# Learning Context-Dependent Temporal Associations Across Time-Scales

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## 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]
- Finer-grained manipulations to assess cortical encoding of sensory dependencies across time[3]
- Visuo-spatial task with motor and sequence-learning components:
  - Engaging - may facilitate learning complex novel associations
  - Sequence learning and spatial memory -> bias towards involvement of fronto-parietal regions (only coarsely mapped in naturalistic paradigms)
- Poster copy and video run-through available at tinyurl.com/stslabposters.

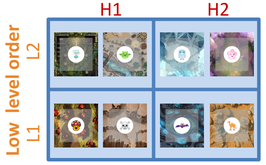
## Novel Statistical Learning Paradigm

### Paradigm: Whack-a-mole

Participants played 8 games that varied in similarity on low- or high-level structure

2 high-level x 2 low-level order conditions

2 games / condition (within subjects)




Low level order: triplet identity (what is 3rd position in each triplet)

High level order: which set of triplets comes in 1st half vs 2nd half of game

So, L1H1 and L1H2 games have the same triplets but in different halves

L1H1 and L2H1 games have different triplets, but same locations in each half

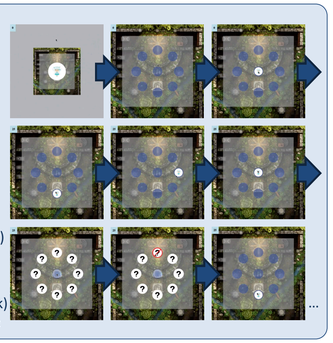
### Anatomy of a Game

Click target image where it appears (9 locations)

Target appears 27 times / game (~35 s / game)

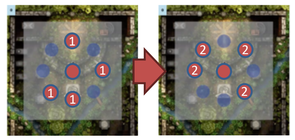
**Shared structure across games**:
- 4 triplets, 3 center trials, 4 triplets
- Triplets all start in center
- Each half of game: 2 triplets shown twice each (differ by half)

**Prediction trial:**
Select where predict target will appear next (w/ feedback)
1/game till last round -> 3/game



Example of Low-Level Order: Triplets present in 1st Half of Game

Example of High-Level Order: Positions in First vs. Second Half of Game



### Procedure

Total session time: ~1 hour 15 min

Instructions & practice game
Practice game held out (random order)

Exposure to games (8 rounds of 8 games)
64 total games
~35-40 min training round: play every game once

Expt 1 instruct
Expt 2 instruct

Similarity judgement task
2 AFC, relate to target

Exit survey
Probe explicit knowledge

### Similarity Judgement Task

After playing games, asked to judge similarity based on order of location target appeared in each game

Expt 1 instructions: Base judgments on when/where the target appeared.

Expt 2 instructions: Base judgments on sequence of locations target appeared in.

Example Trial:


Trial Types:

Attention Check: One game identical to top game

Same Conditions vs. Both High and Low Level Order Different

Same Conditions vs. Different Low Level Order

Same Conditions vs. Different High Level Order

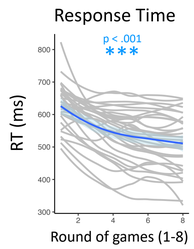
Both Different vs. Same Low Level Order

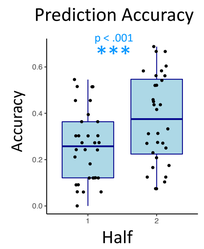
Both Different vs. Same High Level Order

N = 32 (16 per instruction condition, recruited online for course credit)

## Results: Successful Acquisition of Low and High-Level Sequential Structure

### Expts 1 & 2: Learning reflected in response time, prediction accuracy



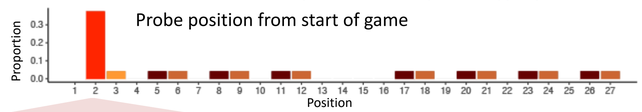




Gross measures suggest learning of game structure:

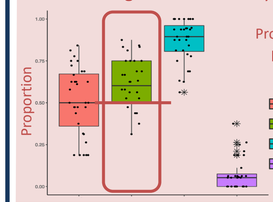
Target onset to target click RTs decline

Prediction accuracy improves from first to second half of exposure

### Expts 1 & 2: Prediction Performance by Trial and Response Type (2nd Half of Exposure)



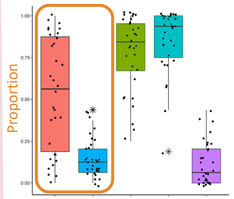

High level sensitivity




Probe first non-center location in game:

**Response Type**
- Correct rules
- No high-level swap
- No swapping 2nd & 3rd
- Multiple error sources

Low level sensitivity




Probe final location of each triplet (positions 3,6,9 ...)

**Response Type**
- Correct rules
- Baseline: Triplet swap within half-game
- No high-level swap
- No swapping 2nd & 3rd
- Multiple error sources

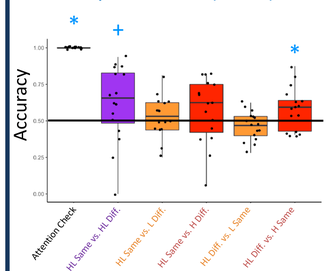
**Explicit prediction of target location**:

By the second half of training, participants showed sensitivity to high-level order condition, predicting locations from the correct half of the game >50% of the time

They were also sensitive to low-level order condition, but this may partly reflect a recency weighted strategy (using recently viewed sequences to help, rather than reliance on game image)

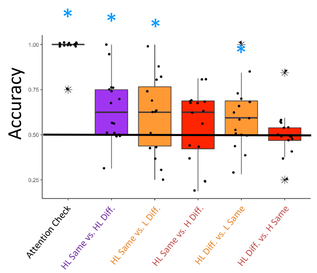
### Similarity Judgement Task Results: Instructional Bias

Experiment 1 (N=16)




When/where the target appeared

Experiment 2 (N=16)




In what sequence of locations the target appeared

* = p < .05 uncorrected
\+ = p < .1 uncorrected

Test of:
- Attention
- High & Low
- Low
- High

Participants show above chance sensitivity to high-level order condition of games when judging similarity based on "when/where the target appeared" but are sensitive to low-level order condition when asked to judge based on the "sequence of locations."

## Planned fMRI + EEG Study Design

**Session 1:** Scanned (fMRI)

Pre-exposure Baseline: View game images 10 trials / game

**Session 2:** EEG recorded

Pre-exposure Baseline (EEG)

Instructions & practice game

Exposure to games (8 rounds of 8 games)

Post-exposure Test (EEG)

Sim judge: High

Sim judge: Low

**Session 3:** Scanned (fMRI)

Re-exposure to games (8 rounds of 8 games)

Post-exposure Test: View game images 10 trials / game

Sim judge: High

Sim judge: Low

Exit survey

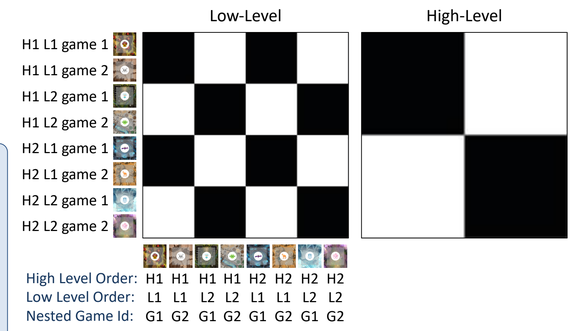
### Pre/post exposure:

...

Design Challenges:
- Baseline similarity structure of game images
  - Counterbalance image assignment
  - Pre vs. Post exposure

post-test: passive viewing only vs. also asked to think about order info.?
- Online measure of learning – adaptation for use w/ EEG
  - keypad, central fixation
  - similarity judgement structure

### fMRI pattern similarity analysis:




| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| High Level Order: | H1 | H1 | H1 | H1 | H2 | H2 | H2 | H2 |
| Low Level Order: | L1 | L1 | L2 | L2 | L1 | L1 | L2 | L2 |
| Nested Game Id: | G1 | G2 | G1 | G2 | G1 | G2 | G1 | G2 |

Whole-brain search-light + ROIs: anterior & posterior hippocampus, vlPFC, mPFC

## Conclusions

- Humans show implicit sensitivity to both low and high level sequential structure, as captured in on-line prediction task and post-training similarity judgements
- Instructions of similarity judgment task bias responding to differentially weight high and low-level order information

### Future directions:

- Preregistered replication of bx'l results; separate extensions of bx'l paradigm
- Computational modeling of bx'l paradigm (inform neural predictions)
- Collection of fMRI + EEG data
  - EEG during learning – implicit measures of learning low and high level structure
  - fMRI pre-post learning response to game images (pattern similarity of contextual cues)

### References

1. Hasson, U., et al., (2008). *J Neurosci*, *28*(10), 2539-2550.
2. Lerner, Y., Honey, C. J., Silbert, L. J., & Hasson, U. (2011). *J Neurosci*, *31*(8), 2906-2915.
3. Hasson, U., Chen, J., Honey, C. J. (2015). *Trends Cog Sci*, *19*(6), 304-313.

### Acknowledgements

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