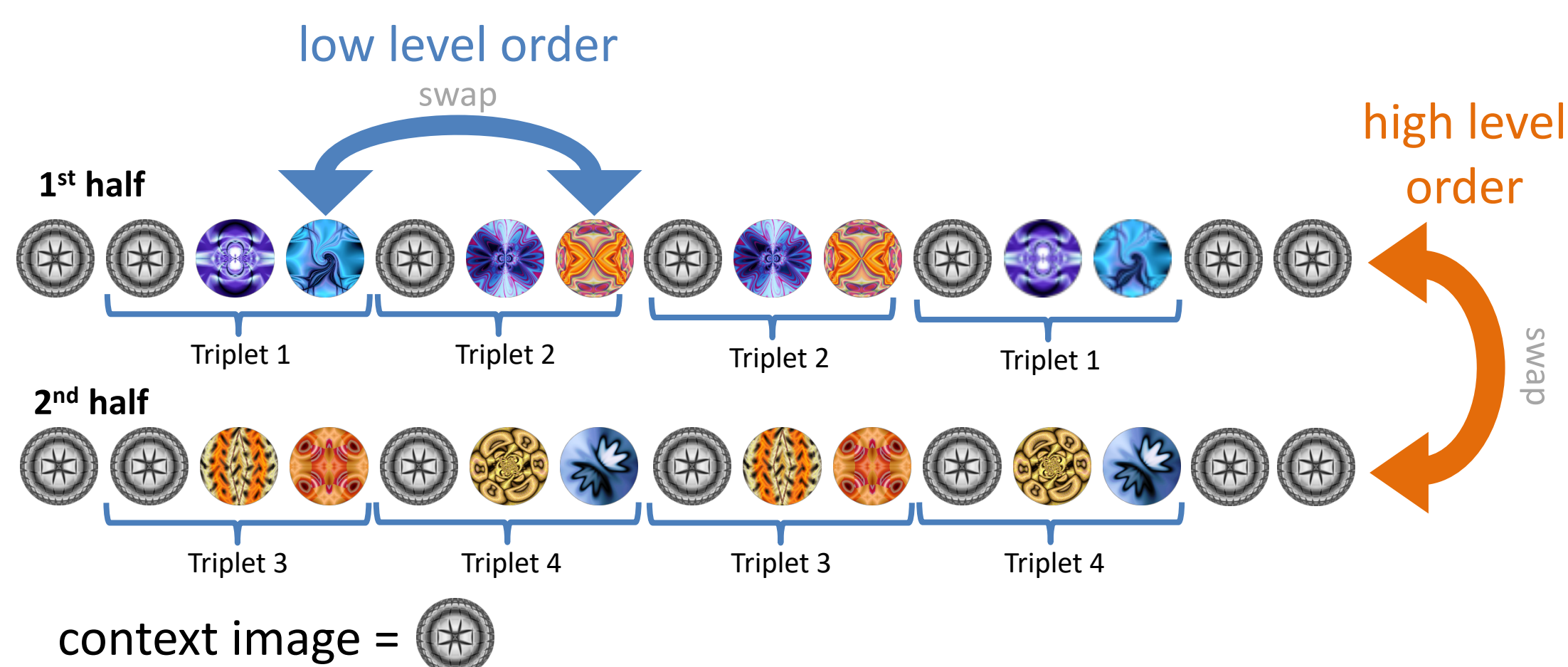
Department of Psychology, University of Pennsylvania

A Hierarchy of Time-Scales in the Brain

- How is sequential structure represented at different hierarchical levels in the brain?
- Combine statistical learning paradigm with neuroimaging: greater control than naturalistic video^[1] or audio^[2]
- Use finer-grained manipulations to assess cortical encoding of sensory dependencies across time^[3]



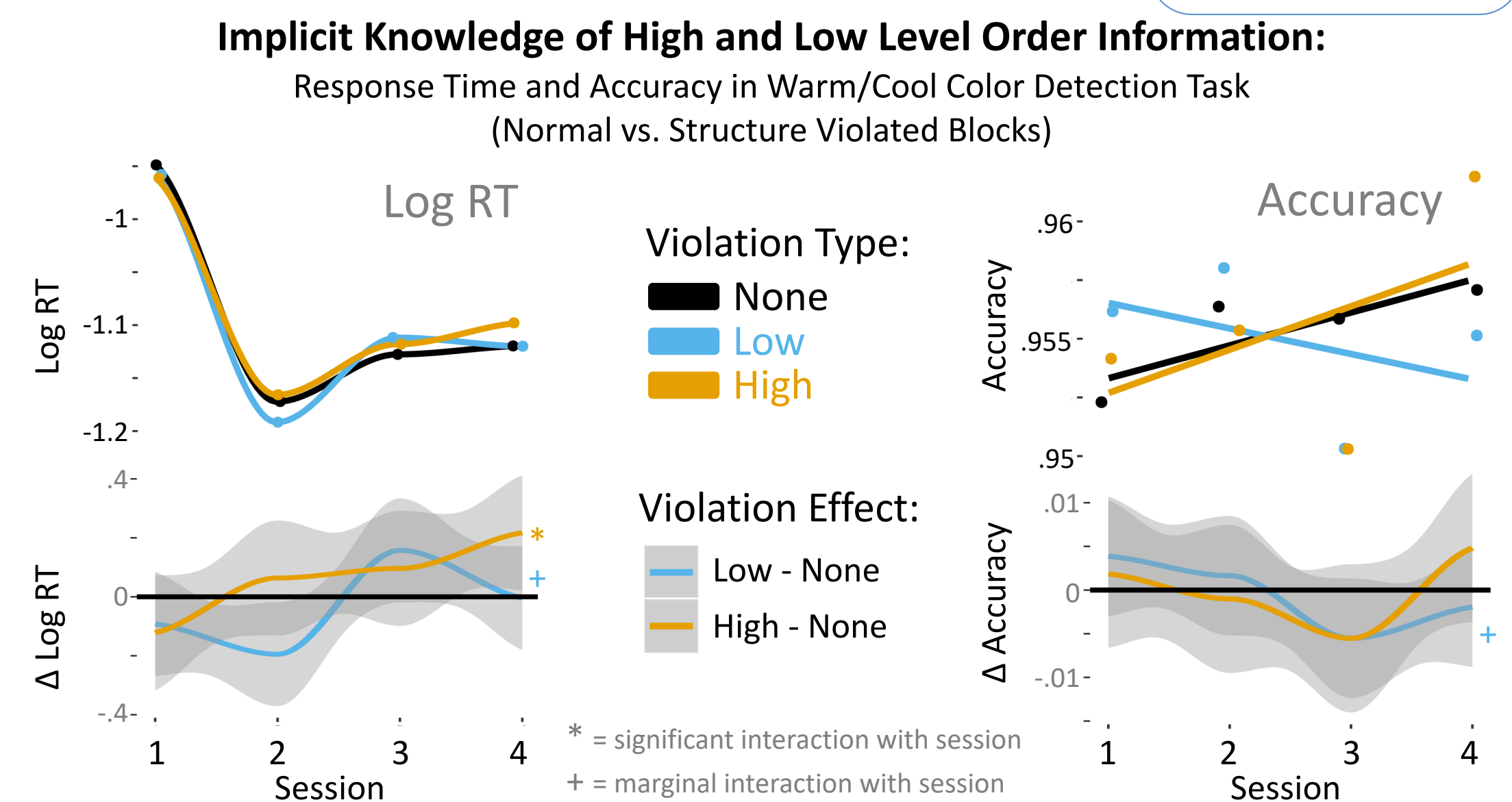
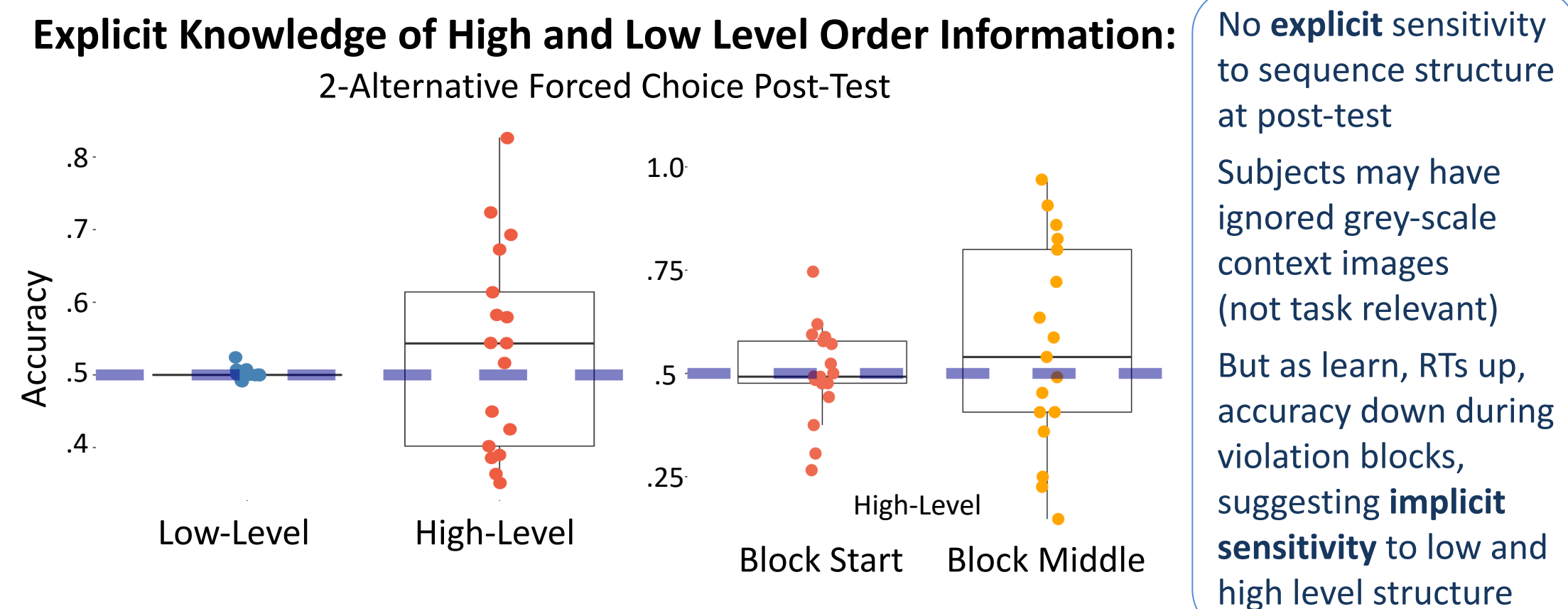
Statistical Learning Paradigm



Behavioral Experiment: Methodological Details

- N = 17, exposed to sequences over 4 sessions (~20,000 images / participant)
- 8 greyscale 'context' images, 8 colored images
- Task = warm/cool color detection (50% warm) on colored images, no button press for greyscale
- For human experiment only: context image appears exactly 4 times at start, middle, end of block, triplets immediately follow each other (for modeling, input more variable to prevent overfitting)
- 90% of blocks follow high and low level order determined by context image
- 10% of blocks follow opposite order rule (high or low level) given context
- Post-test: view a short sequence, choose which of two images comes next -- context (in)congruent
 - Low-level order: view first two images in a triplet
 - High-level order:
 - Block start: view 3x context image A, then 5x context image B
 - Block middle: view triplet (starts with context image A) followed by 5x context image A

Humans Implicitly Learn Low and High-Level Sequential Structure



Modeling Hierarchical Sequence Learning with Recurrent Neural Networks

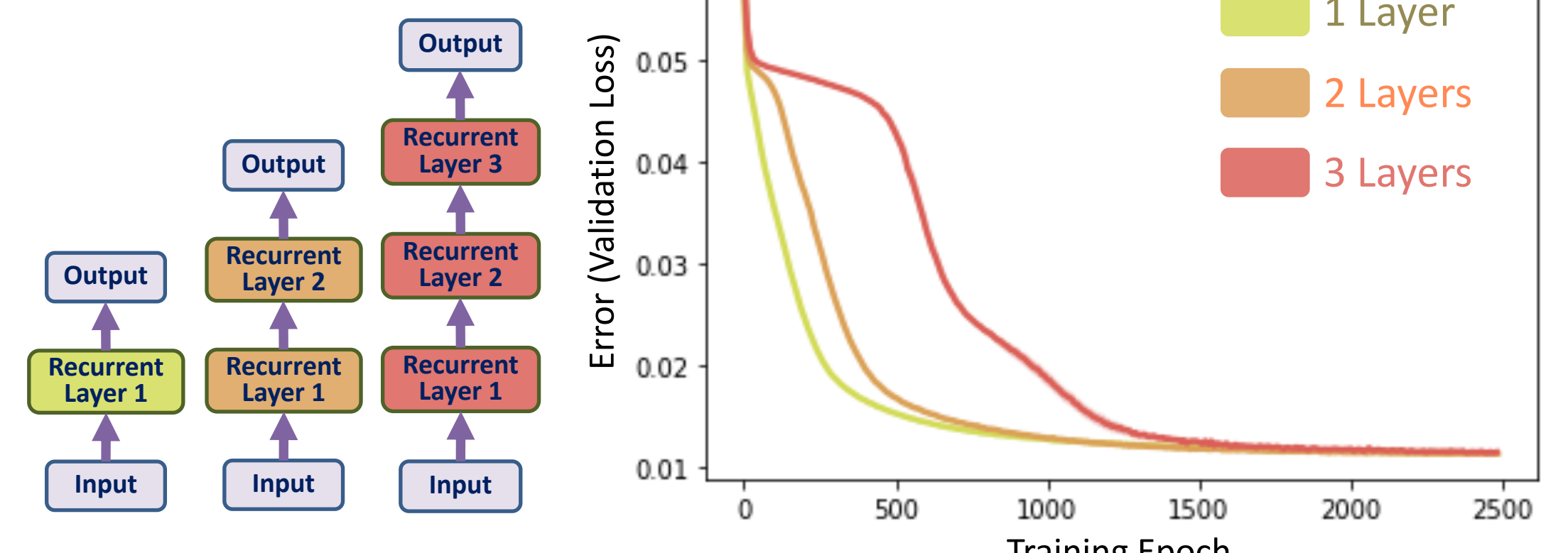
Task: Predict next image Long-Short Term Memory (LSTM)

Fix total n recurrent units (150)

Vary number of stacked layers (1-3)

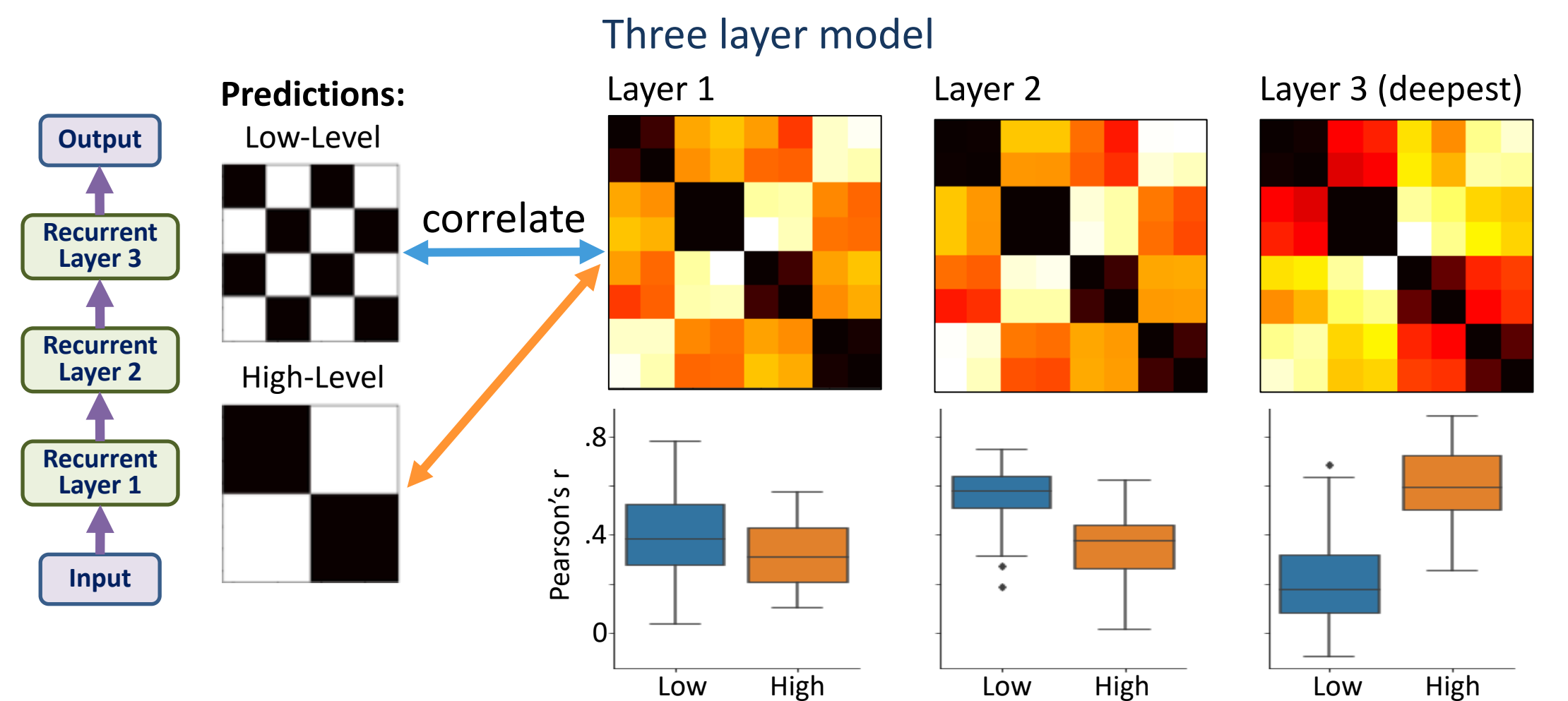
50 instances per model type

one-hot encoding of 16 images

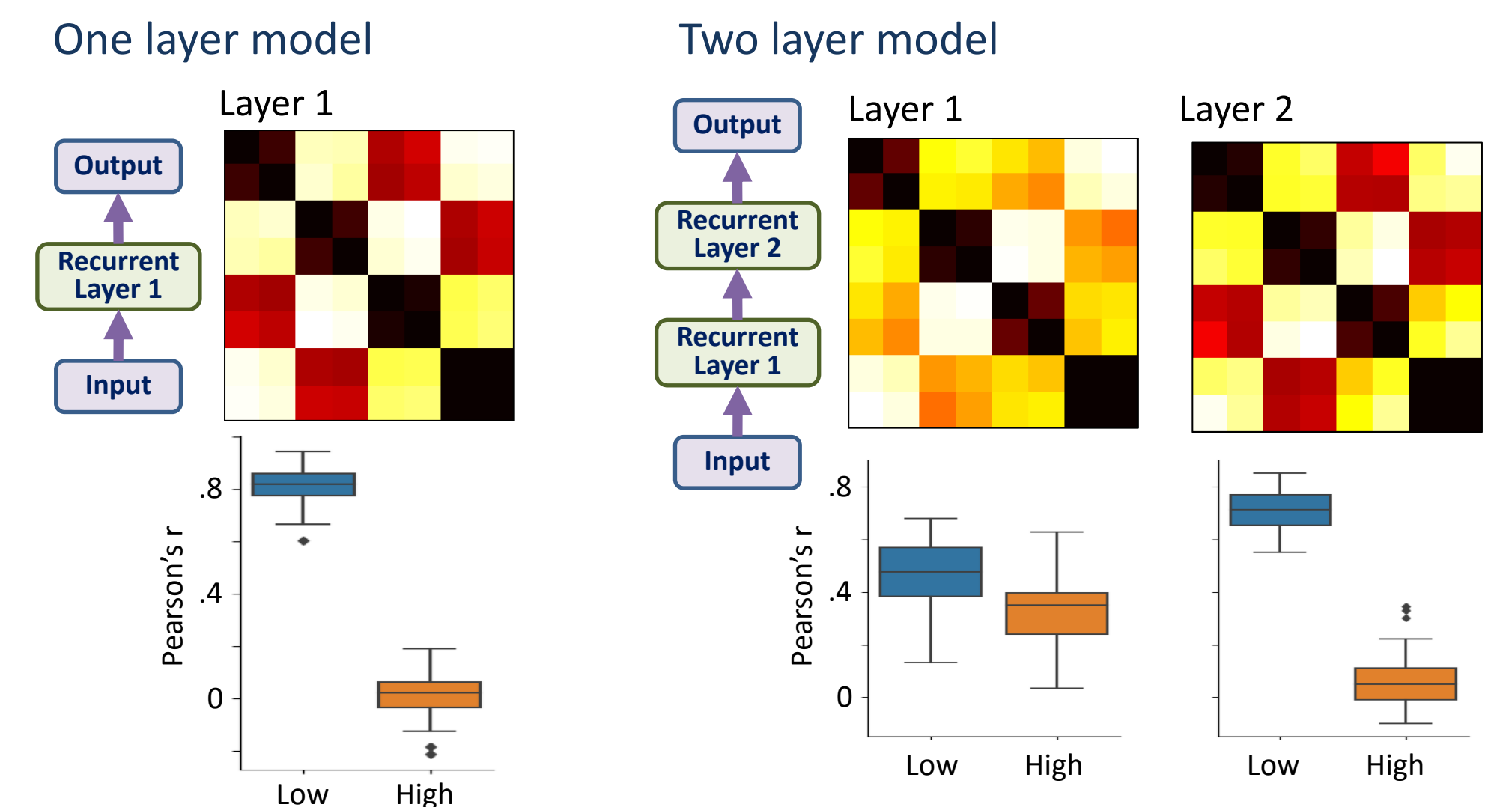


'Deep' Neural Networks Show Temporal Gradient

Deeper layers group context images based on **longer** time-scale order information



Pattern similarity to high-level structure is contingent on sufficient network depth



Conclusions

- Humans show implicit sensitivity to both low and high level sequential structure after extended learning (~20,000 images)
- Deep layers in neural network (LSTM) more sensitive to high-level structure of input, but need sufficient depth

Future directions:

- Further behavioral piloting to improve learning of low & high-level structure
- Model comparison with existing sequential learning models (e.g. HAT^[4])
- Collection of fMRI + EEG data
 - EEG during learning – implicit measures of learning low and high level structure
 - fMRI pre-post learning response to context cue images (pattern similarity)
- Comparison with auditory sequence data

References

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