Parallel Processing of Color and Shape During Visual Search

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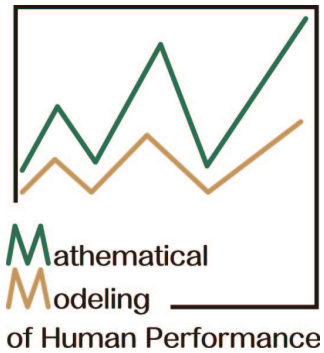
DEPARTMENT OF
PSYCHOLOGY



Serial or Parallel?

- How do basic visual features (e.g., color and shape) influence attention?
- Example: Treisman and Gelade (1980)
  - Parallel stage: Features processed in separate salience maps
  - Serial stage: Each item is attended one at a time and its features are bound into a coherent object
- Search slopes (right) often used as evidence

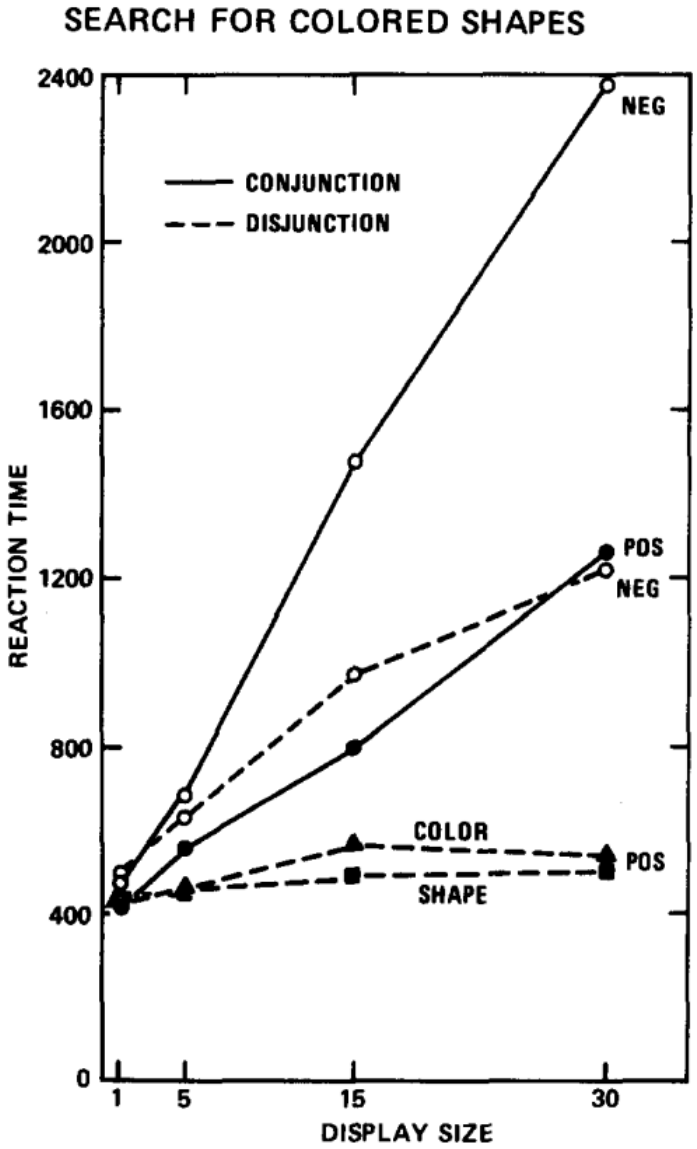


FIG. 1. Search times in Experiment I.

Search Slopes Cannot Distinguish Serial or Parallel

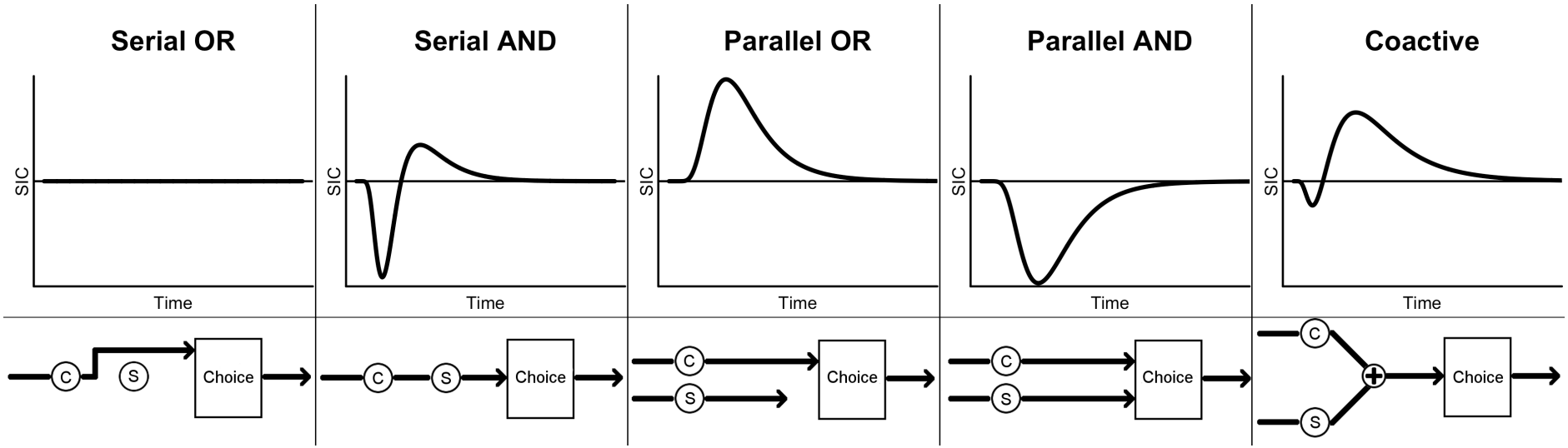
- Search slopes do not control for workload
- Potential for model mimicry (Townsend, 1972; Little et al., 2017; Townsend and Nozawa, 1995)
  - Example: limited capacity parallel models can produce positive search slopes
- Other methods have been developed
  - Multifeature Whole-Report Paradigm (Kyllingsbæk and Bundesen, 2007)
  - Redundant Target Paradigm (Miller, 1982)
- The opportunity exists for more direct evidence for parallel or serial processing

Study Goals

- Use Systems Factorial Technology (Townsend and Nozawa, 1995) to investigate the temporal organization of color and shape feature processing in visual search
  - Feature dimensions – NOT items
- We hypothesize color and shape to be processed in parallel
  - Many prominent theories assume parallel feature processing at some point (e.g., Wolfe, 2007; Bundesen, 1990)
- We will explore any trends in workload capacity or variation in stopping rule

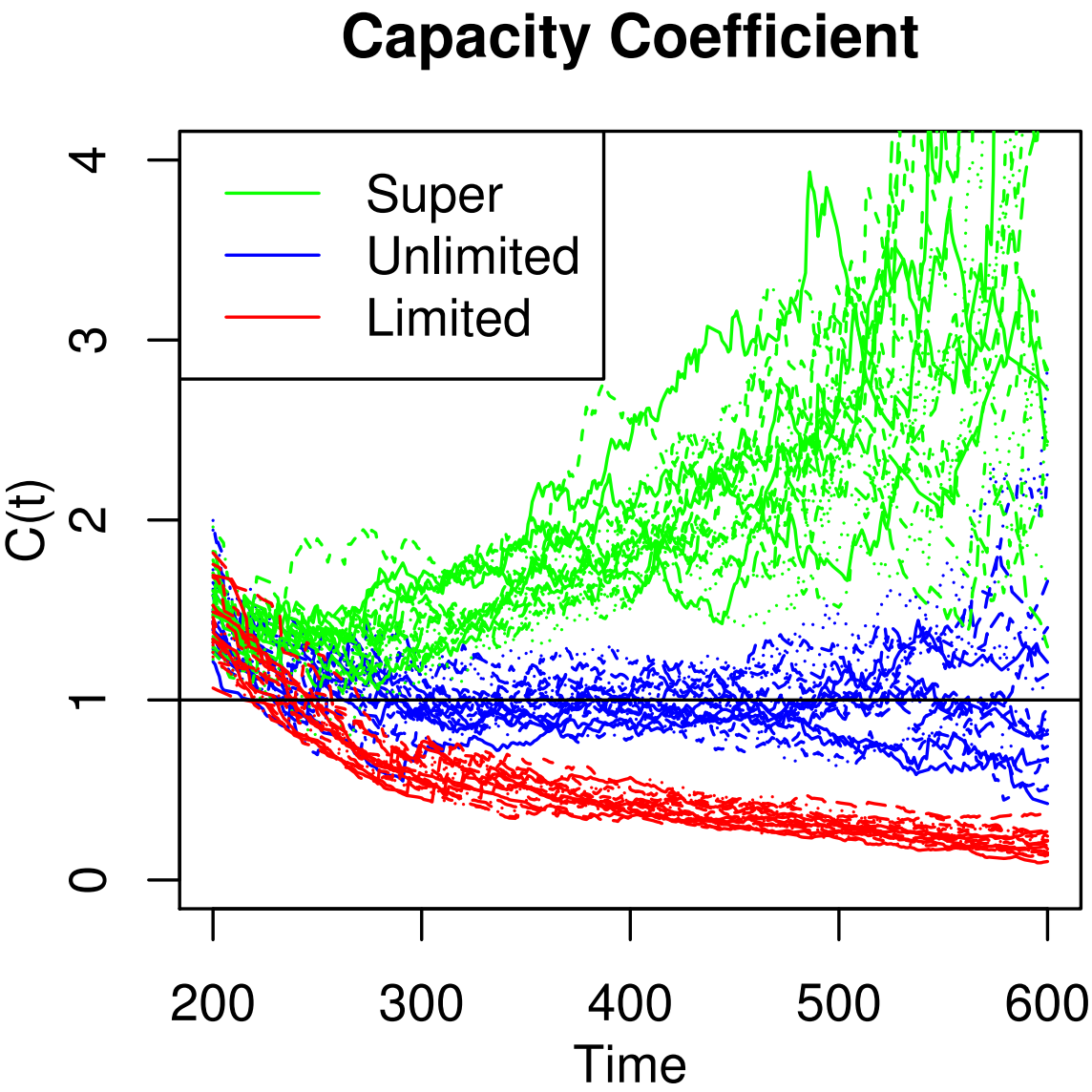
Systems Factorial Technology

$$\mathrm{SIC}(t) = [\mathrm{S}_{\mathrm{LL}}(t) - \mathrm{S}_{\mathrm{LH}}(t)] - [\mathrm{S}_{\mathrm{HL}}(t) - \mathrm{S}_{\mathrm{HH}}(t)]$$



$$\mathrm{MIC} = [\overline{\mathrm{RT}}_{\mathrm{LL}} - \overline{\mathrm{RT}}_{\mathrm{LH}}] - [\overline{\mathrm{RT}}_{\mathrm{HL}} - \overline{\mathrm{RT}}_{\mathrm{HH}}] = \int \mathsf{SIC}(t)\ dt$$

Workload Capacity



$$C_{OR}(t) = \frac{H_{1\ldots n}(t)}{\sum_{i=1}^{n} H_i(t)}$$

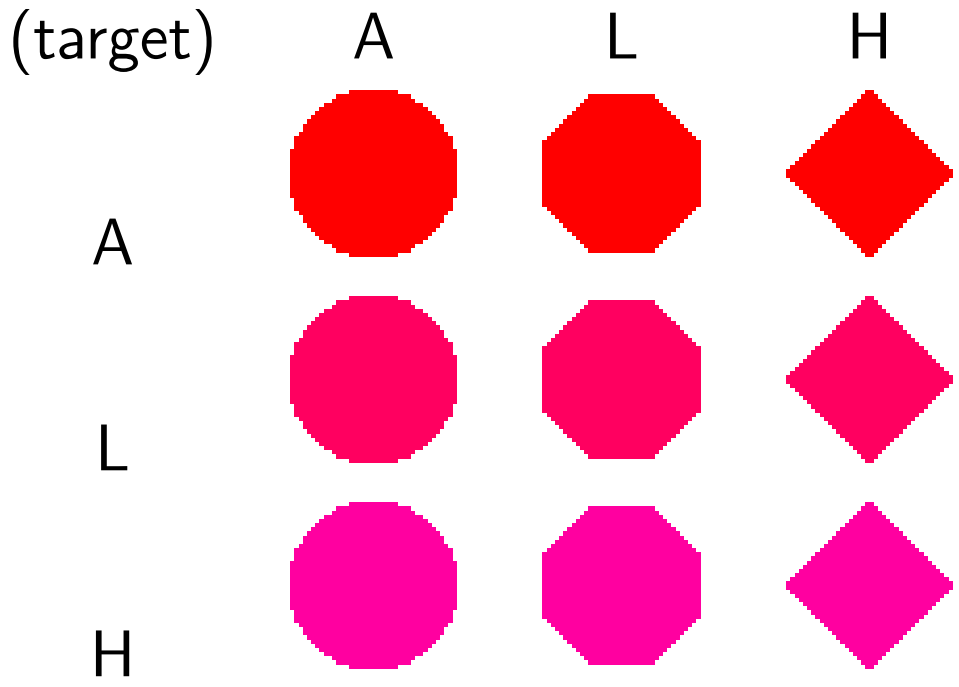
$$C_{AND}(t) = \frac{\sum_{i=1}^{n} K_i(t)}{K_{1\ldots n}(t)}$$

Baseline Model:
Unlimited **C**apacity
Independent **P**arallel
(UCIP) Processing

General Method

- 15 subjects in each experiment
- Always 24 items in display
  - Randomly placed and available until response
- Target present on half of all trials
  - Yes/No response
- Manipulate target-distractor dissimilarity
- Three blocks per session, 4-5 sessions (drop first)
  - Two single-feature blocks to measure UCIP baseline
  - Dual-feature block to measure SIC and MIC

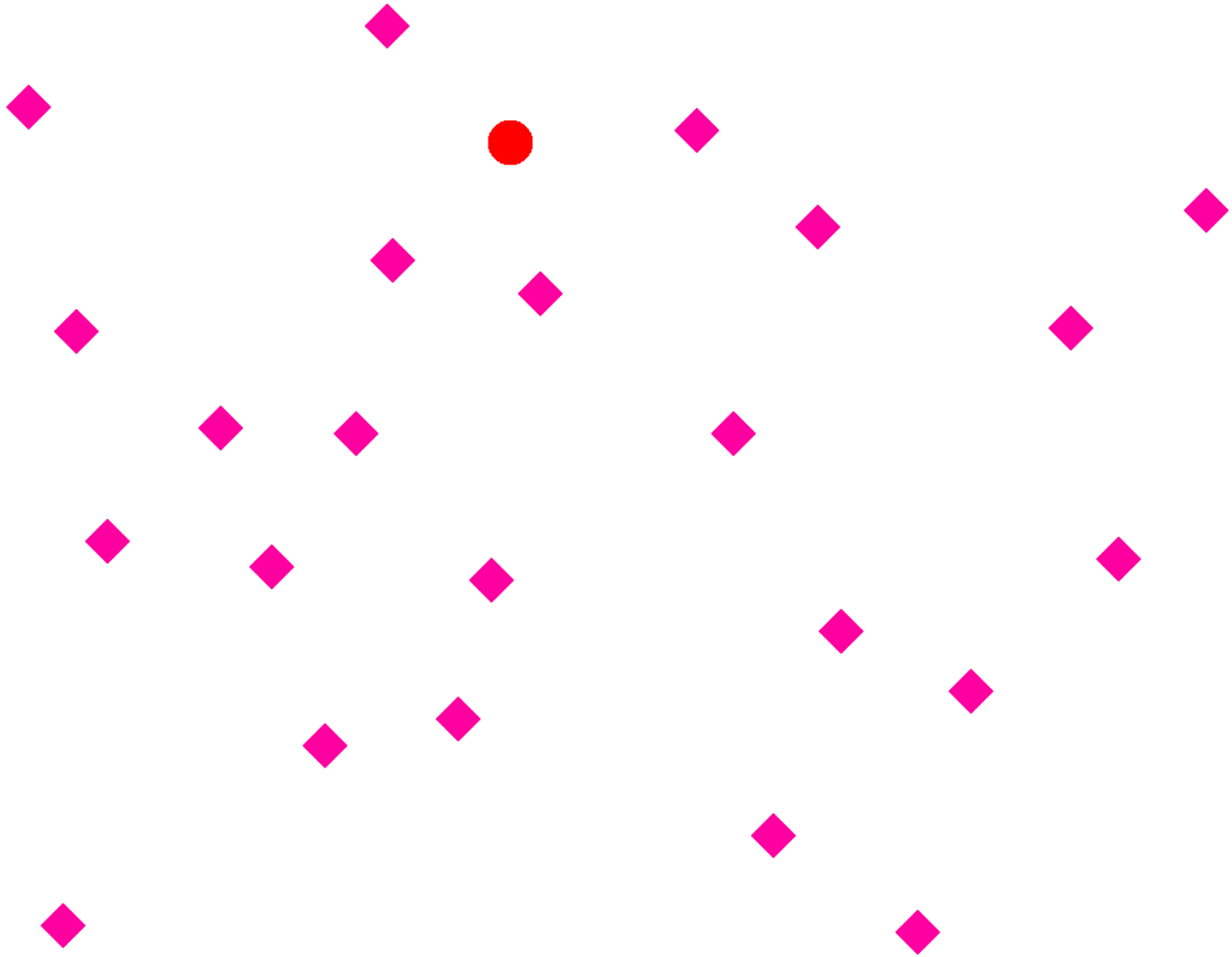
Experiment 1 — Feature Search



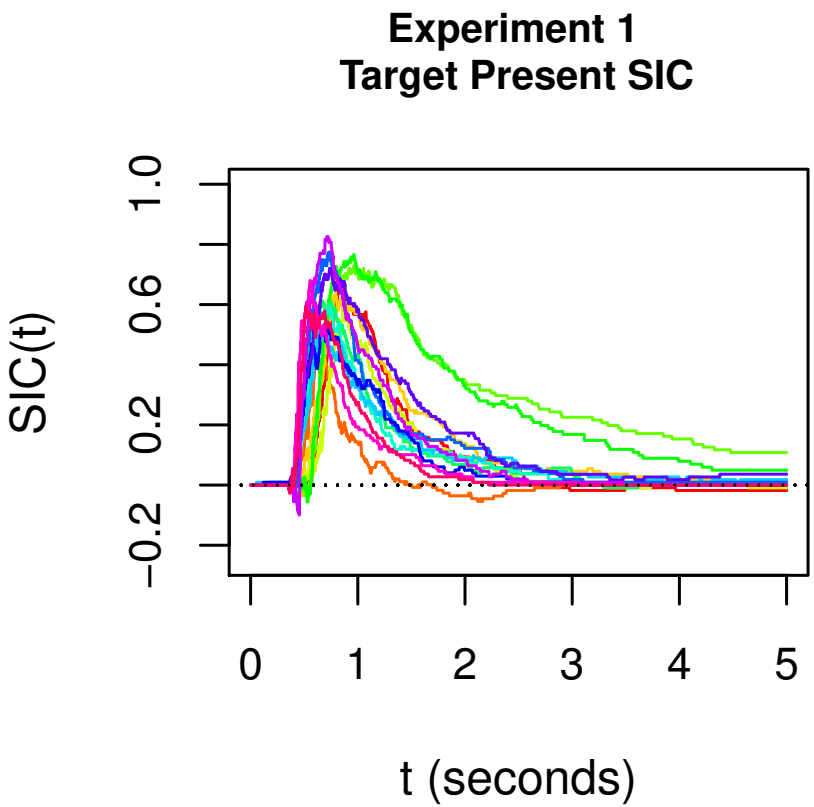
Degree of dissimilarity to the target

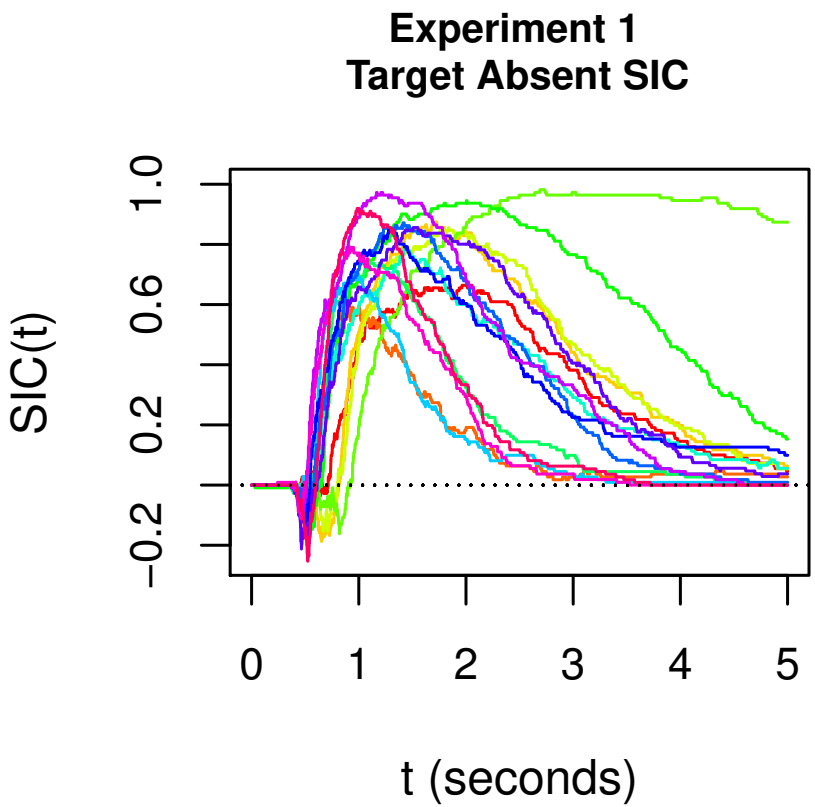
A: Absent, **L:** Low, **H:** High

Experiment 1 — Feature Search



Results — SIC and MIC





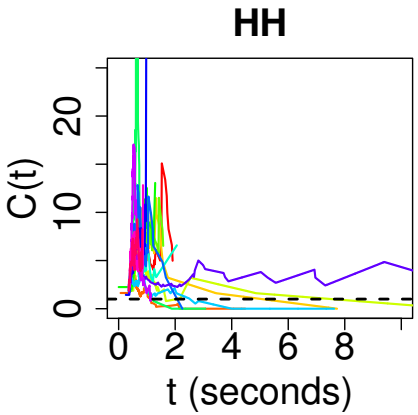
Bayesian Group MIC:

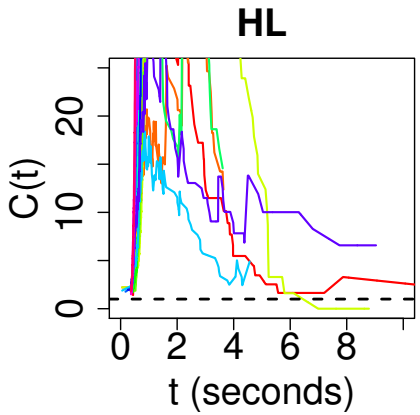
$\hat{p_+} = .91$

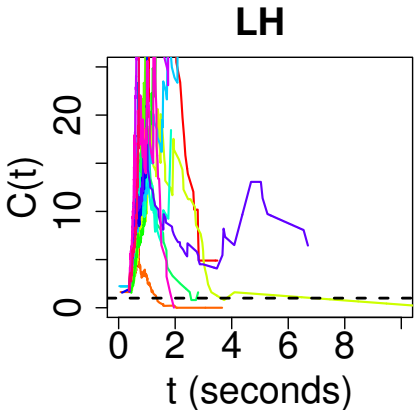
$\hat{p_+} = .91$

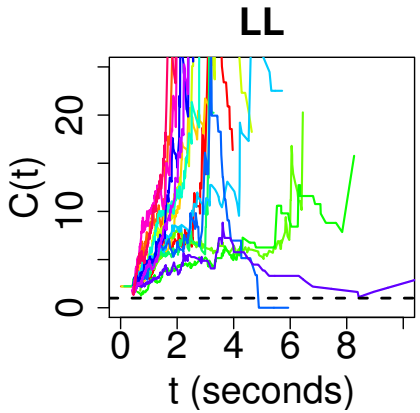
Results — Workload Capacity

Target Present

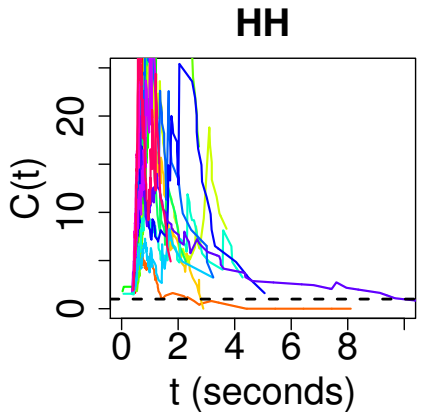


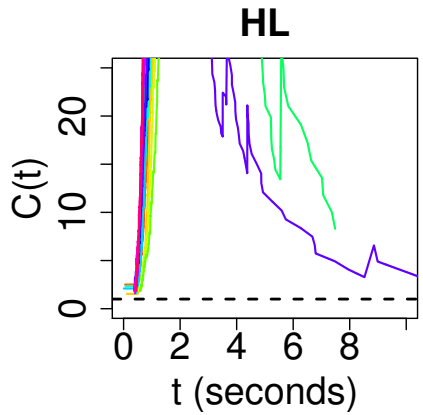


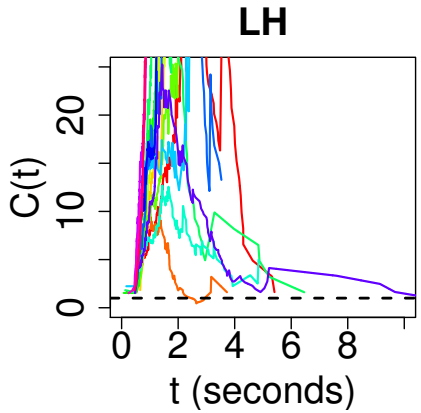


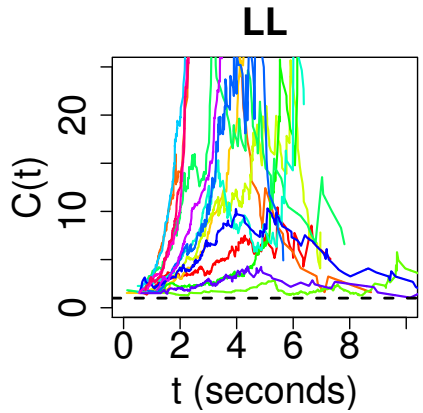


Target Absent





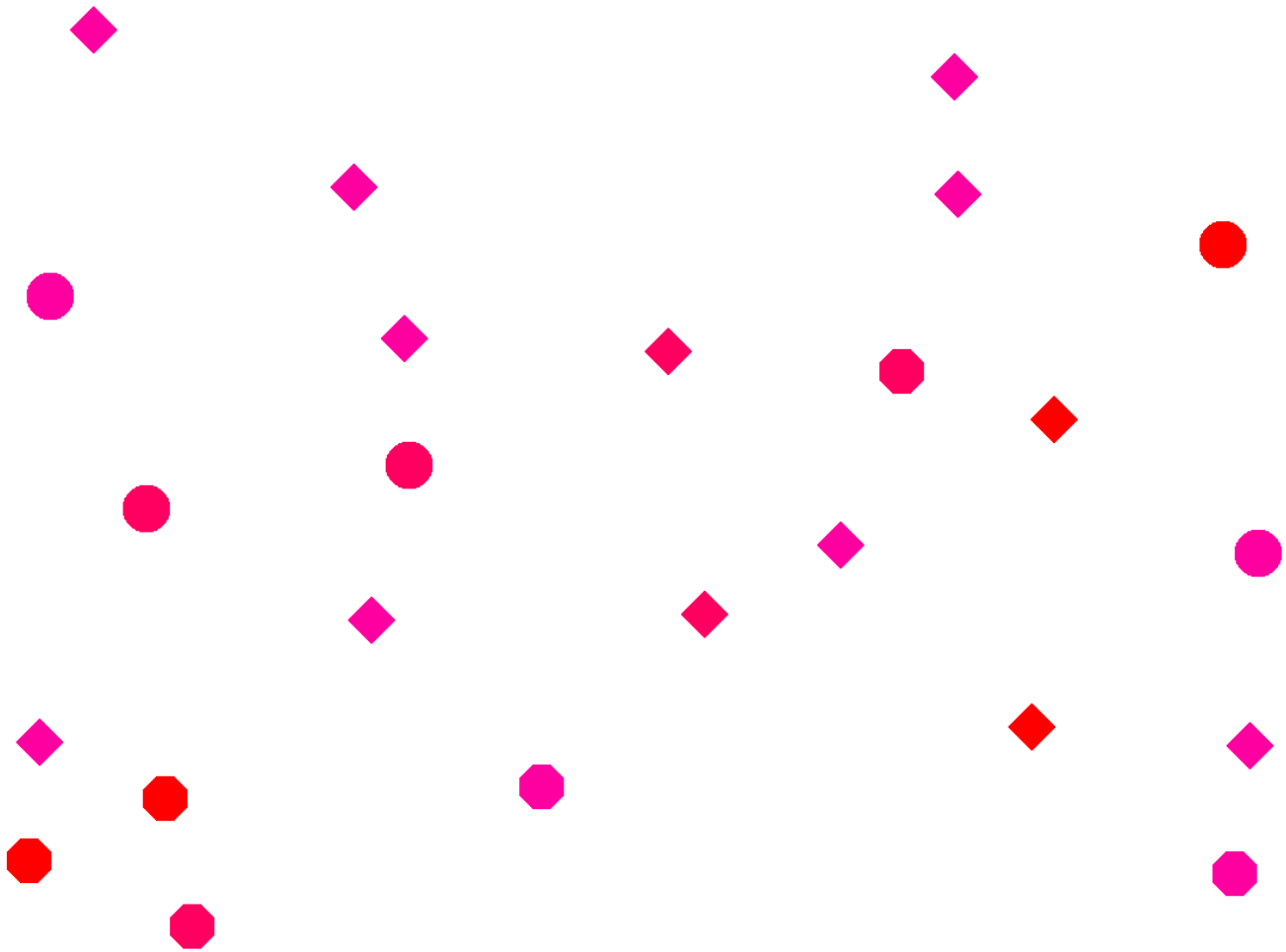




Discussion of Experiment 1

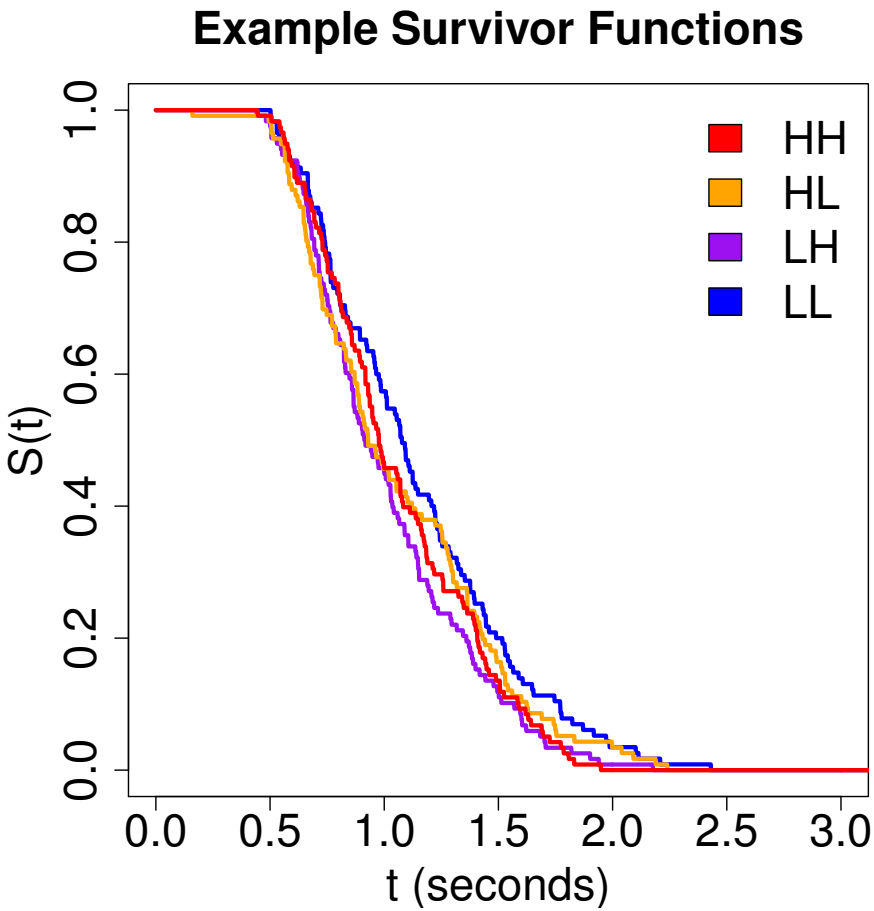
- Reject all serial models and independent, exhaustive parallel models
  - Target Present: All positive SIC and MIC
  - Target Absent: 7/15 subjects had significant negative SIC deviations as well, suggesting coactive processing
- All subjects demonstrated super (AND) capacity
- However, the task did not force a single strategy
  - Template-matching strategy (AND)
  - Singleton-search strategy (OR)
- Experiment 2 (conjunctive search) and Experiment 3 (odd-one-out search) designed to control for strategy

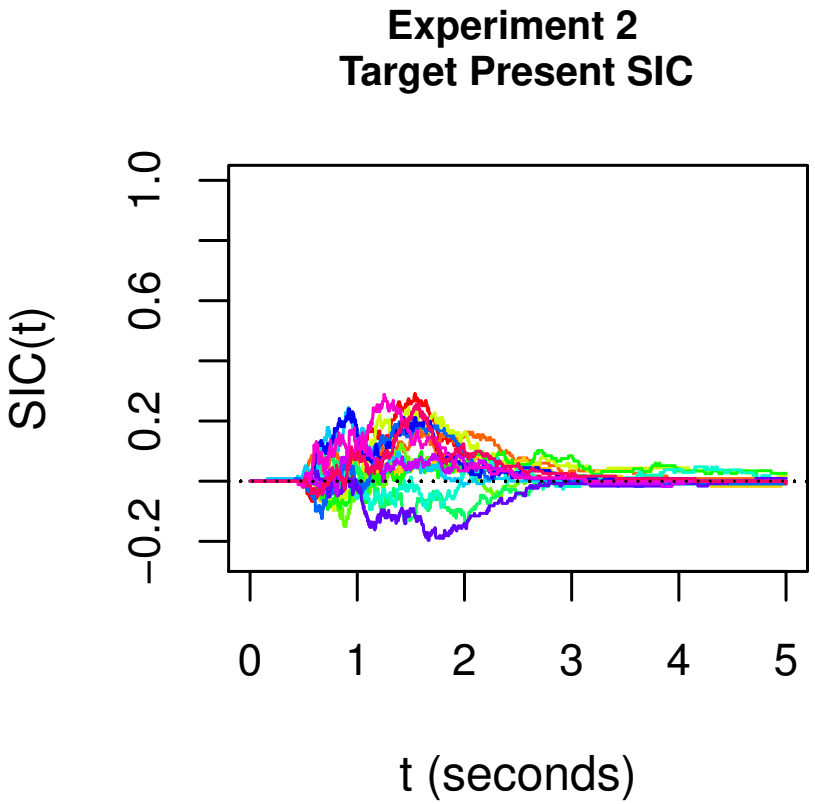
Experiment 2 — Conjunction Search



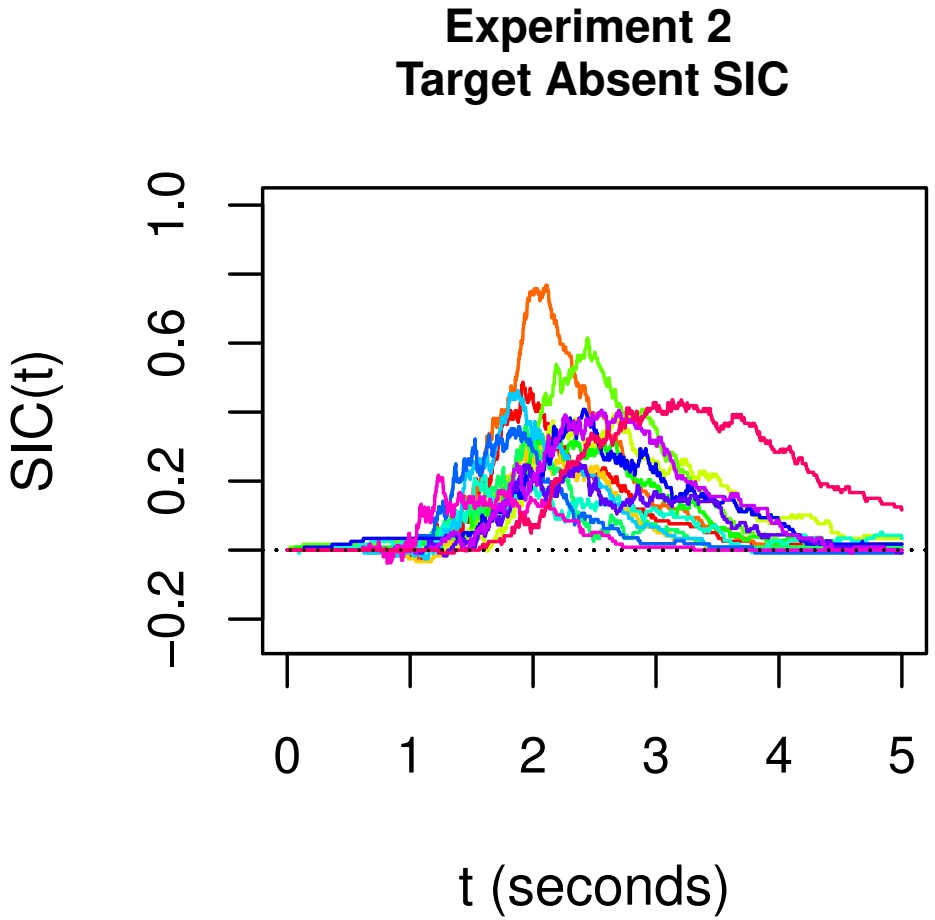
Results — Target Present

Selective Influence Failed — Unable to Interpret SIC and MIC





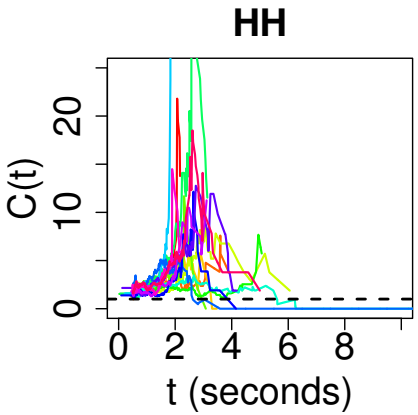
Results — SIC and MIC

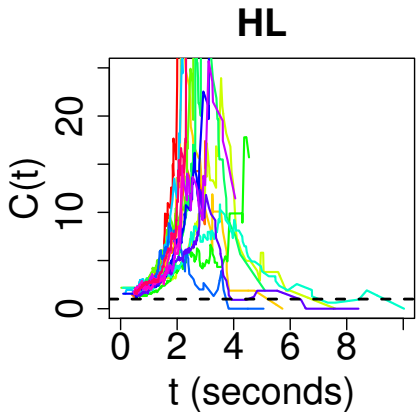


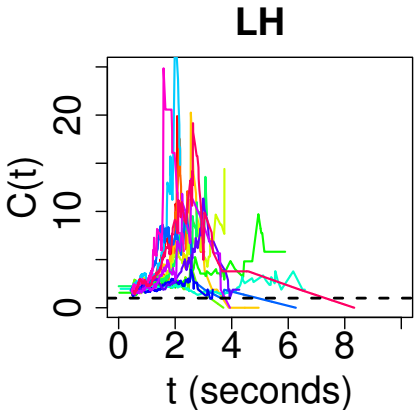
Bayesian Group MIC: $\hat{p_+} = .88$

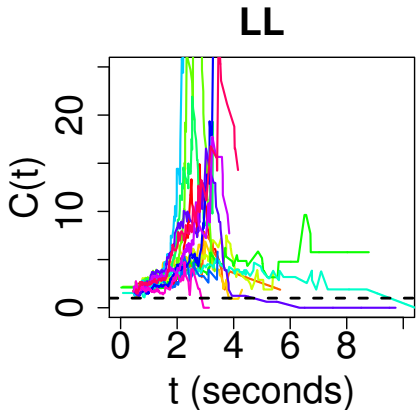
Results — Workload Capacity

Target Present

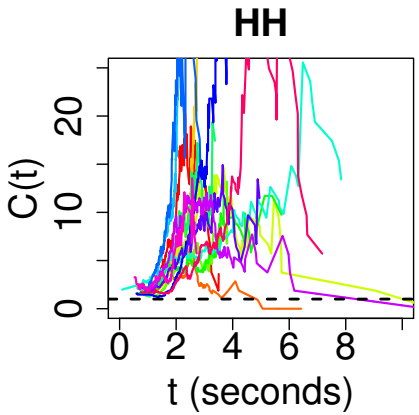


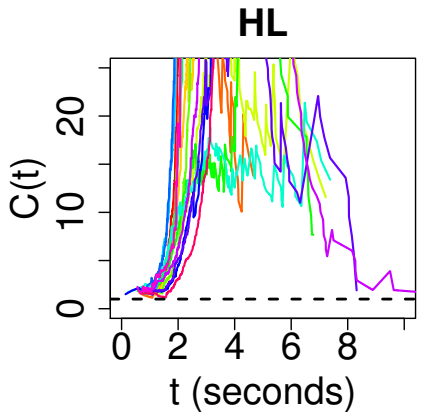


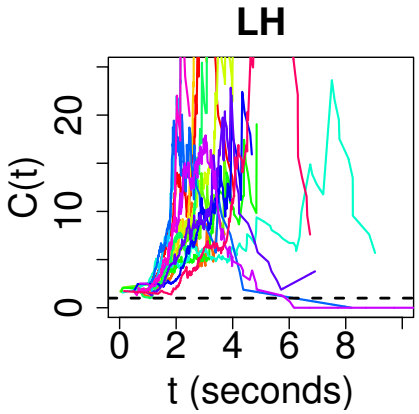


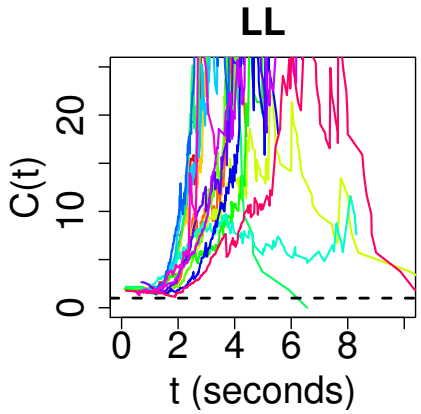


Target Absent





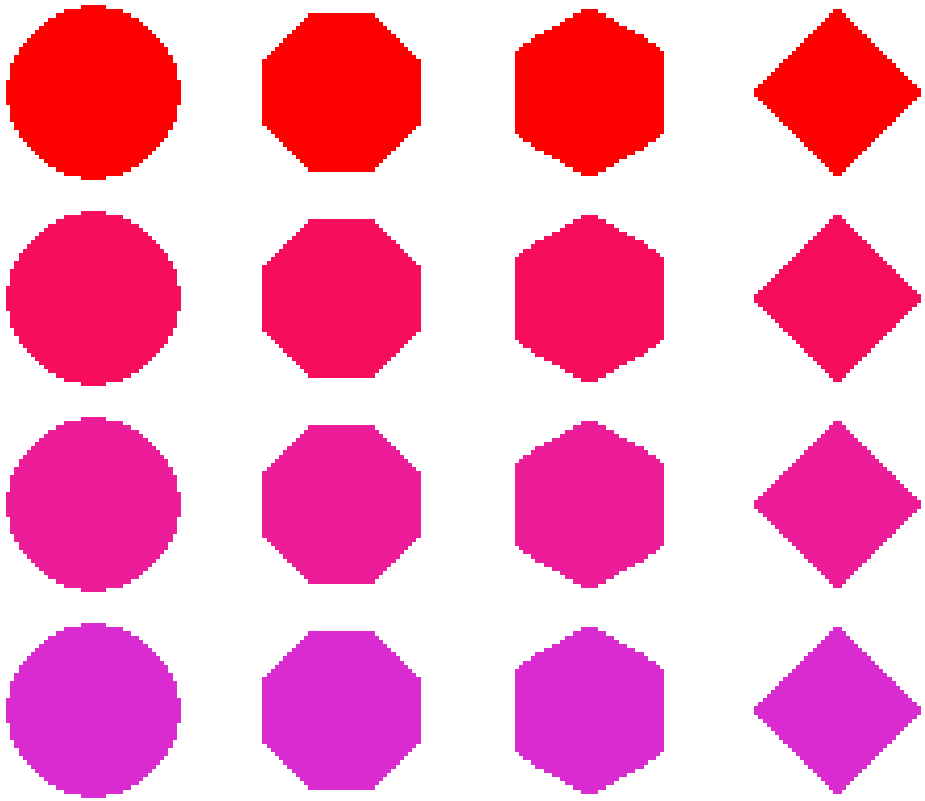




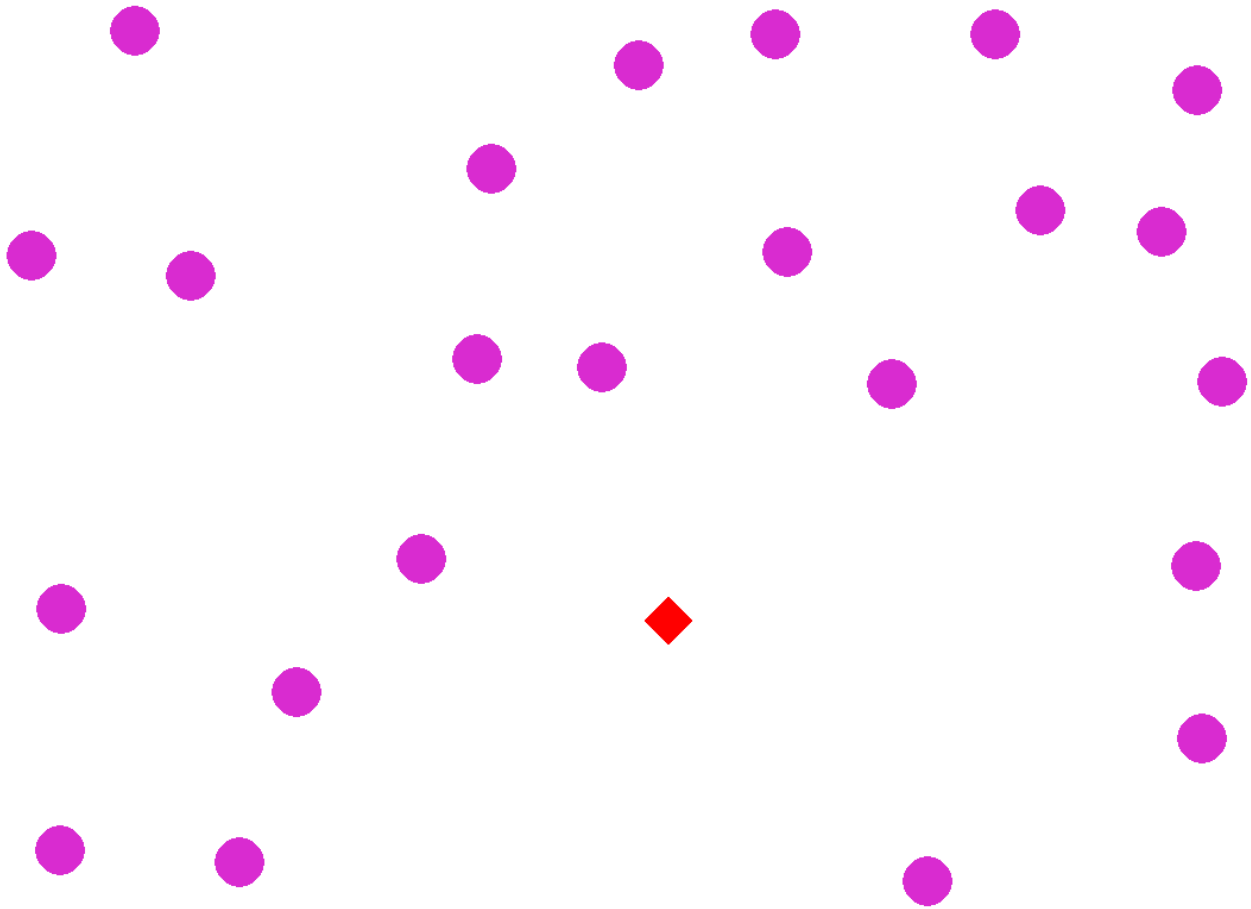
Discussion of Experiment 2

- Target Absent
  - Reject all serial models and independent, exhaustive parallel models
    - All positive SIC and MIC
  - All subjects demonstrated super capacity
  - Coactive processing seems to be the more likely model
- Target Present
  - All subjects demonstrated super capacity
  - Could not infer architecture
    - Why did selective influence fail?
    - Heterogeneous distractors may have introduced grouping effects

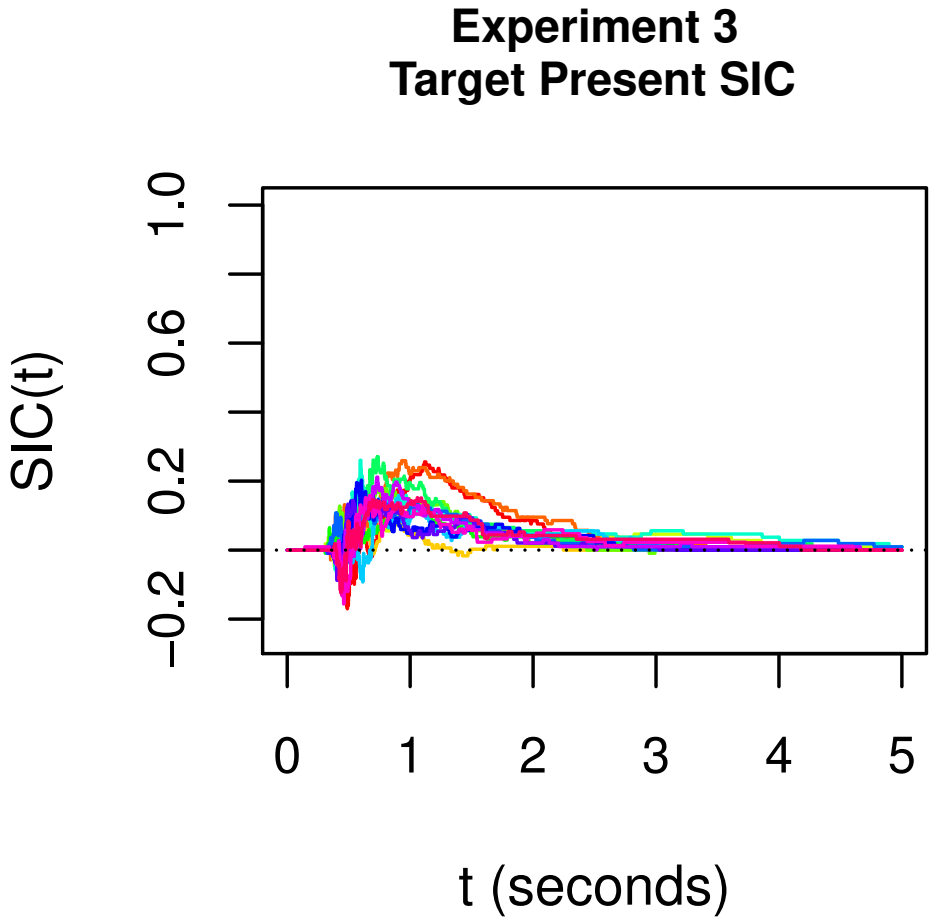
Experiment 3 — Odd-One-Out Search



Experiment 3 — Odd-One-Out Search



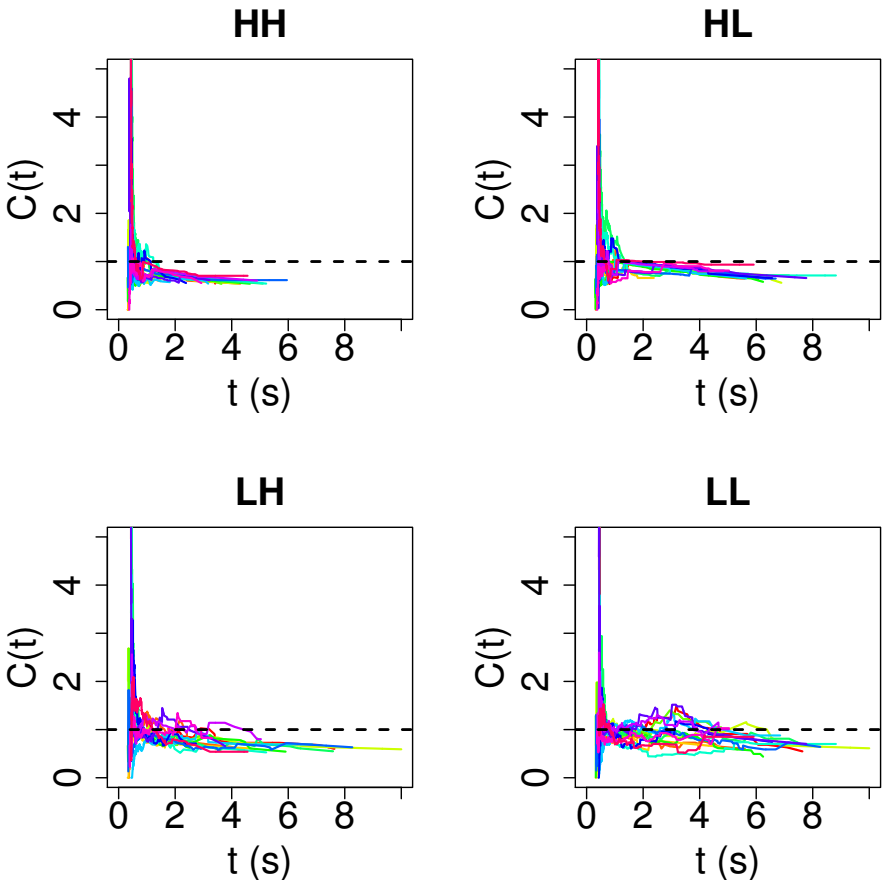
Results — SIC and MIC



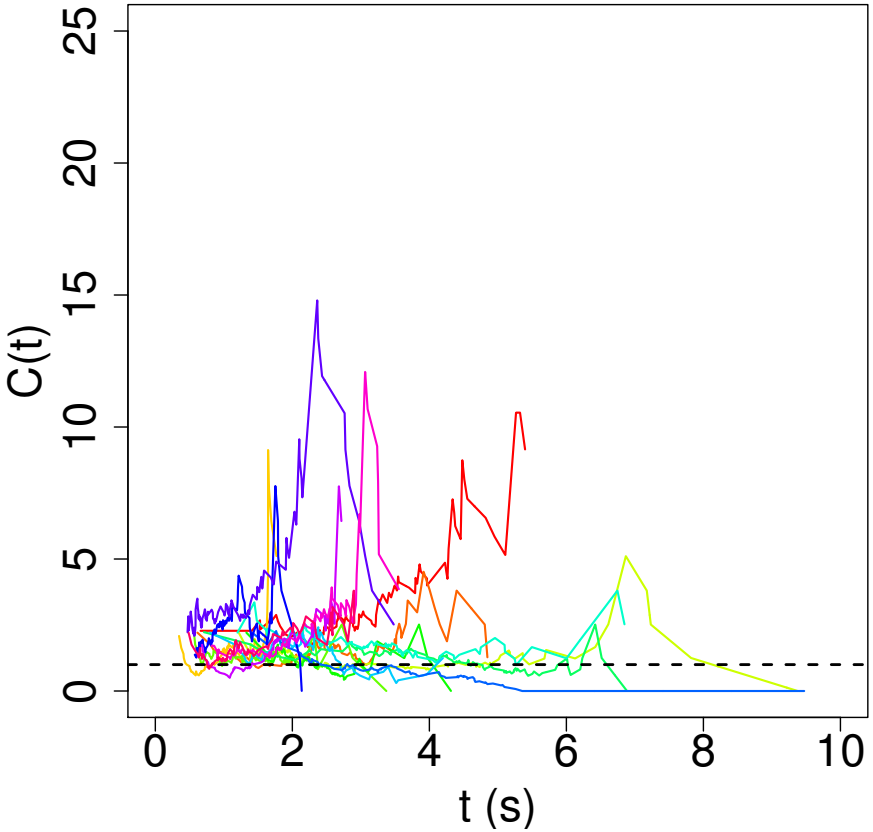
Bayesian Group MIC: $\hat{p_+} = .80$

Results — Workload Capacity

Target Present



Target Absent

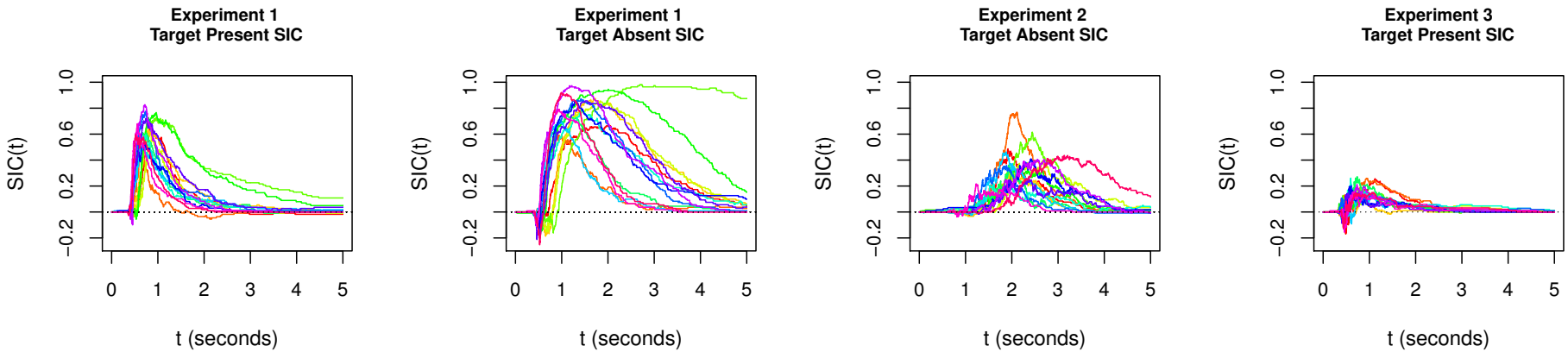


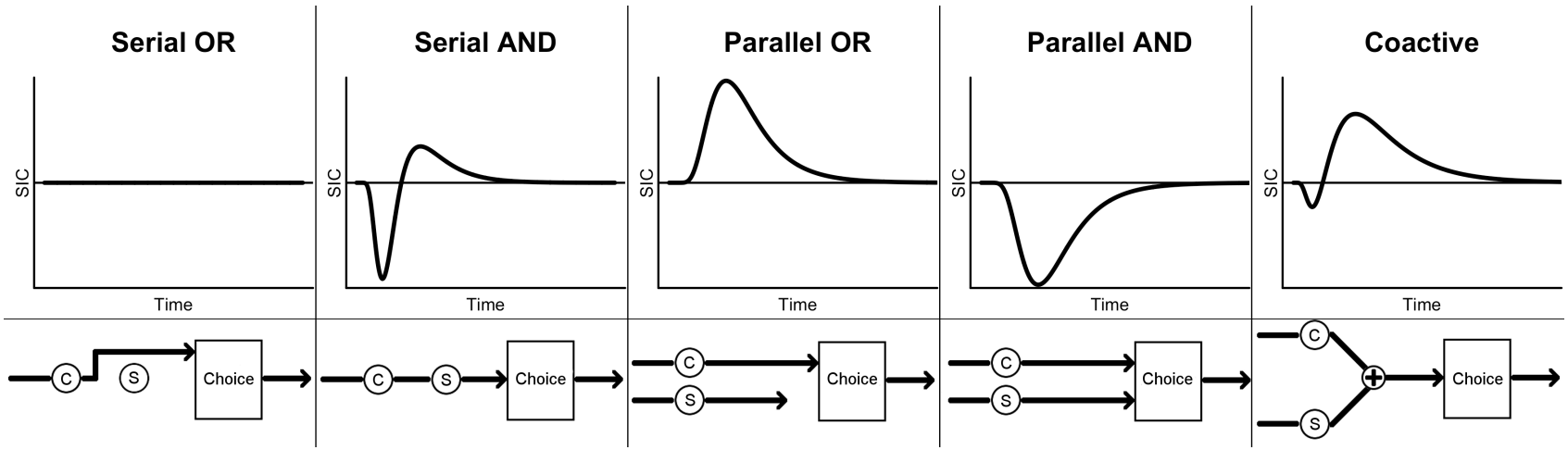
Discussion of Experiment 3

- Target Present
  - Reject all serial models and independent, exhaustive parallel models
    - All positive SIC and MIC
    - 2 subjects had significant negative SIC deviations as well, suggesting coactive processing
  - Subjects demonstrated unlimited capacity
- Target Absent
  - Mixture of unlimited and (mostly) super capacity
  - Could not infer architecture (no meaningful target-distractor dissimilarity)

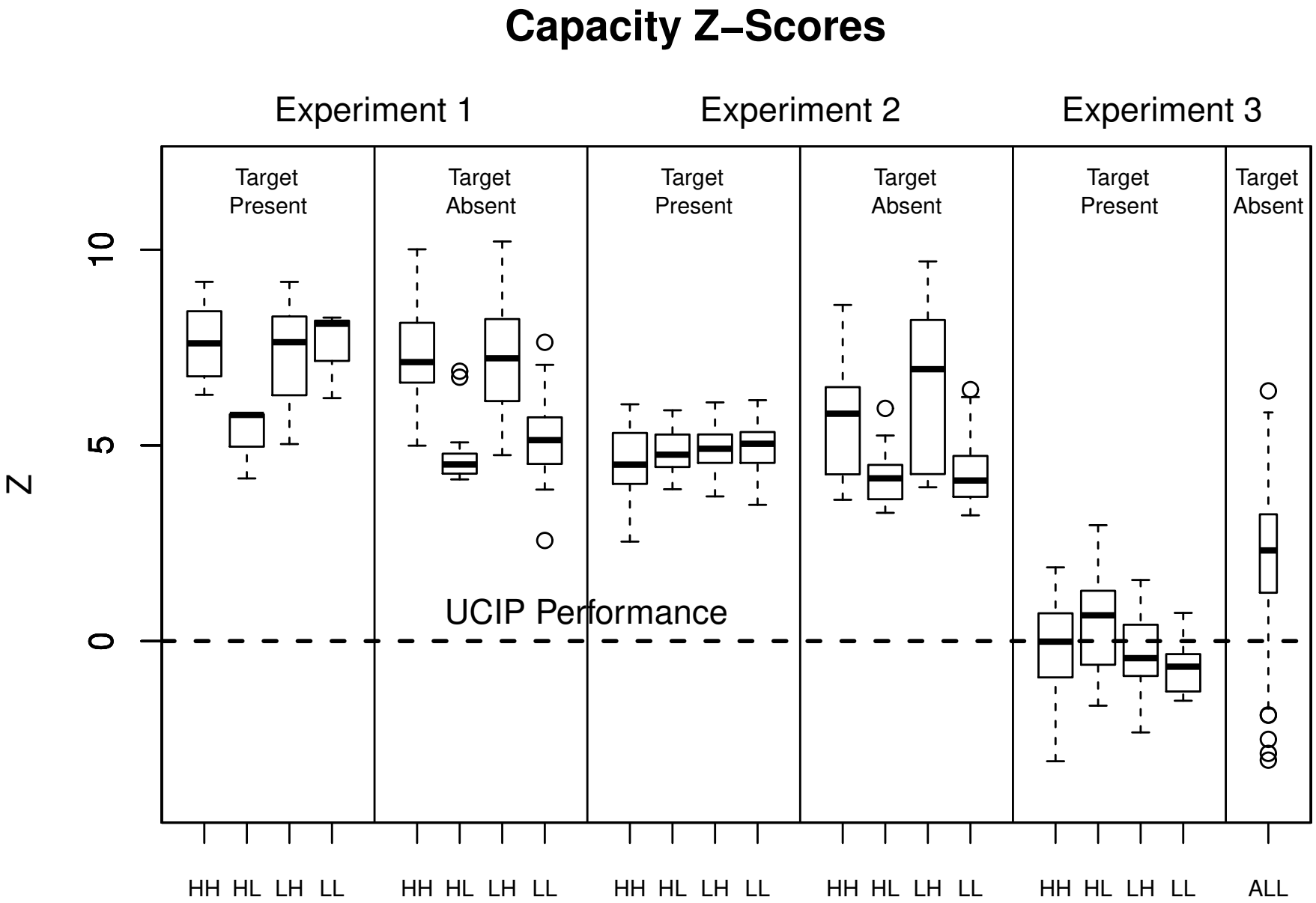
Summary of Results

Architecture Across Experiments





Capacity Across Experiments



General Discussion

- We investigated feature search, conjunctive search, and odd-one-out search
- Color and shape feature dimensions are processed in parallel
- Processing may be facilitatory dependent
- Supports existing theories of visual attention (e.g., Wolfe, 2007)
- Future work needs to confirm these conclusions in target-present conjunctive search and target-absent odd-one-out search

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