Processes influencing visual search efficiency in conjunctive search

A rational analysis approach

Clayton T. Stanley &
Michael D. Byrne
Department of Psychology
Rice University
Houston, TX 77005
clayton.stanley@rice.edu
byrne@rice.edu
http://chil.rice.edu

chil
THE COMPUTER-HUMAN
INTERACTION LABORATORY AT RICE UNIVERSITY

Overview

- Problem
- Salience computation
- Methods
- Participant results
- ACT-R model
- Model results
- Comparison
- Discussion
- Closing remarks

Problem

- When deploying the eyes, how does the human visual system decide where to look next?
- Since its inception, the ACT-R visual system hasn't really addressed these issues
  - Currently doesn't handle bottom-up salience nor err on conjunctive searches
- Here is a first attempt to address such concerns

Salience Computation

Salience of feature *i* in the visual icon

bottom-up weightings

noise

$$L_i = \sum_{k=1}^{\#attr(i)} \log_2 \frac{1}{p_i(v_k)} \gamma_k + \log_2 \frac{1}{p_i(v_s)} + \sum w_j S_{ji} + \varepsilon$$

bottom-up salience

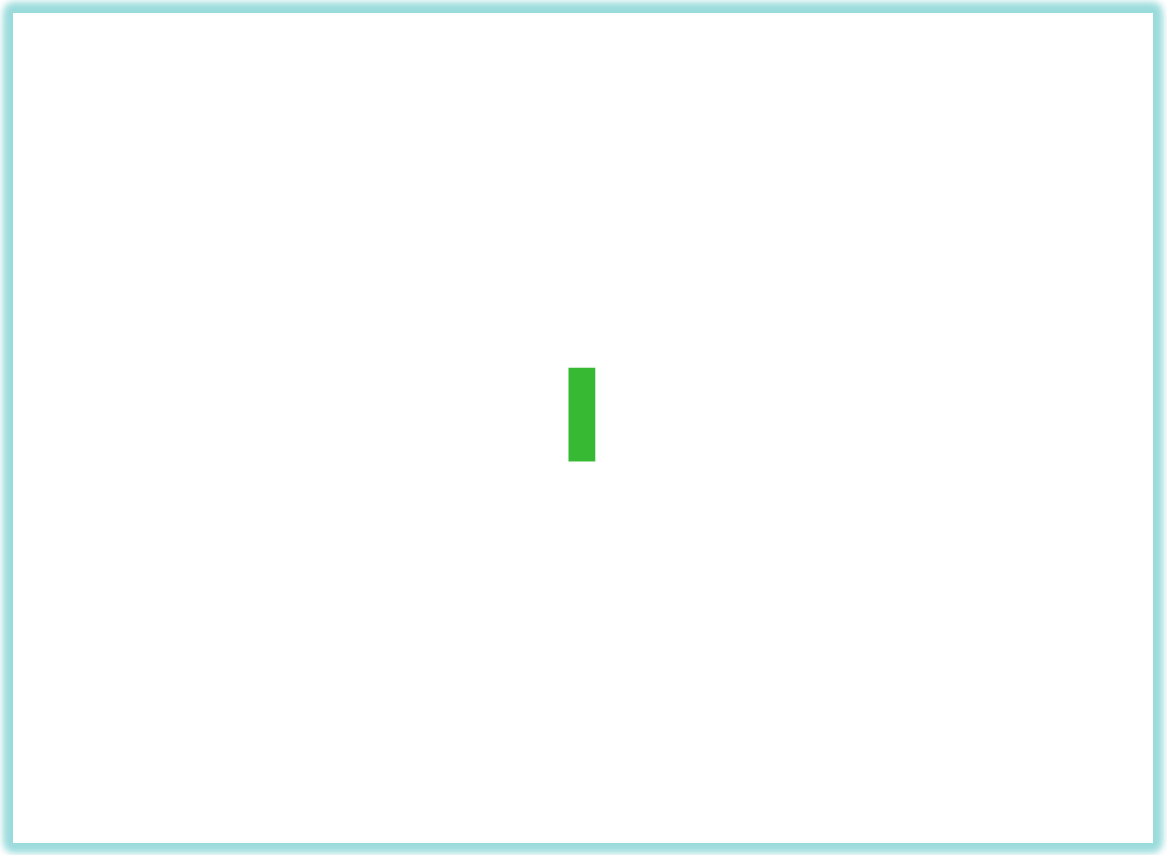
top-down spatial guidance

top-down value guidance

Methods

- 16 subjects
- 4 possible rectangular targets
  - (Red, Green) color
  - (Horizontal, Vertical) orientation
- 2 target conditions
  - (Present, Absent)
- 21 manipulated cells
  - Alters relative frequency of the two types of conjunctive distractors as well as number of disjoint distractors
- 3 repetitions of each configuration
- 504 shuffled trials per run
- Number of objects
  - 36 for target absent condition; 1 additional when present (target doesn't replace an object)

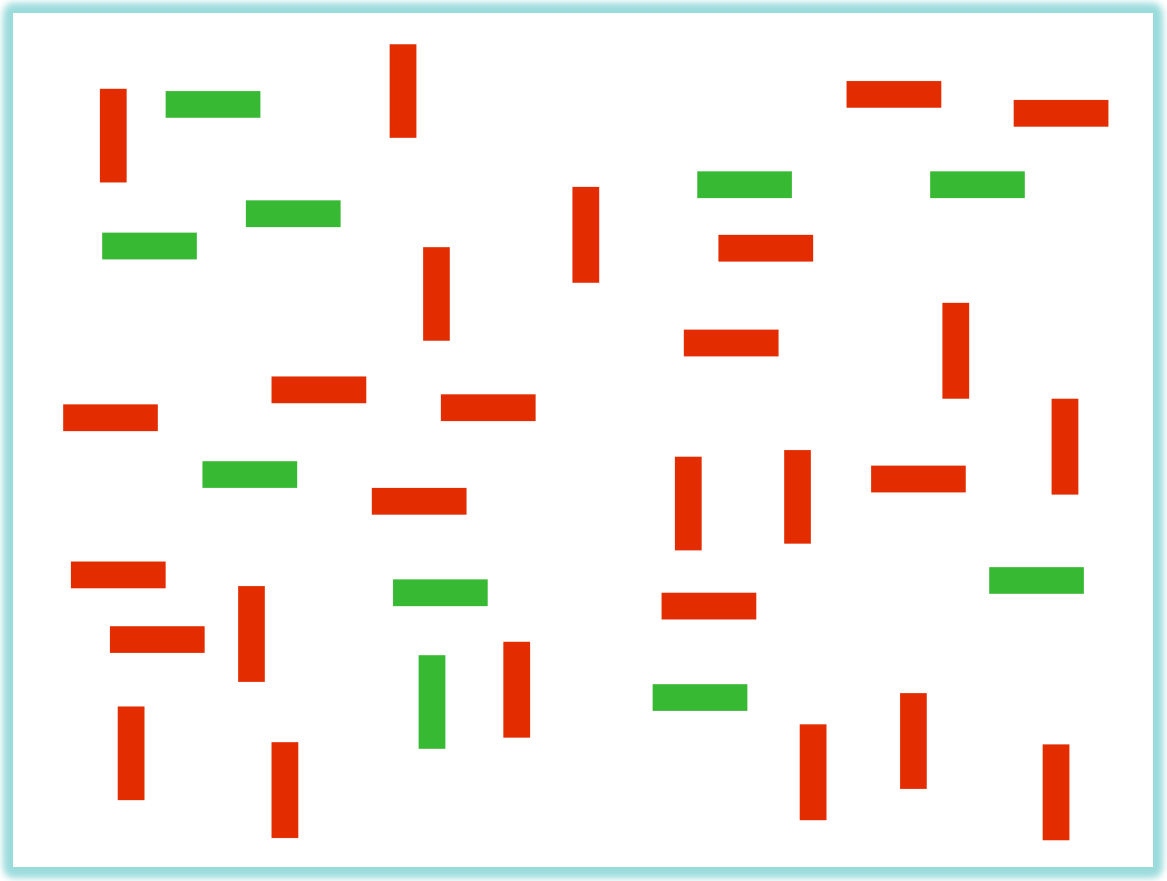
Methods



Target encoding

Methods

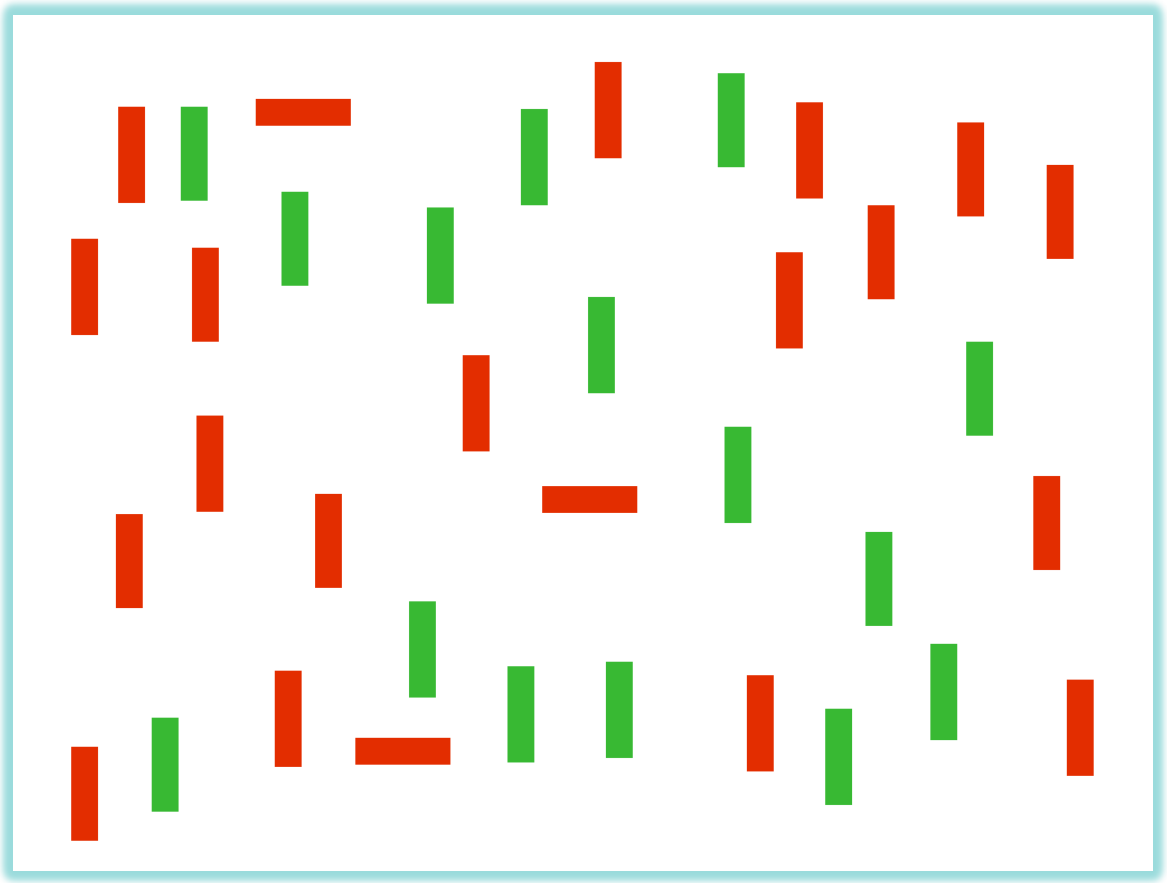
Target Present (GV)
Distract RV 15
Distract GH 9
Disjoint Distract RH 12



Search trial ex. a

Methods

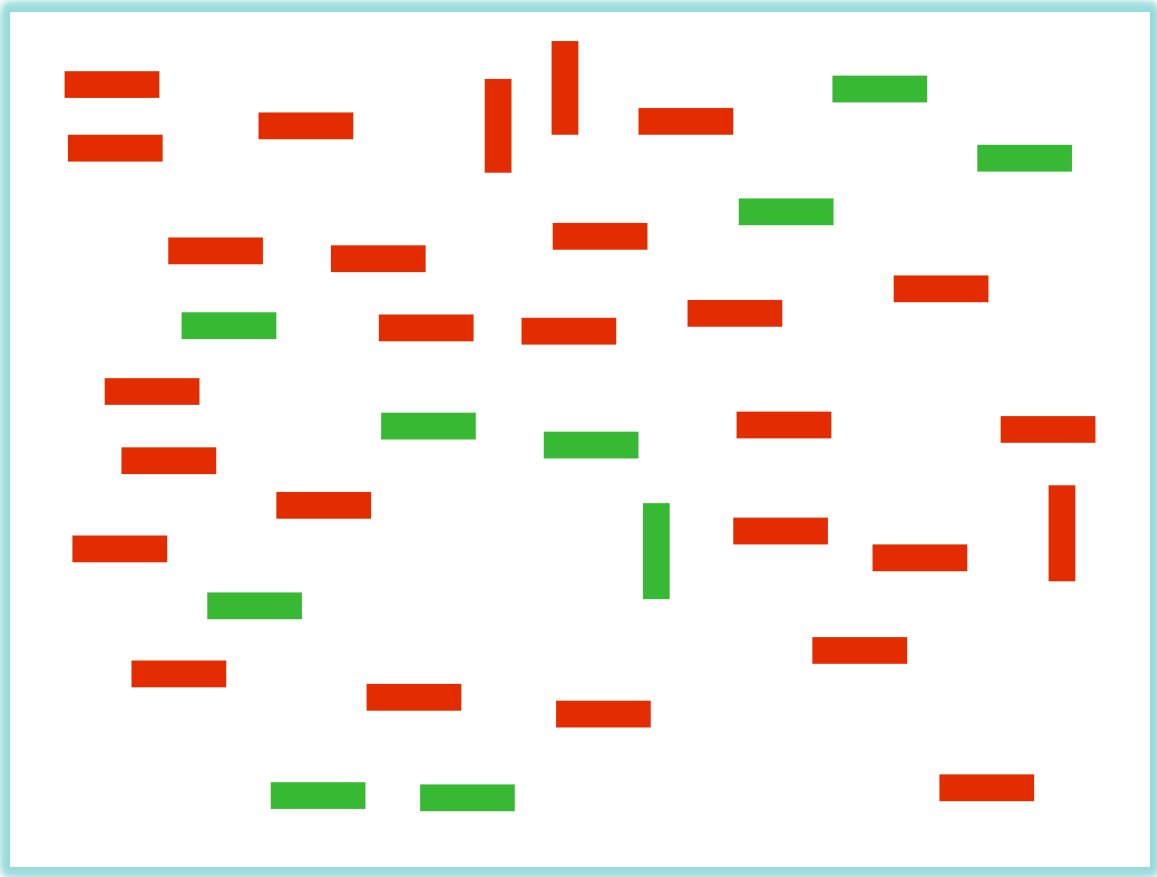
Target Absent (GH)
Distract RH 3
Distract GV 15
Disjoint Distract RV 18



Search trial ex. b

Methods

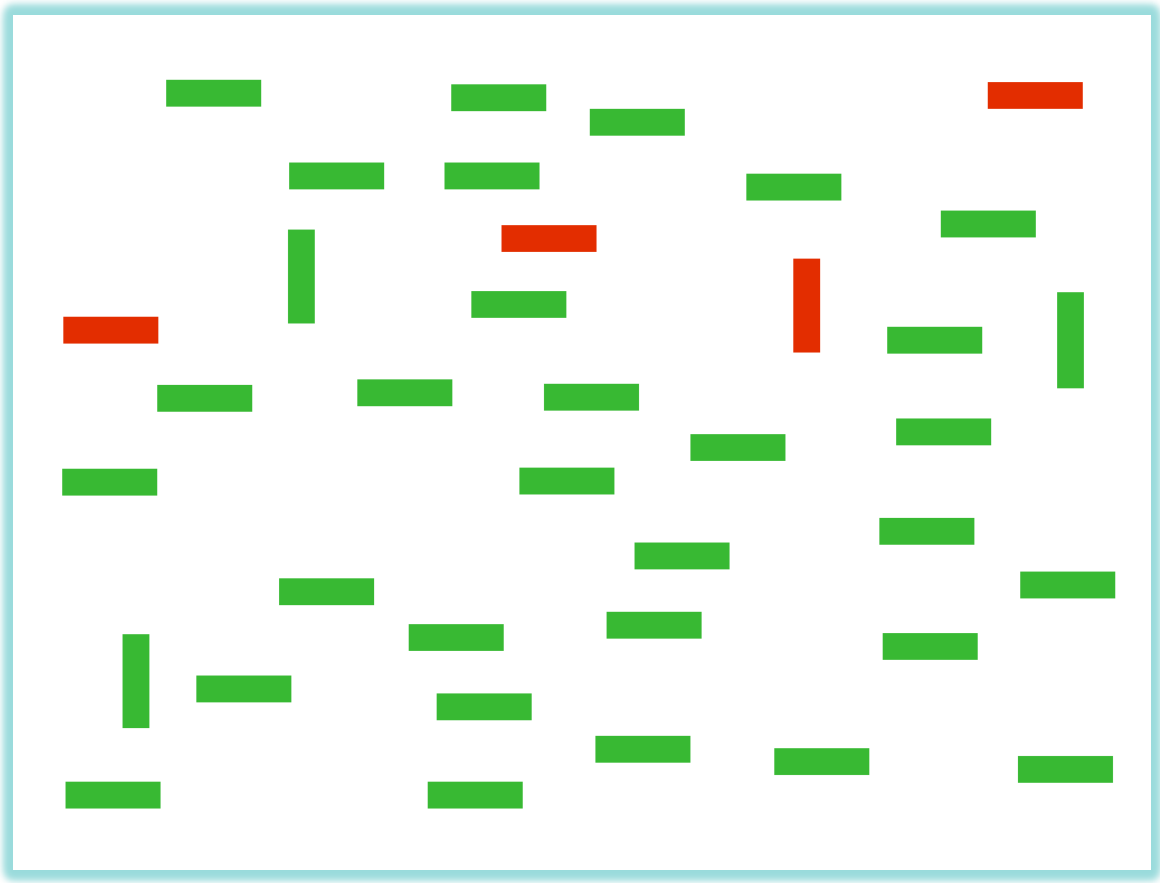
Target Present (GV)
Distract RV 3
Distract GH 9
Disjoint Distract RH 24



Search trial ex. c

Methods

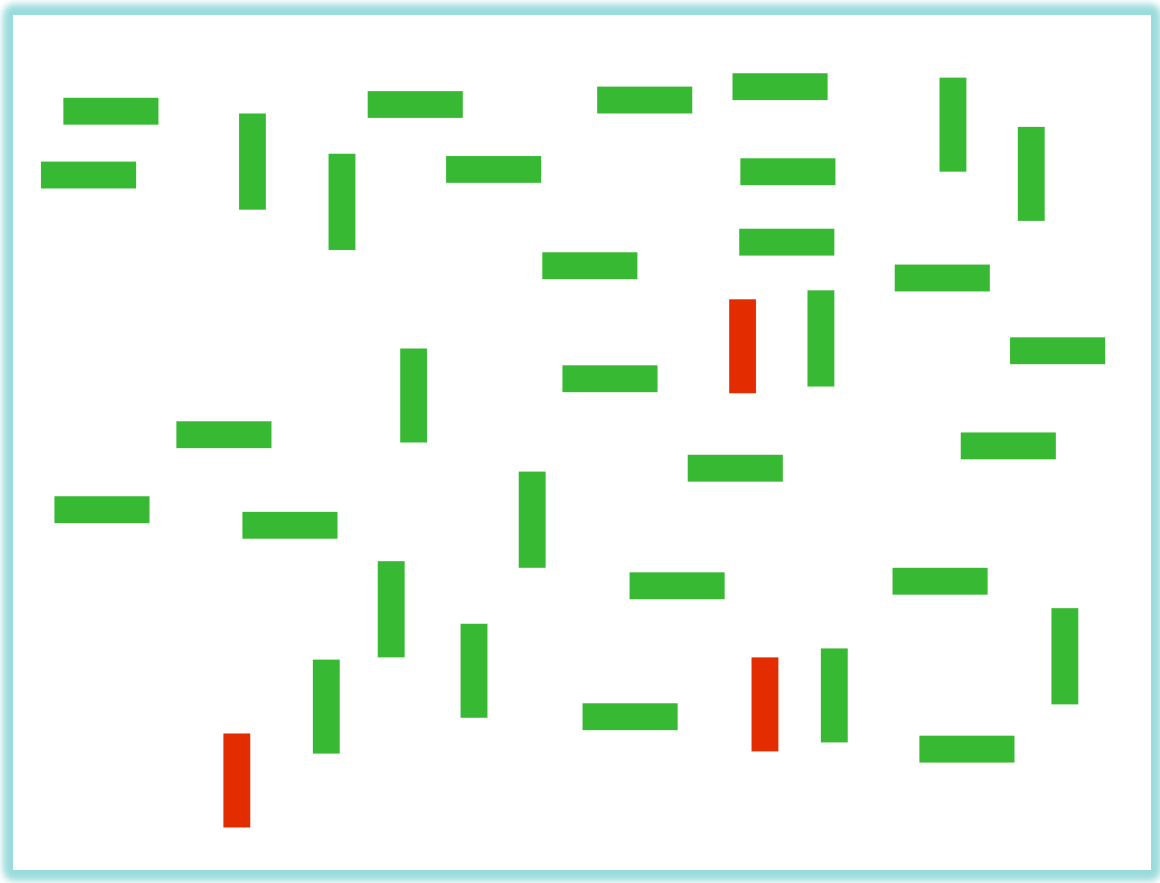
Target Present (RV)
Distract GV 3
Distract RH 3
Disjoint Distract GH 30



Search trial ex. d

Methods

Target Absent (RH)
Distract GH 21
Distract RV 3
Disjoint Distract GV 12



Search trial ex. e

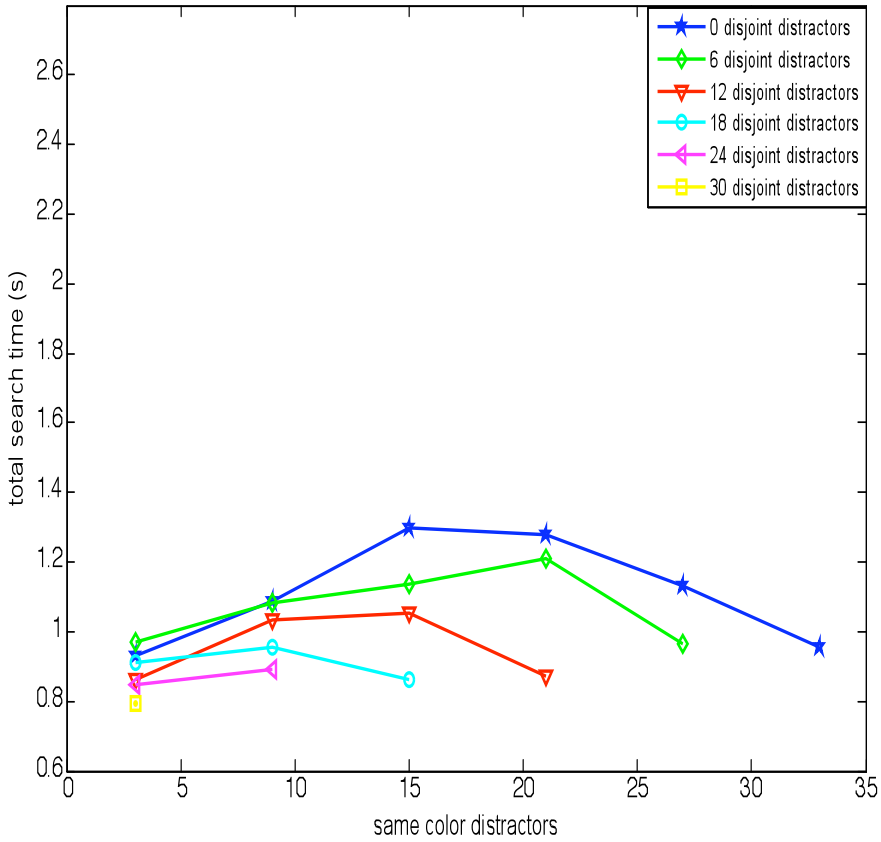
Methods

		# same orientation distractors					
		3	9	15	21	27	33
# same color distractors	3	30 (d)	24	18	12 (e)	6	0
	9	24 (c)	18	12 (a)	6	0	-
	15	18 (b)	12	6	0	-	-
	21	12	6	0	-	-	-
	27	6	0	-	-	-	-
	33	0	-	-	-	-	-

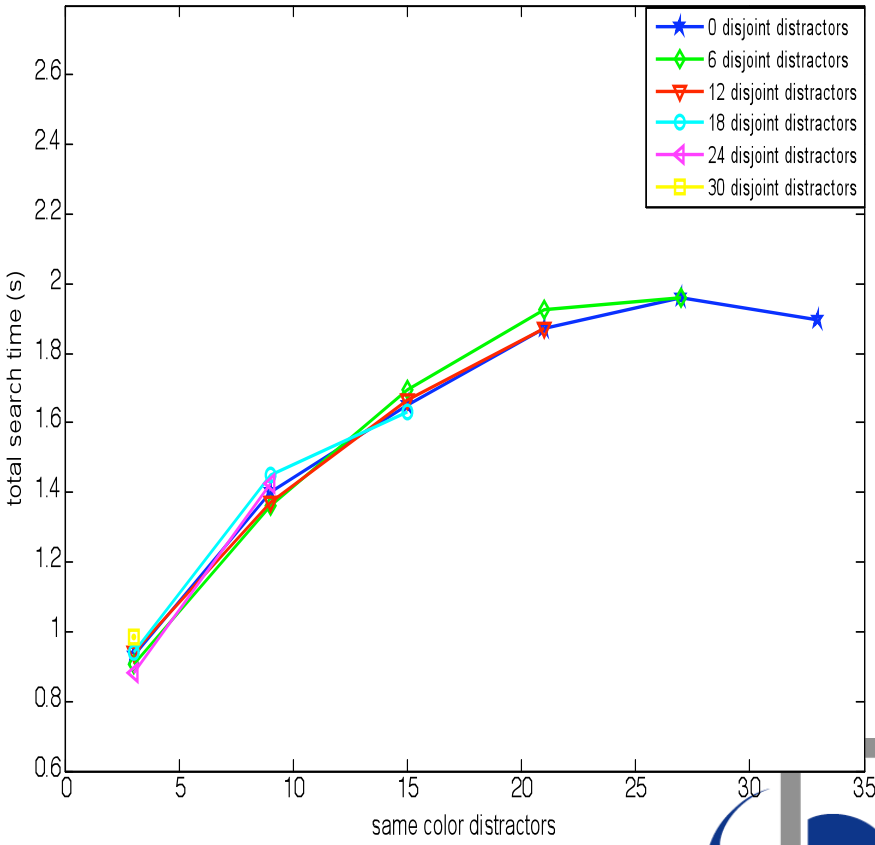
- Hyphens represent cells that were not tested. Numbers within a cell indicate the number of disjoint distractors placed on the screen

Results

Hit responses



Correct rejection responses



Discussion

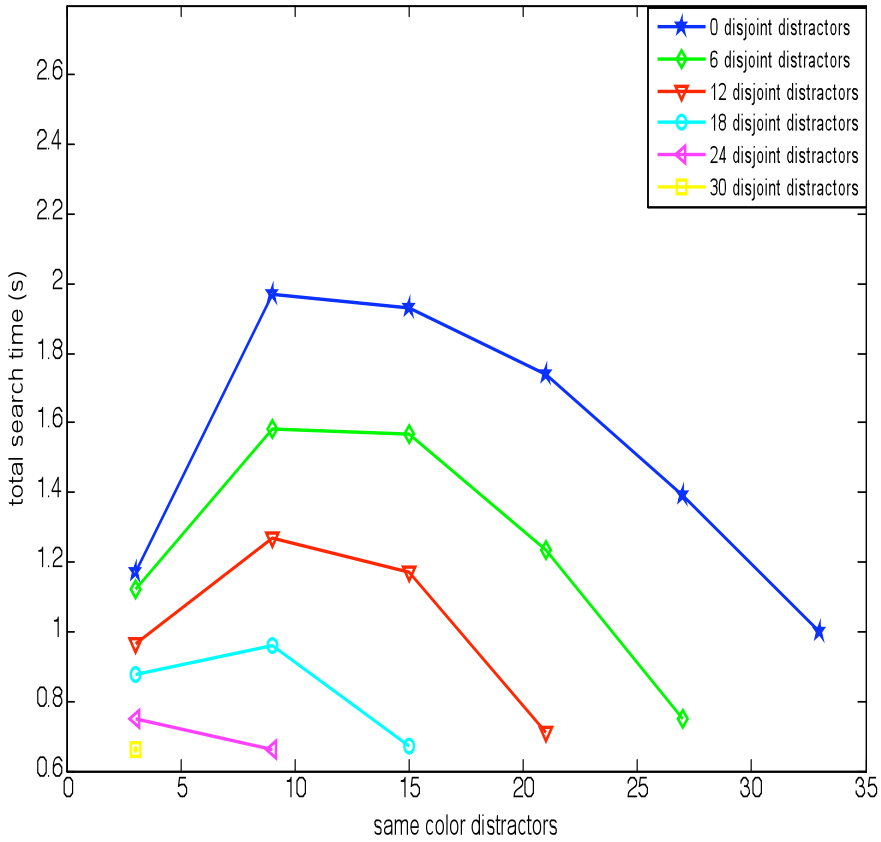
- Average miss & false alarm rates were .06 & .013 respectively
- Asymmetrical curves for hit & correct rejection responses
  - Two components
    - First, the shape of the curves
      - Strong quadratic component of trend for hit responses
      - Almost asymptotic for correct rejections
    - Next, the 'squishiness' of the curves
      - Evidence for strong serial search component in hit responses
      - Evidence non-existent for correct rejections
- Interpretation
  - Difficult looking only at these data without a strong understanding of the underlying processes involved

ACT-R Model

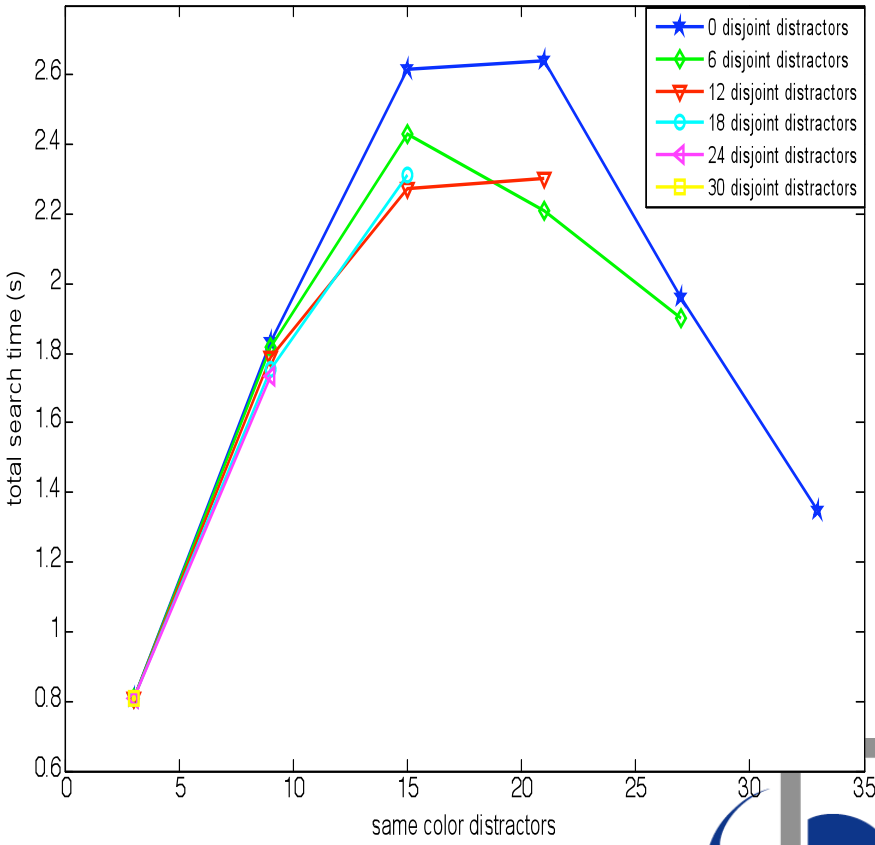
- Target rectangle encoded and placed in goal buffer
- +visual-location> requests cause model to find object with highest activation
  - Includes a slot only for target color
  - If object activation is greater than *salience-thresh*, chunk is placed in buffer; else nothing is returned
- If nothing is returned, model concludes that target is absent
    - Analogous to a memory retrieval failure
- If an object is returned and it is the target object, model concludes that target is present; else the model keeps looking
- If an object has been looked at, the object won't be looked at again

ACT-R Model Results

Hit responses

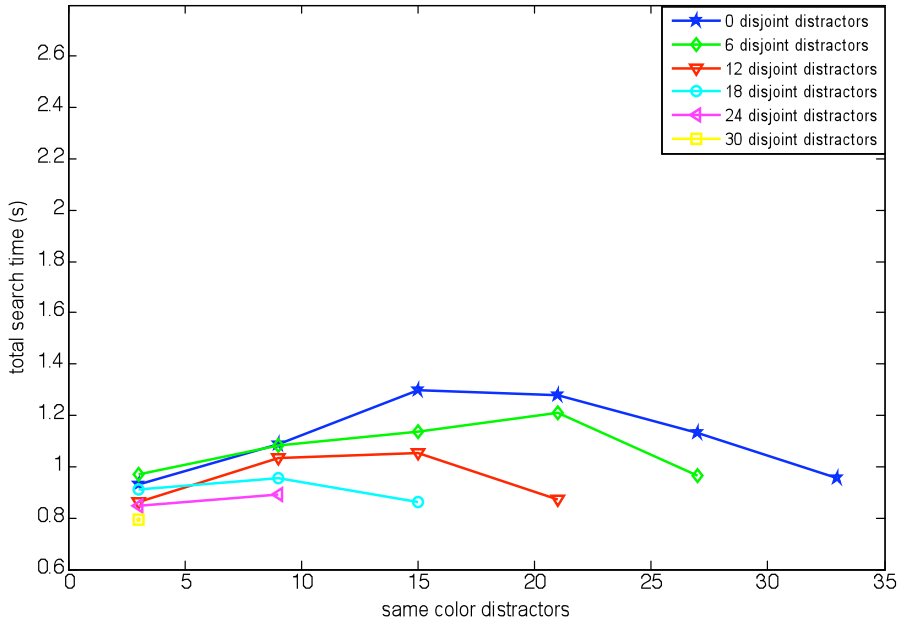


Correct rejection responses

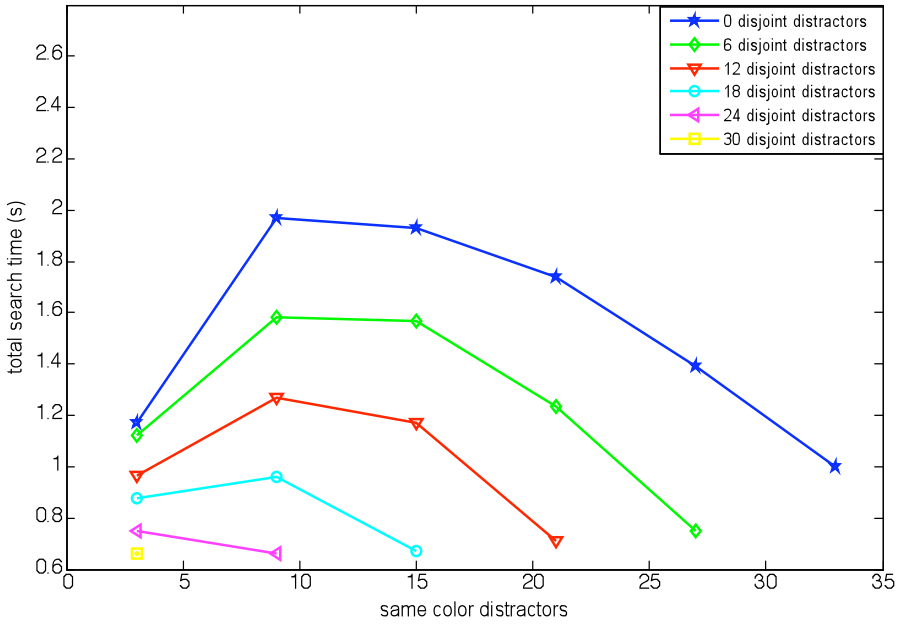


Model Fit: Hits

Participant data



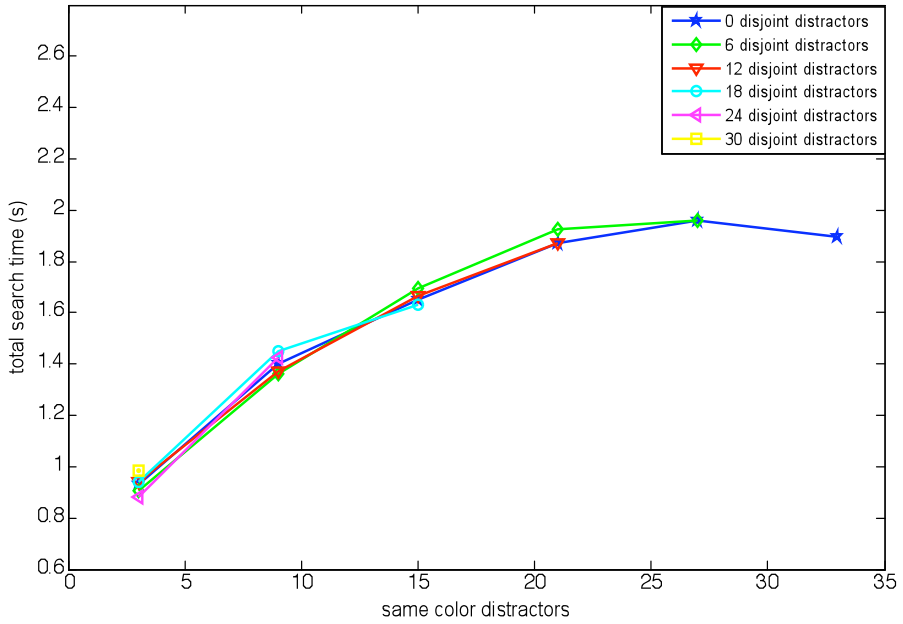
ACT-R data



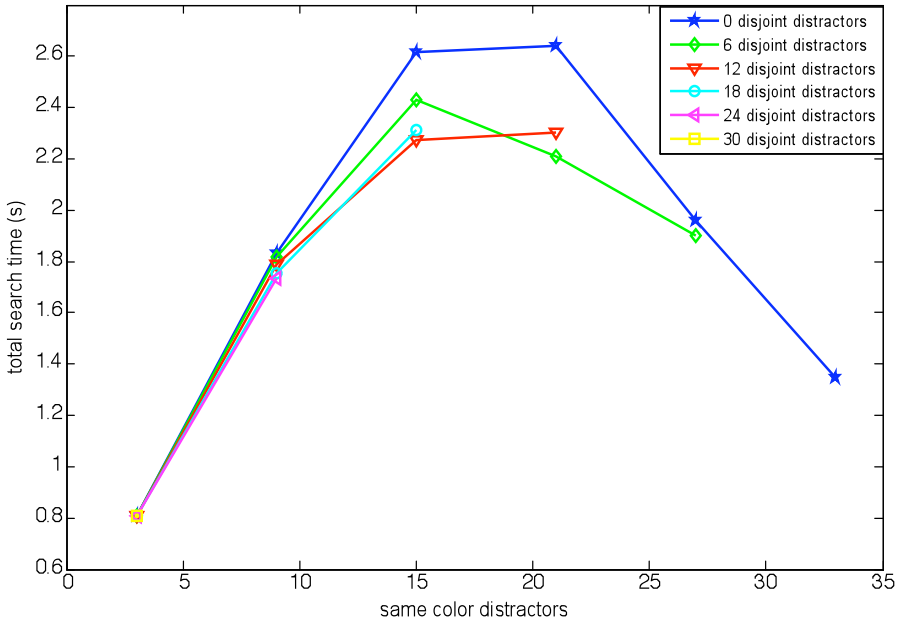
$R^2(19) = .74 \quad MAD = 245ms$

Model Fit: Correct Rejections

Participant data



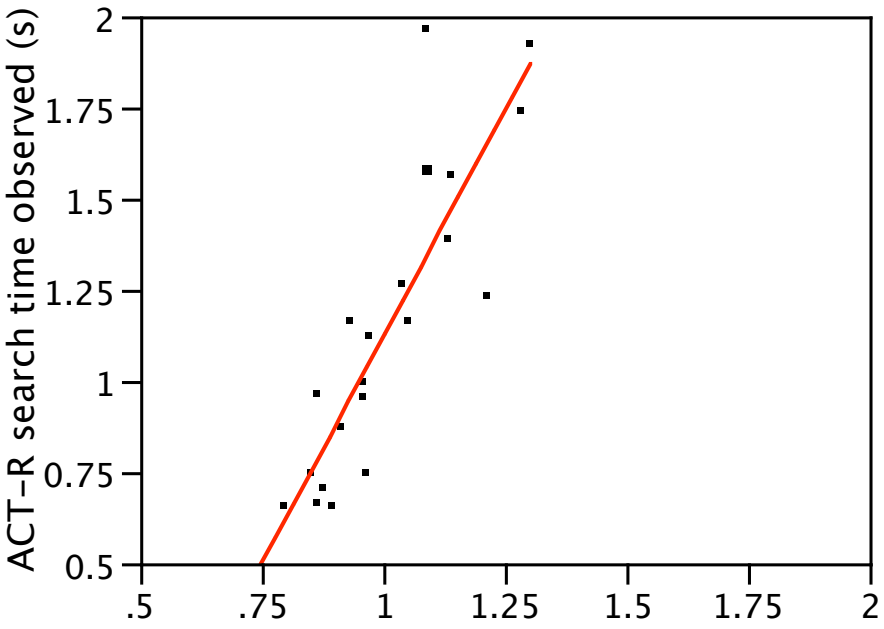
ACT-R data



$R^2(19) = .70 \quad MAD = 367ms$

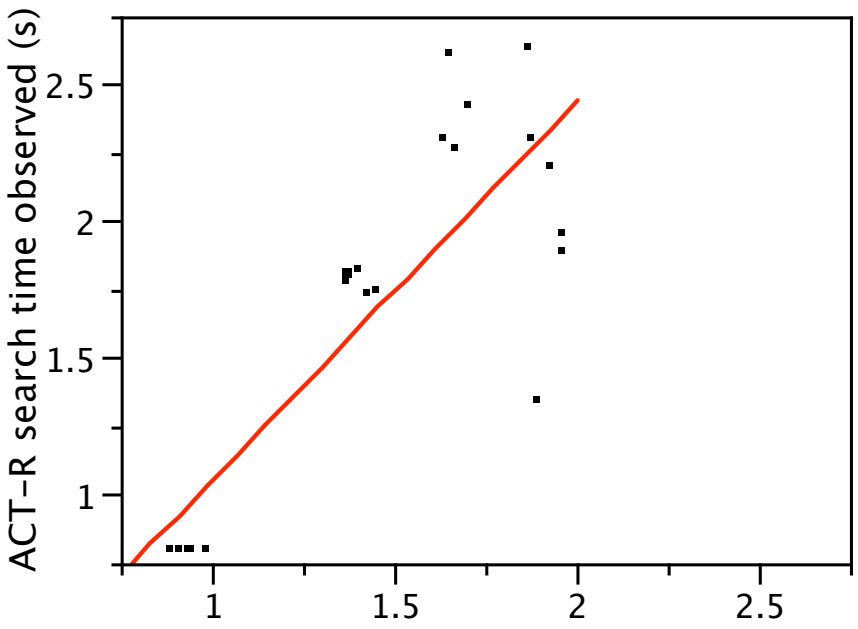
Model Fit: *r* Scatter

Hit responses



$R^2(19) = .74 \quad MAD = 245ms$

Correct rejection responses



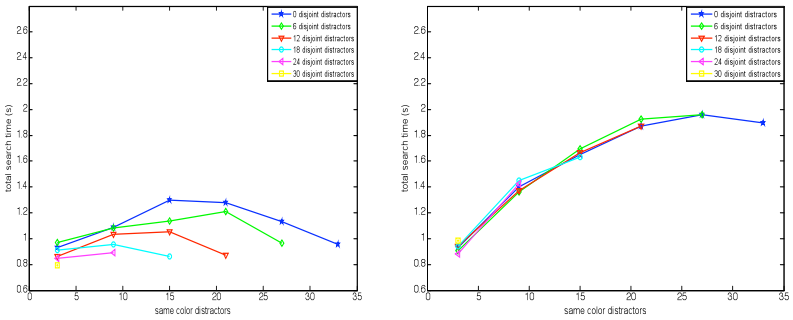
$R^2(19) = .70 \quad MAD = 367ms$

Model Fit: Incorrect Responses

- Miss responses
  - Salience threshold calibrated to match miss rate
  - Therefore consistent miss rate for ACT-R (.07) and participant (.06) data
- False alarms
  - Small (but non-zero) for participants (.013)
  - Not modeled with ACT-R currently

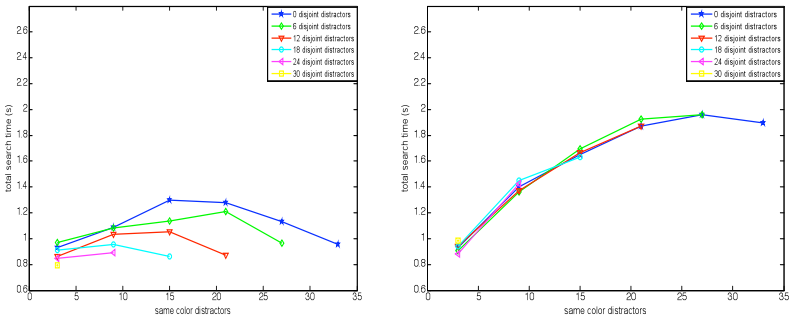
Discussion: Asymmetrical Shape

- Subjects utilizing color primarily to guide their search
  - High bottom-up activation percentage for color relative to orientation
  - Top-down guidance only for color
  - High ratio of top-down/bottom-up activation
  - However, a bit of bottom-up activation for orientation still necessary to produce the strong quadratic present in the hit responses



Discussion: Asymmetrical 'Squishiness'

- Hit responses
  - Disjoint distractors are not often attended (if ever); however, their presence acts to 'shadow' conjunctive distractors relative to the target
  - Causes more accurate target pinpointing when a high number of disjoint distractors are displayed
  - Works alongside serial search effects to separate level curves



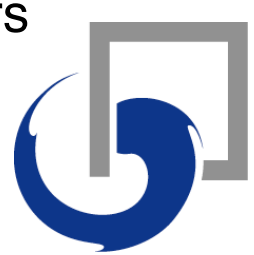
Discussion: Asymmetrical 'Squishiness'

- Correct rejections
  - Subjects concluding 'target absent' by an analogous memory retrieval failure for the vision system
  - Disjoint distractors again not often attended; however, their presence acts to increase information content for conjunctive distractors
  - Assuming a constant threshold, may cause a higher proportion of conjunctive distractors searched before concluding 'target absent'
  - Works against serial search effects to overlap level curves
    - Overlapping may also be influenced by a strong tendency to search for color

Discussion: Future Predictions

- Modified experiment: remove disjoint distractors

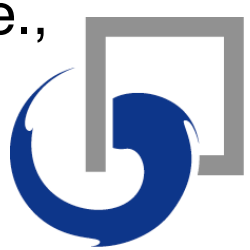
- Predictions using previous hypotheses
  - Hit responses
    - Less efficient search overall
    - Level curves closer together (i.e., more overlap)
  - Correct rejections
    - Curious about the interaction between salience threshold and task
    - If threshold unaltered, search time should decrease (more prominently where larger numbers of disjoint distractors resided)



Closing Remarks

- Strengths of model
  - Good correlations with participant data
  - Produces asymmetrical results for hit/cr conditions present in data
  - Interpretation of parameters are enlightening and seem plausible for the task

- Weaknesses
  - Search times still a bit long even after decreasing ‘visual -attention-latency’ to 25ms
  - Areas where longer search times exist in ACT-R model are not exchanged with more accurate responses (i.e., miss rate higher than participant data in these areas)



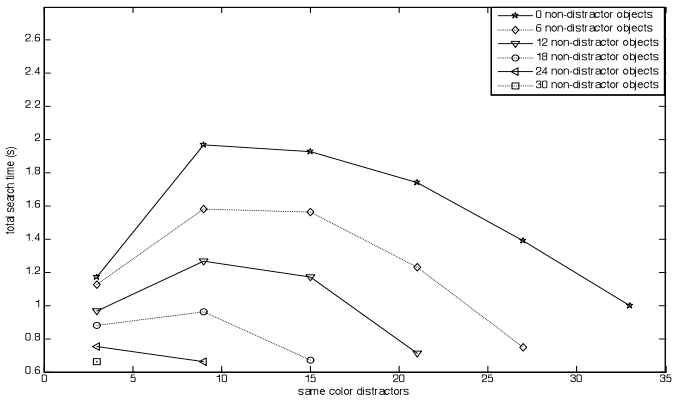
Closing Remarks

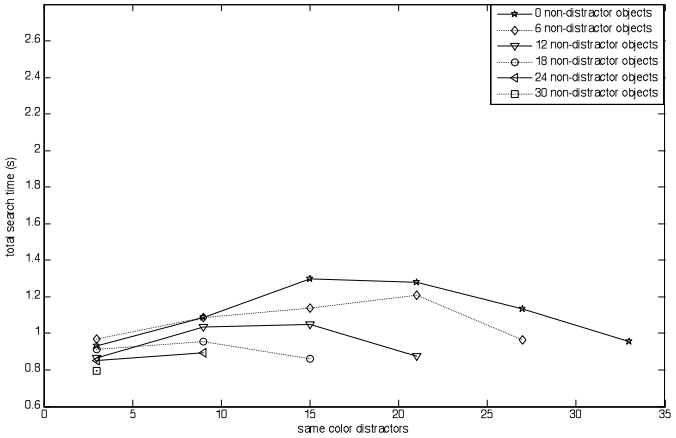
- Model predictions
  - Although disjoint distractors are not highly salient, their presence may actually improve search efficiency for the task by causing more accurate target pinpointing when the target is present
  - When the target is absent, disjoint distractors increase the information content of conjunctive distractors, affecting the average time elapsed before terminating the search
  - Next experiment aimed to challenge these predictions

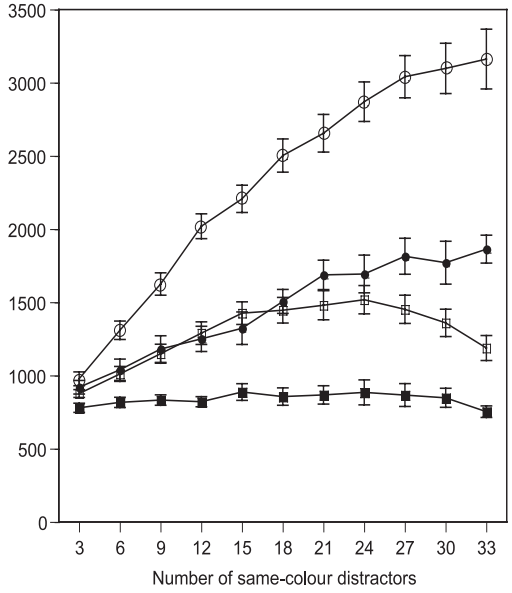
- Code for the salience computations which works with the new vision module is available @
  - http://chil.rice.edu/projects/salience/

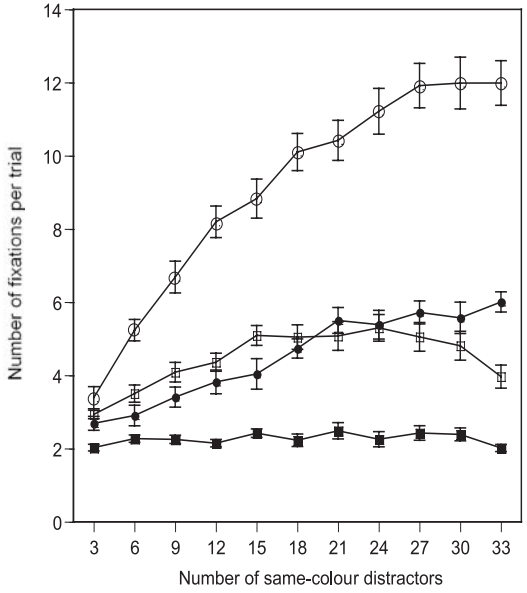
Questions

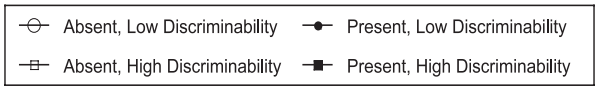
Interpreting Results: Hit Responses





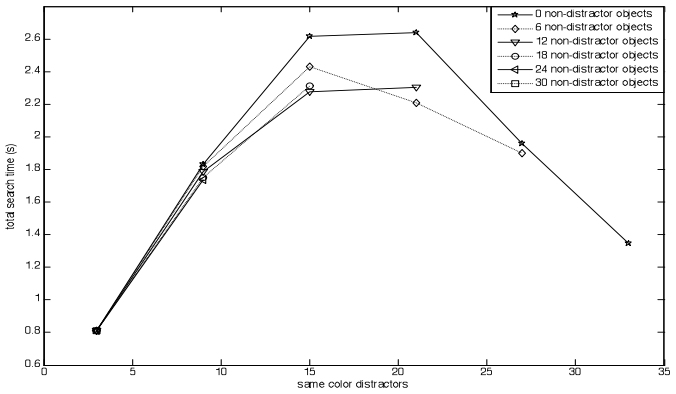


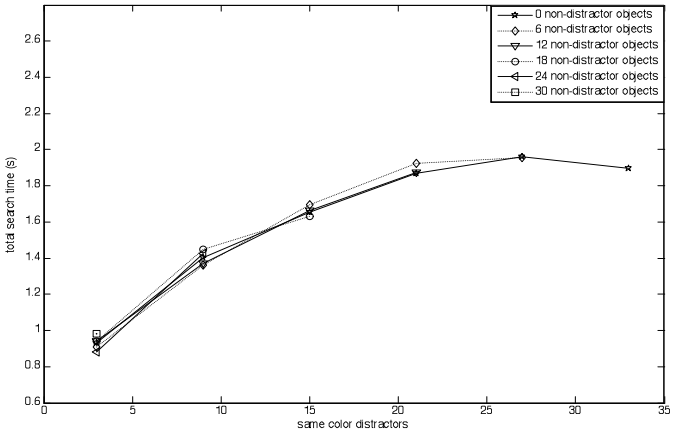


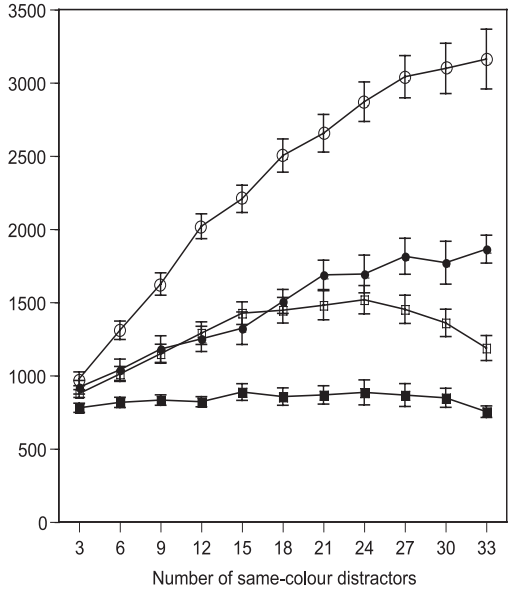


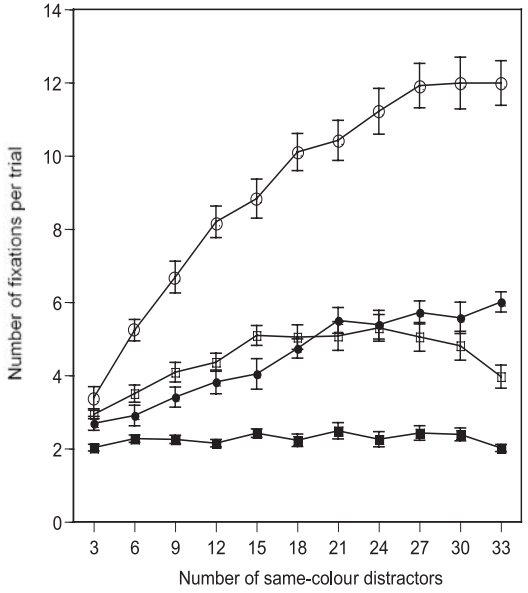
A B

Interpreting Results: CR Responses









A B