Combinatorial algorithms guide economic deliberation

Tao Hong, William Stauffer

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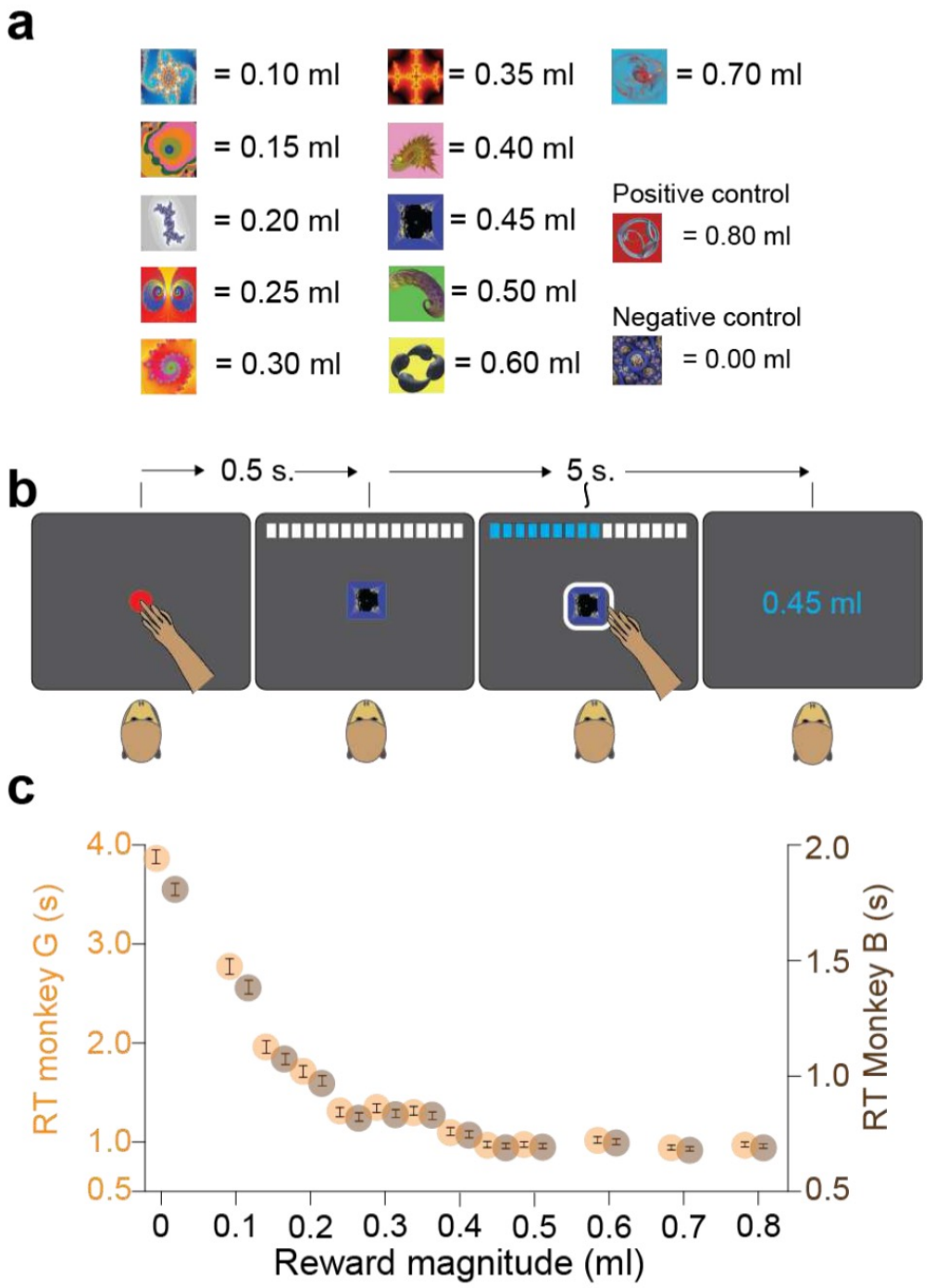
The aim

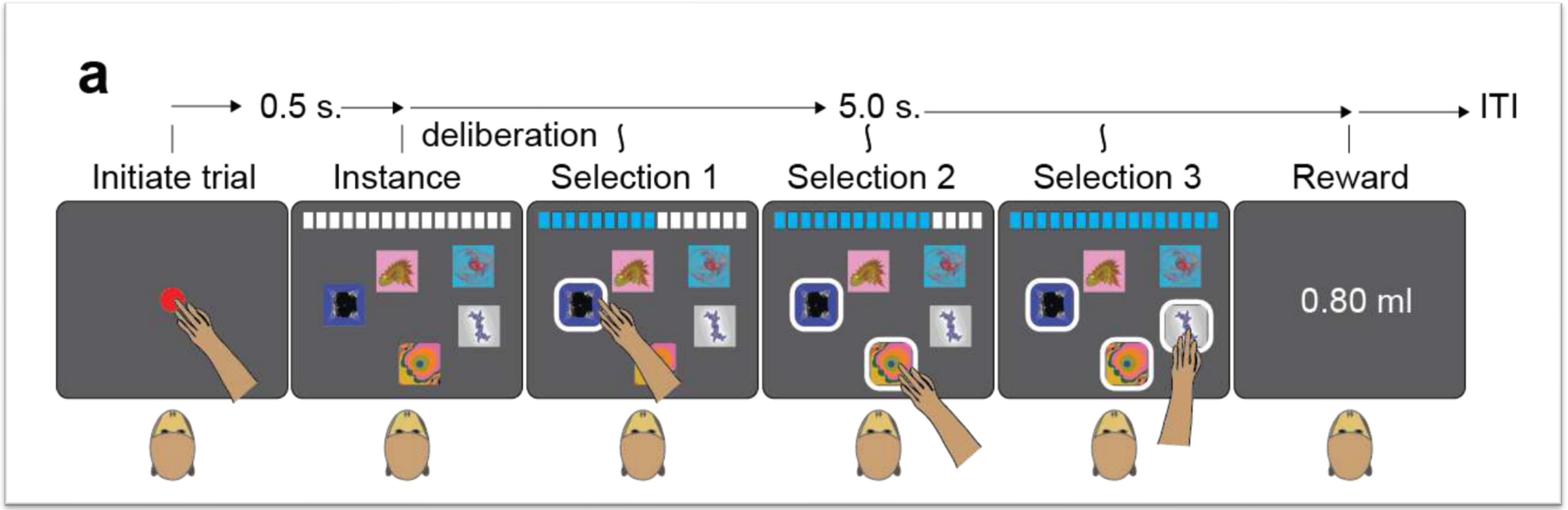
- “The main purpose of this study was to determine the step-by-step processes, or algorithms, that the animals used to optimize economic values.”

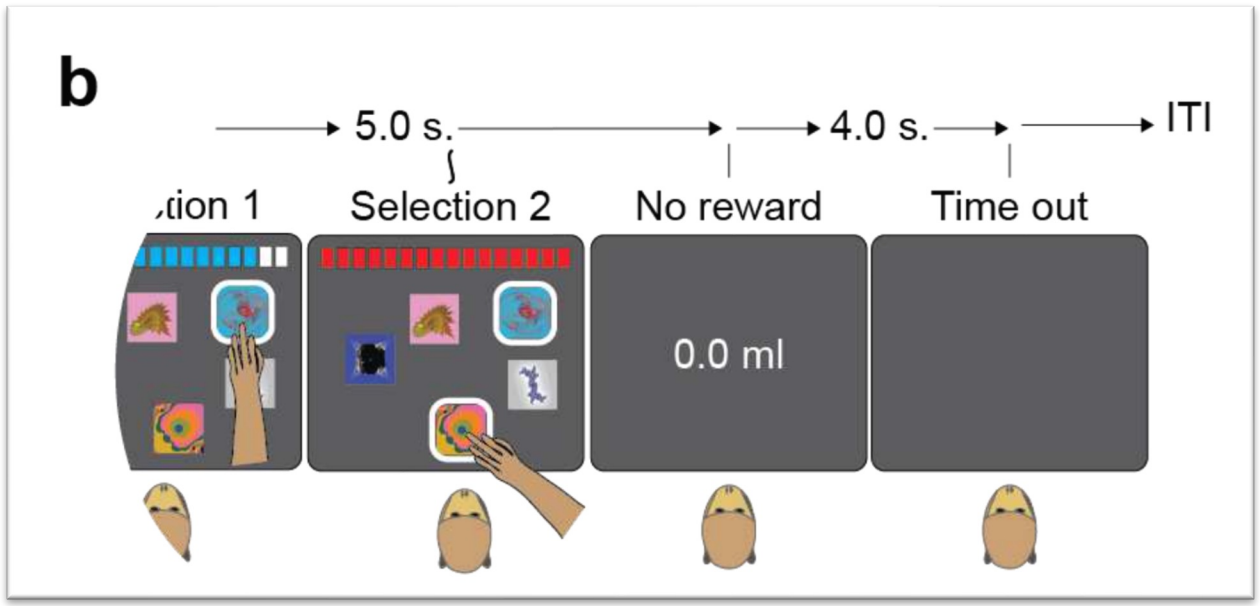
The design

- 2 Rhesus Macaque monkeys
- 11 fractals
- 2 control fractals
- 462 possible instances.
- 1 Month => new fractals
- 300-400 trials per day
- How many months? Trials?

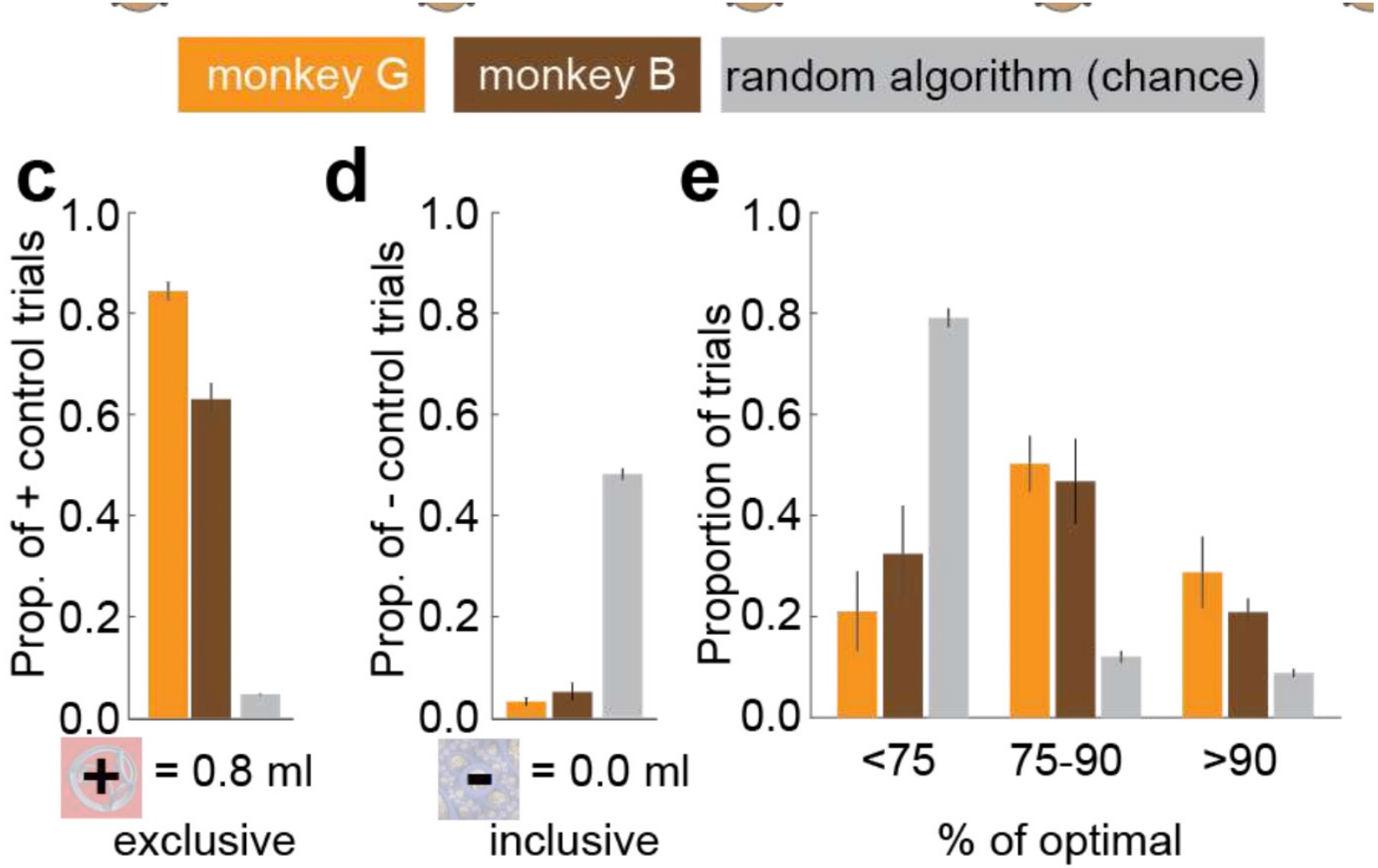


The task

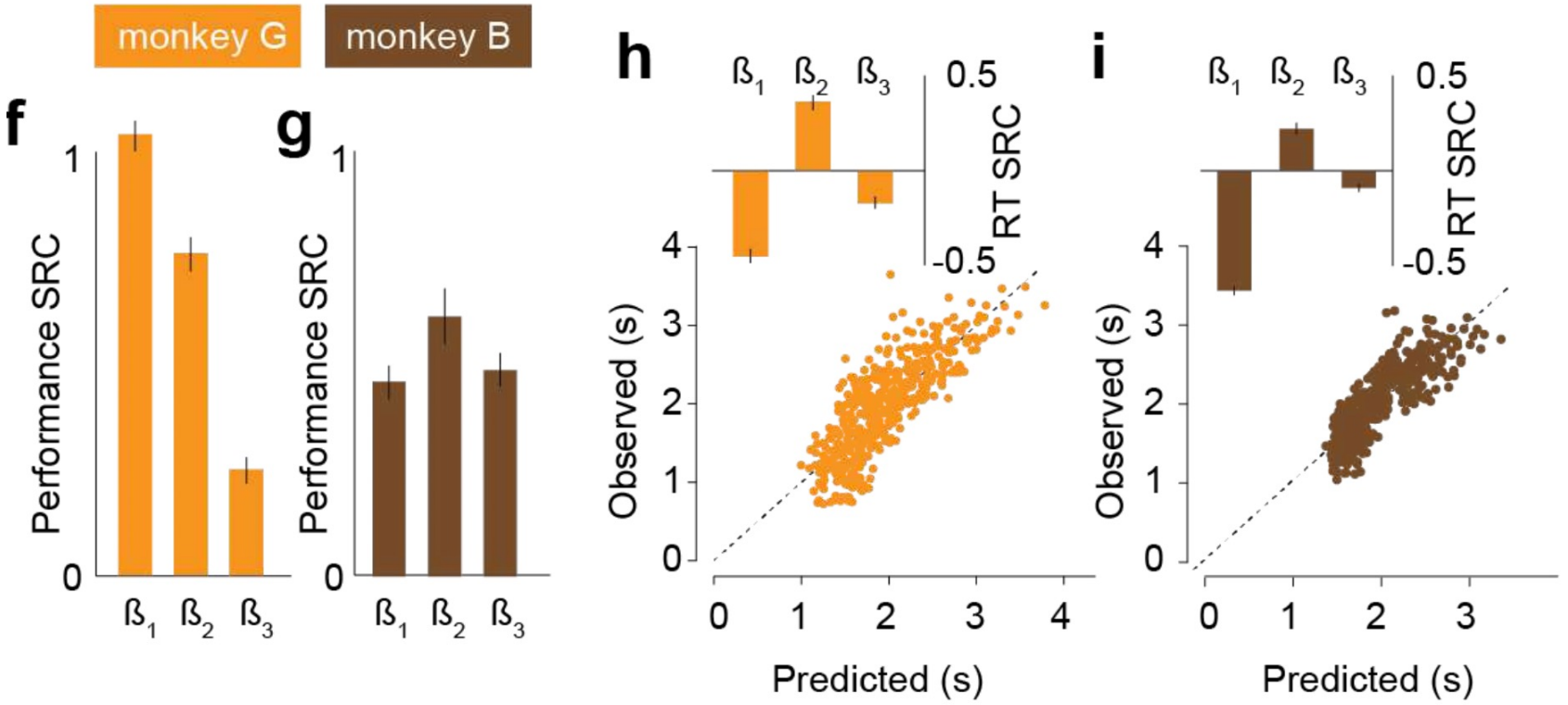

a
0.5 s.
deliberation
5.0 s.
ITI
Initiate trial
Instance
Selection 1
Selection 2
Selection 3
Reward
0.80 ml


b
5.0 s.
4.0 s.
ITI
Selection 2
No reward
Time out
0.0 ml

Results: Summary statistics



Results: Properties of the task



Bar graphs show the standardized regression coefficients for

- maximum item value (*ß1*),
- number of witnesses (*ß2*),
- and random score (*ß3)*

Error bars are ±SEM

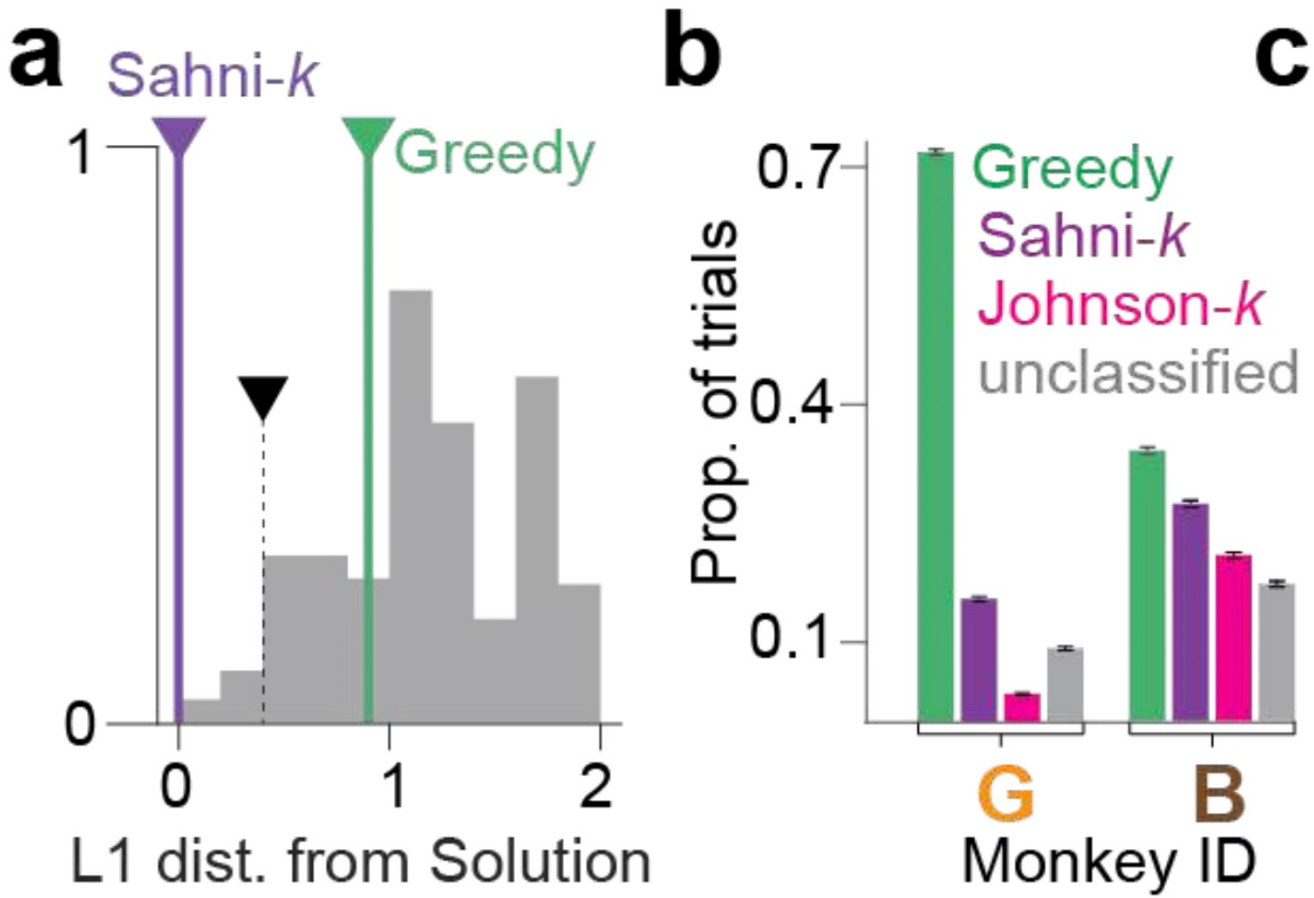
Results: Algorithms

- Three algorithms
  - Greedy
  - Sahni-k
    - Exhaustive search of size k
    - => greedy
  - Johnson-k
    - Best combination among items with value > 0.8/(k+1)
    - => greedy
- What algorithms did monkeys use?

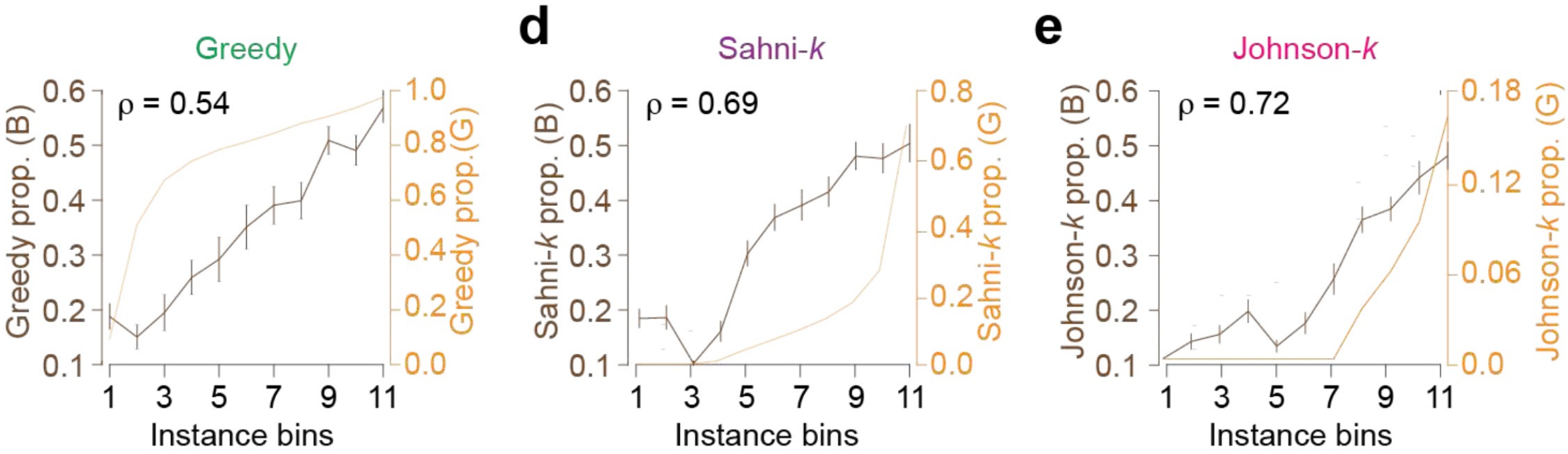
Methods: Algorithms

1. d1 = [1,0,0,1,0] vs. [0,1,0,1,1]
2. d2 = L1(sol=[0.4,0.2,0.1,0,0], beh=[0.4,0.1,0.2,0,0])
3. Null distribution to of d2
   - d2 < 0.05 of distances to solution

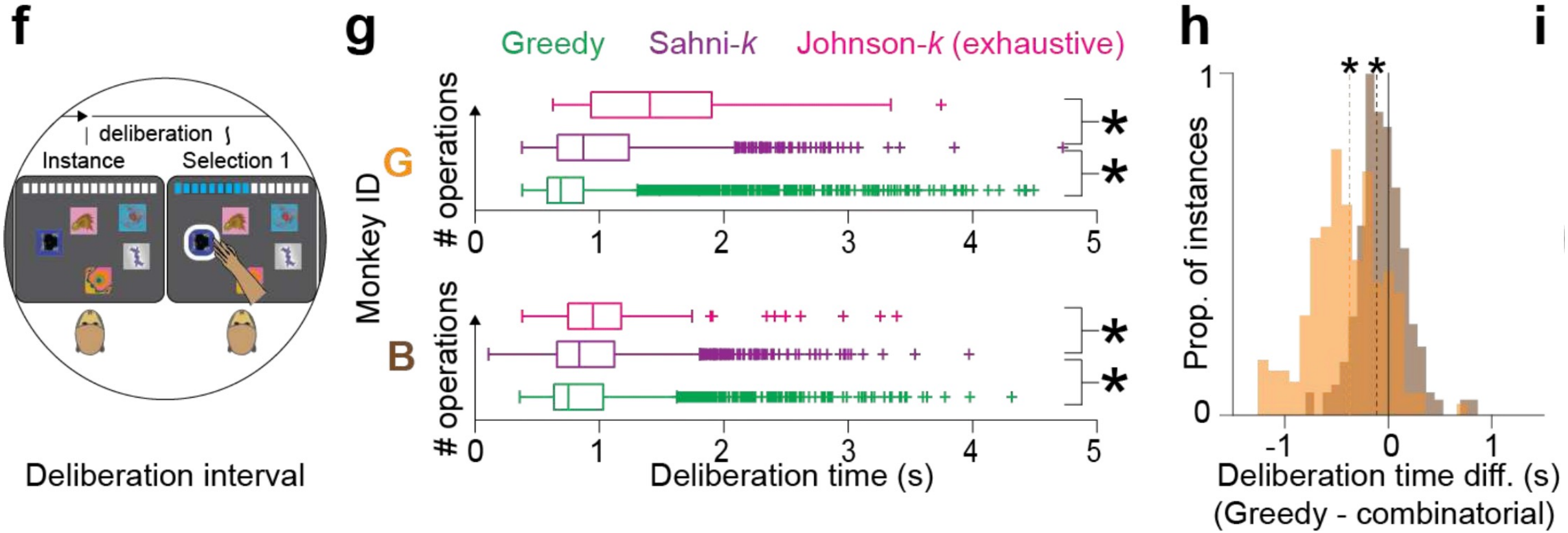
Results: Algorithms



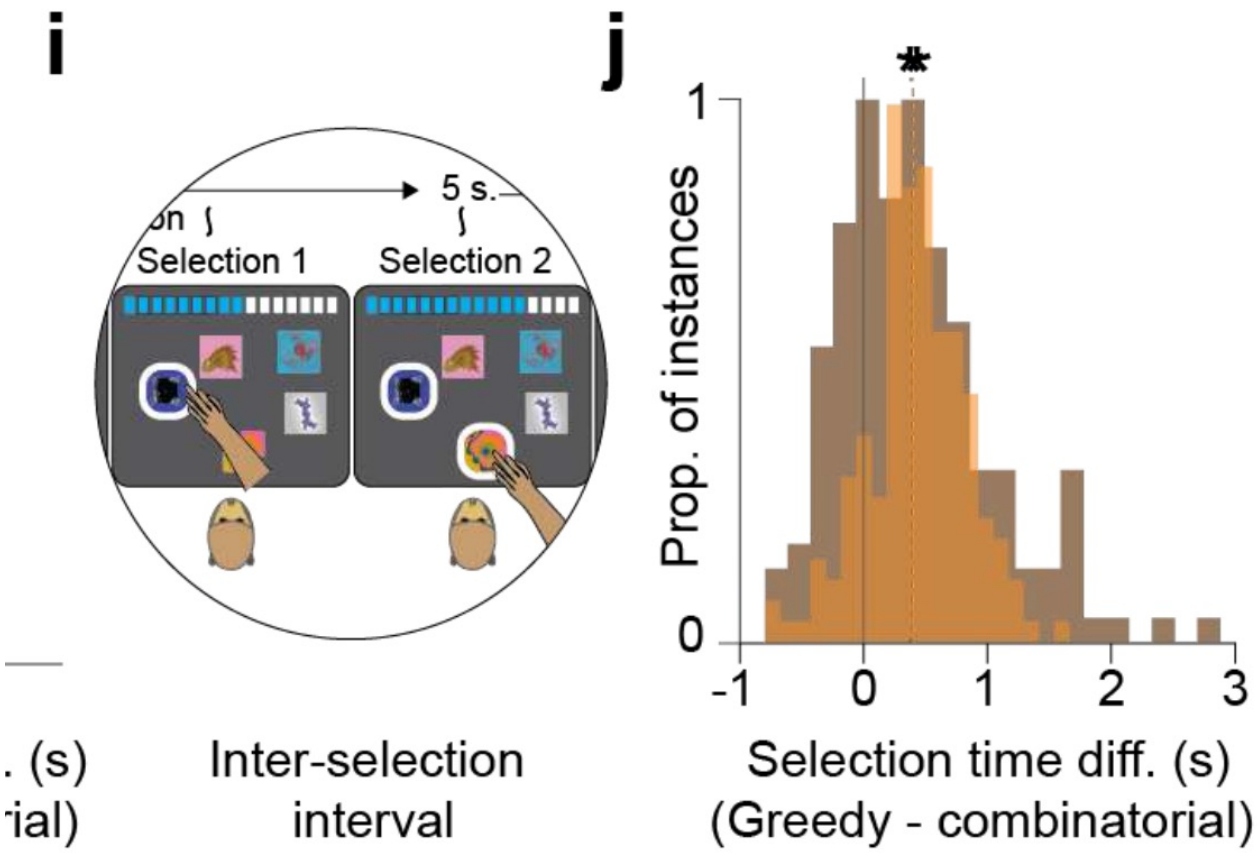
Results: Algorithms



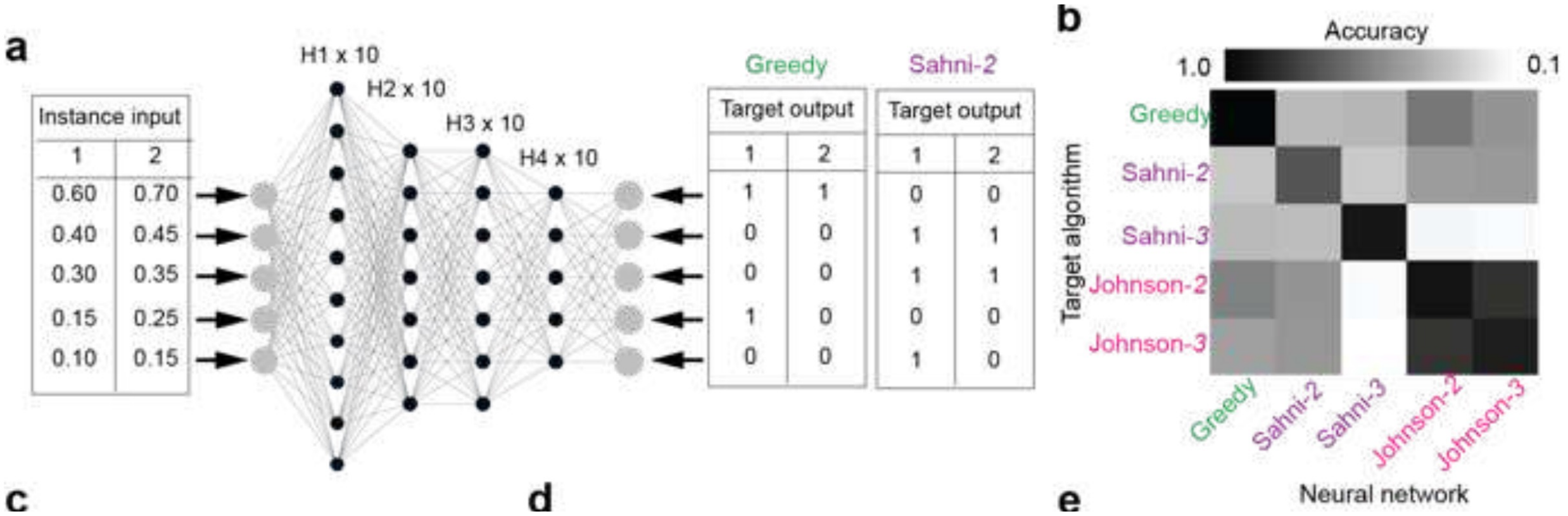
Results: Algorithms



Results: Algorithms



Results: Artificial neural networks



Conclusions

- The conclusion that the animals performed algorithmic optimization in general, and combinatorial reasoning specifically.
    1. Combinatorial properties of the instances affected both the performance and the response times (Fig. 1f-i).
    2. The order and the identity of the chosen subsets matched the order and identity of items selected by discrete computational algorithms.
    3. The algorithms that matched the instance solutions were highly correlated between the animals, suggesting that ‘algorithm selection’ was not random, but based on properties of the instance
    4. The deliberation times and subsequent response times all reflected the number of operations each algorithm required, at each timepoint.
    5. Finally, artificial neural networks (ANNs) trained to mimic combinatorial and noncombinatorial algorithms mimicked combinatorial and noncombinatorial behaviour, respectively.

Thank you!

Discussion time…