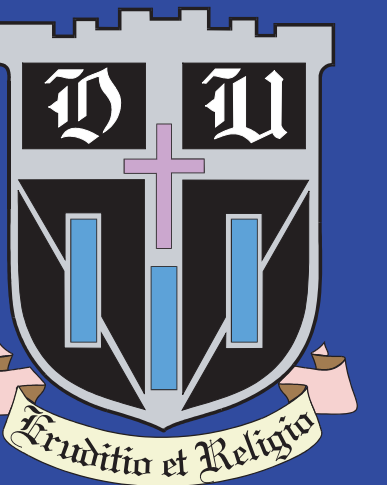




Cardinal Number Representation in Rhesus Macaques

Kerry E. Jordan and Elizabeth M. Brannon

Center for Cognitive Neuroscience and Department of Psychological and Brain Sciences, Duke University



Introduction

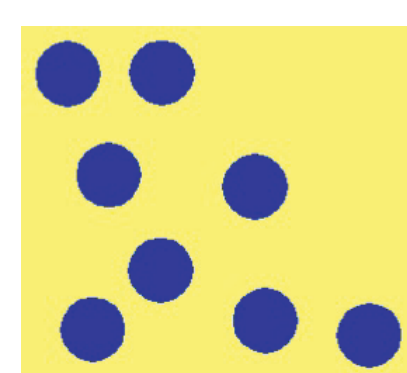
This work addresses the nature of cardinal number representation in nonhuman primates. While the abstract nature of such representations in adult humans is well-documented, less is known about the possible evolutionary origins of such central cognitive capacities. This series of delayed match-to-sample (DMTS) studies specifically investigates the abilities of rhesus monkeys to match stimuli based on number.

DMTS Method

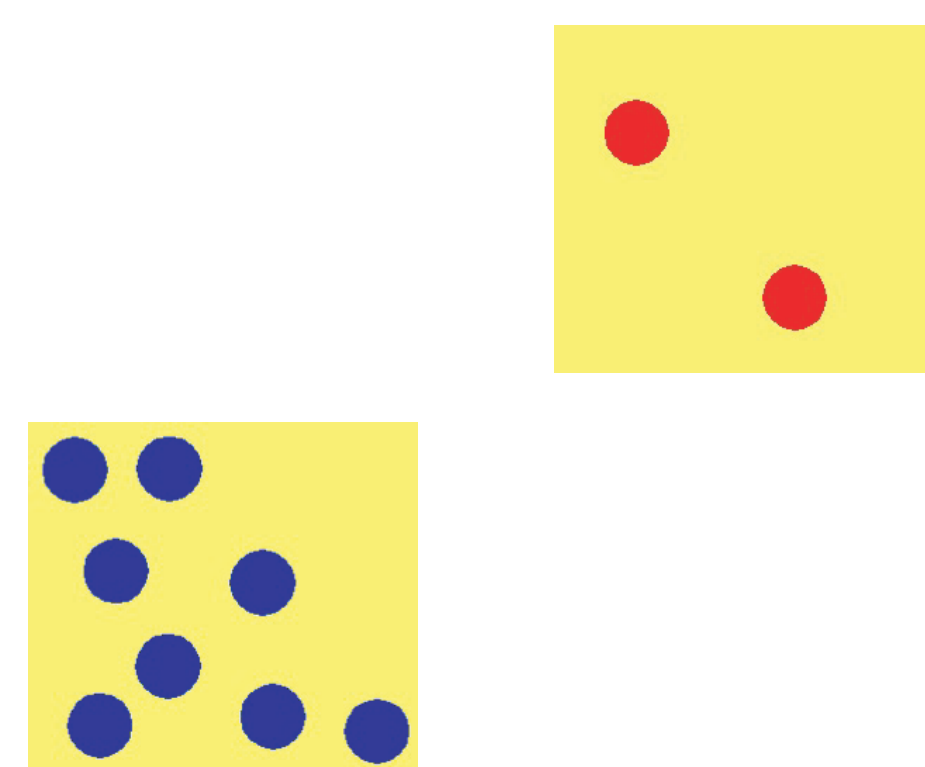
Subjects and general apparatus:

- 3 female rhesus macaques (Mikulski, Schroeder, and Feinstein)
- Tested in primate chairs inside sound-isolated booths
- Responded via a touch screen for juice reinforcement

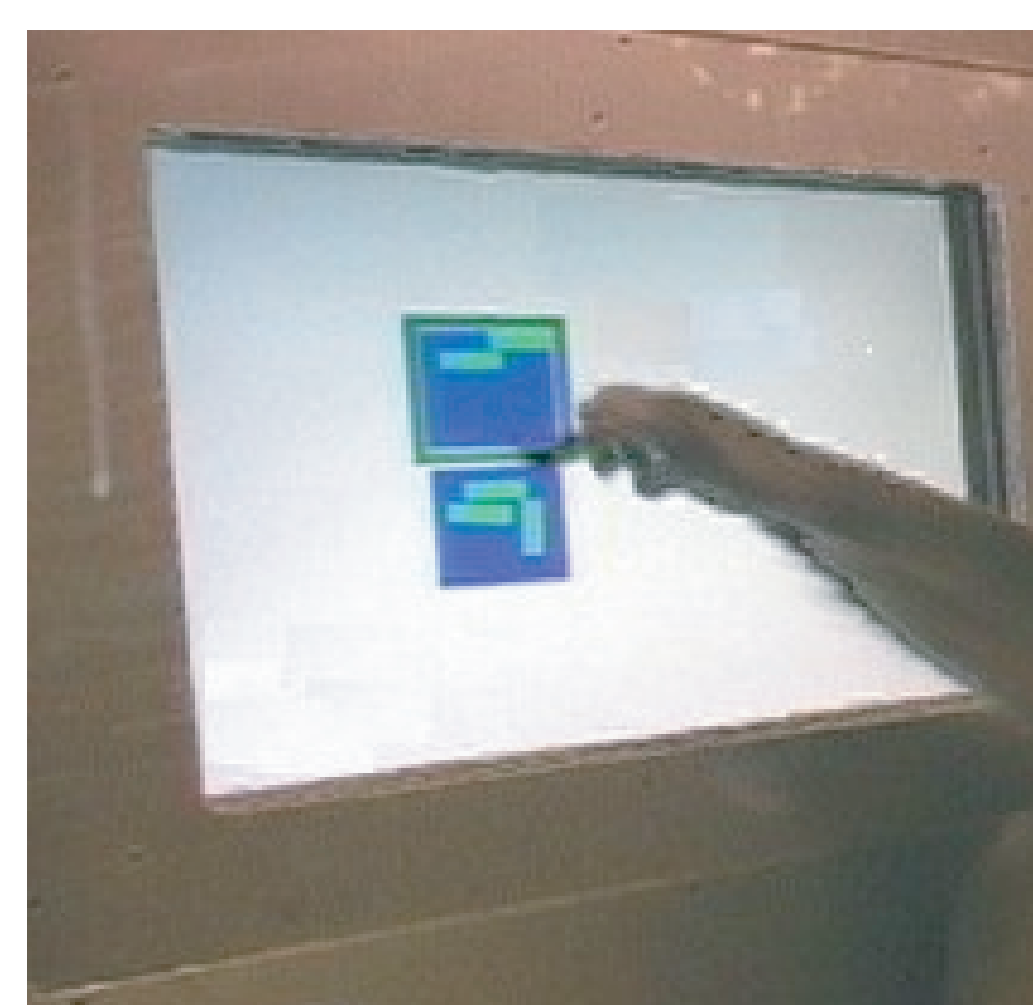
Sample



Test



Correct numerical matches were rewarded with a green border flash and fruit juice. Incorrect numerical choices resulted in the disappearance of the stimuli and a 5s timeout.

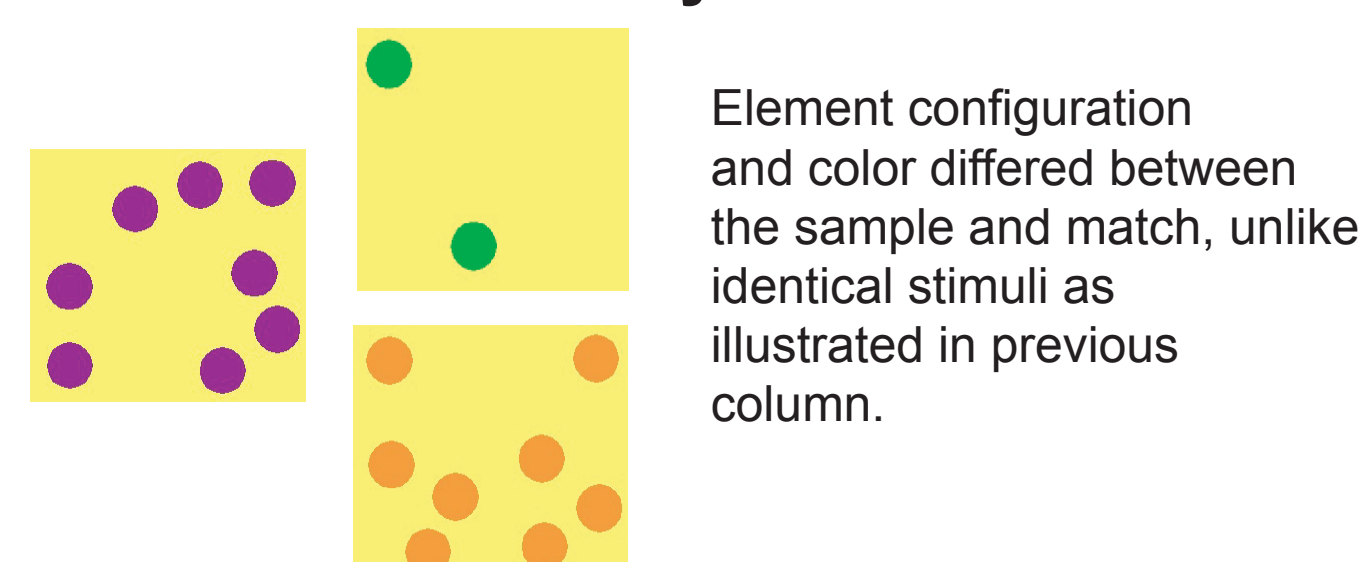


Experiment 1: Monkeys match stimuli based on numerical equivalence

Sample was an exemplar of 2 or 8
 Test stimuli were one exemplar of 2 and one of 8
 Trained with each stimuli control set to a criterion of 80% accuracy

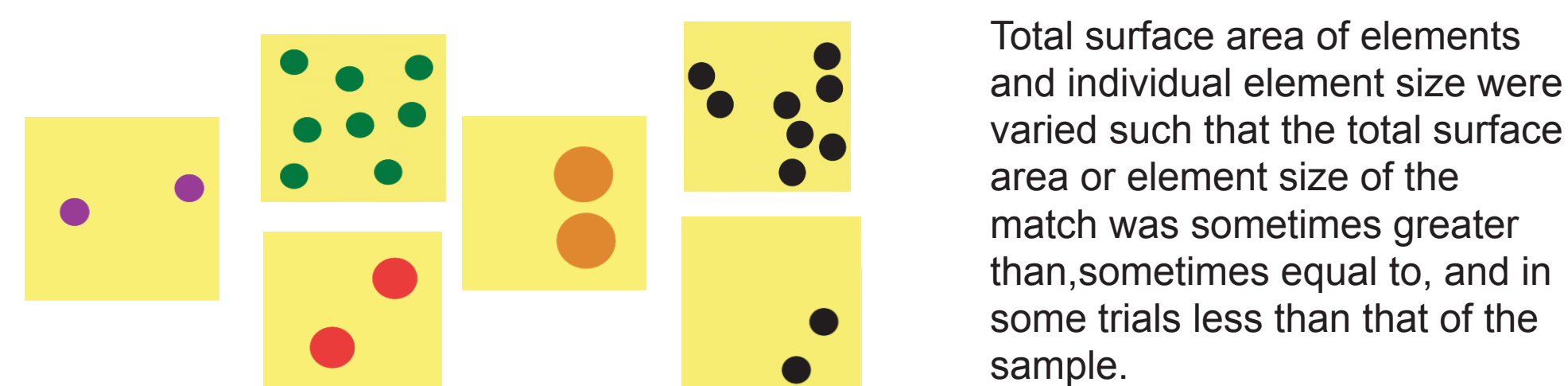
Stimulus Examples

Non-Identity



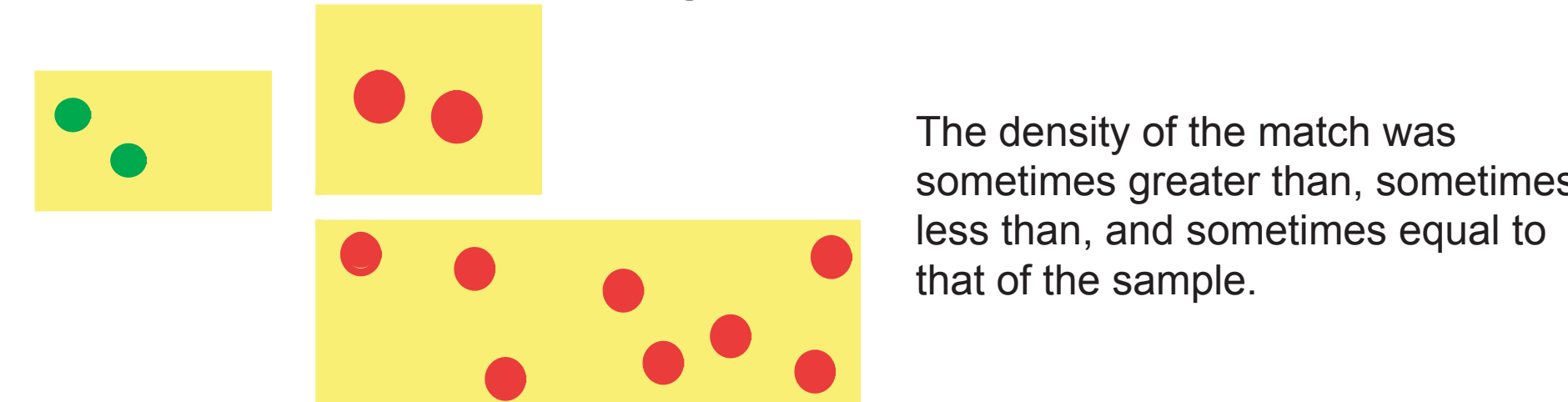
Element configuration and color differed between the sample and match, unlike identical stimuli as illustrated in previous column.

Surface area and element size control



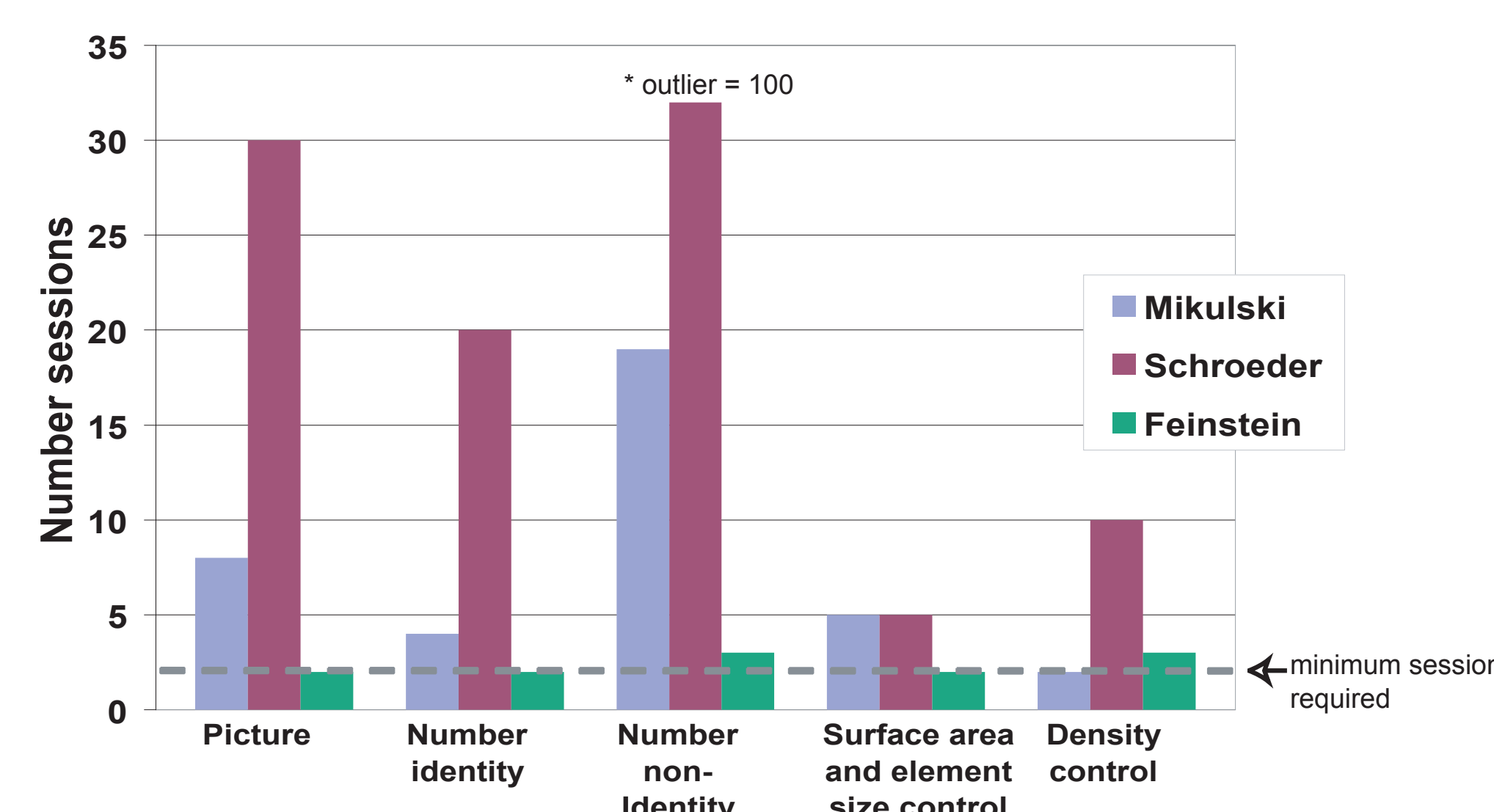
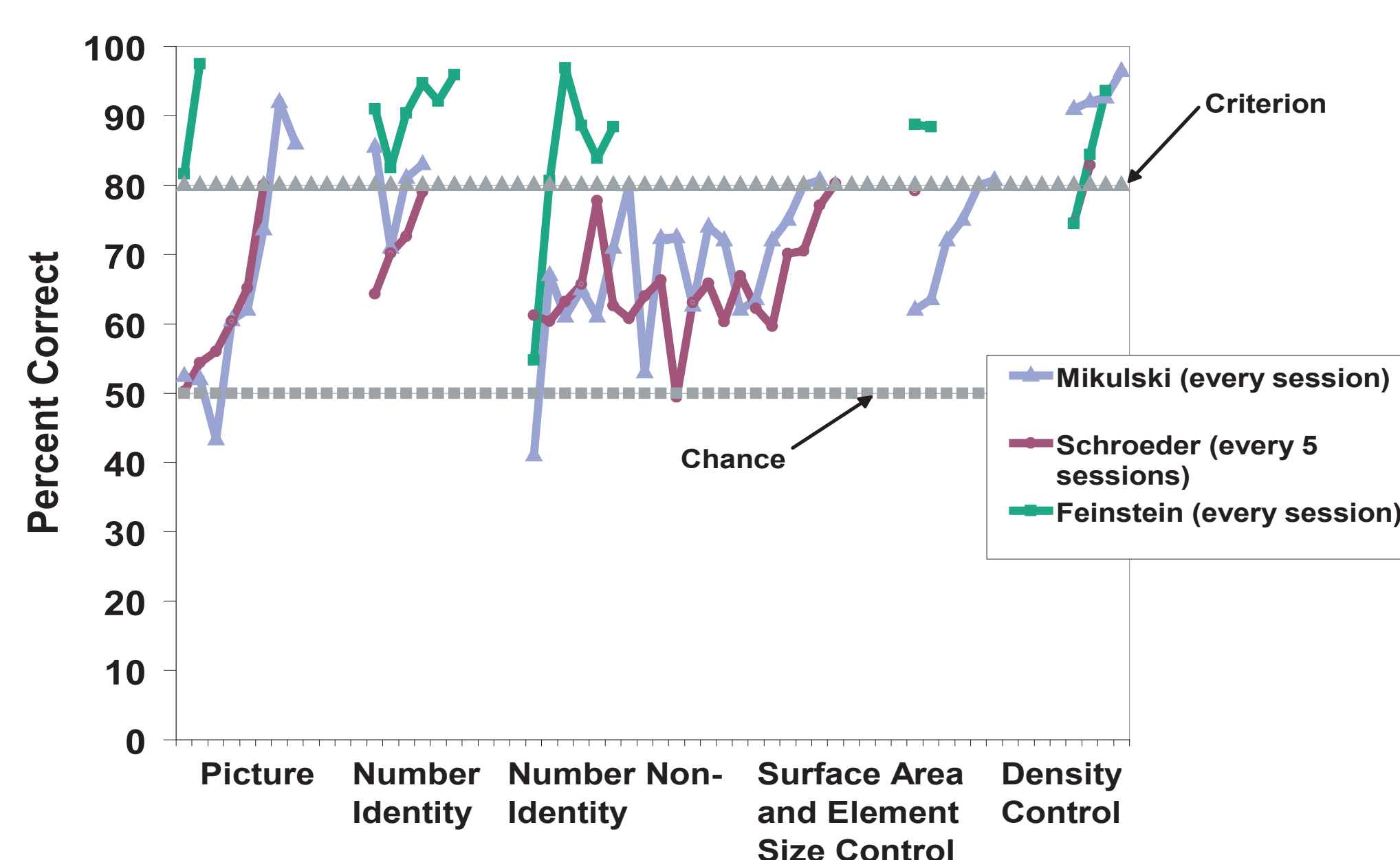
Total surface area of elements and individual element size were varied such that the total surface area or element size of the match was sometimes greater than, sometimes equal to, and in some trials less than that of the sample.

Density control



The density of the match was sometimes greater than, sometimes less than, and sometimes equal to that of the sample.

Performance minimally affected by stimulus controls

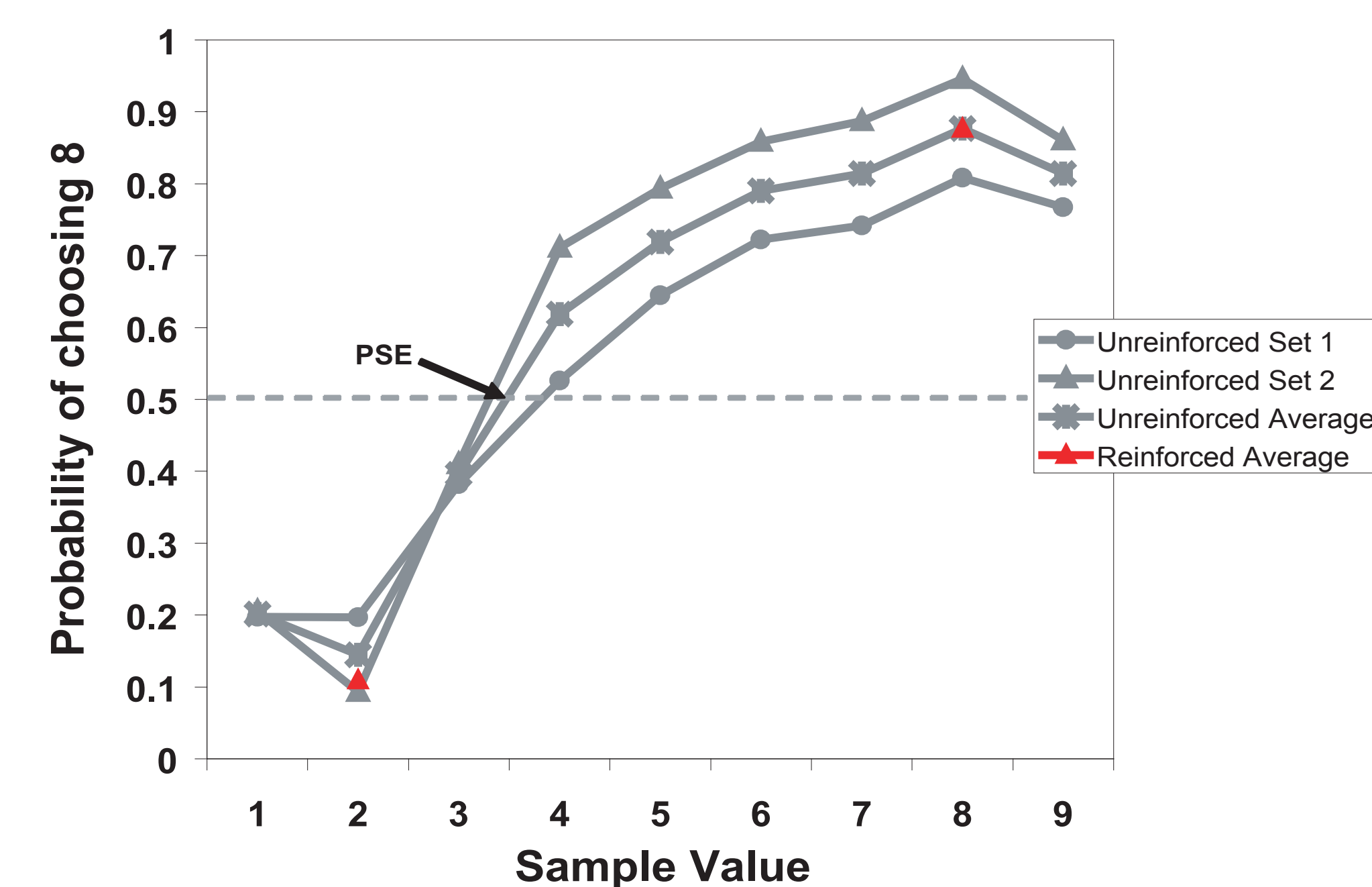


Experiment 2: Number bisection task

Methods

Subjects: Mikulski, Schroeder, Feinstein
 Stimuli: 2 sets, approximately 3000 trials/set
 Sample: numerosities between 1-9
 Test stimuli: 2 and 8
 Reinforcement:
 70% trials reinforced with sample numbers 2 & 8
 15% trials unreinforced with sample numbers 2 & 8
 15% trials unreinforced with novel sample numbers 1,3,4,5,6,7,9

Probability of choosing 8 systematically increases with number



The point at which monkeys are equally likely to classify a numerosity as 2 or 8 is the point of subjective equality, or PSE.

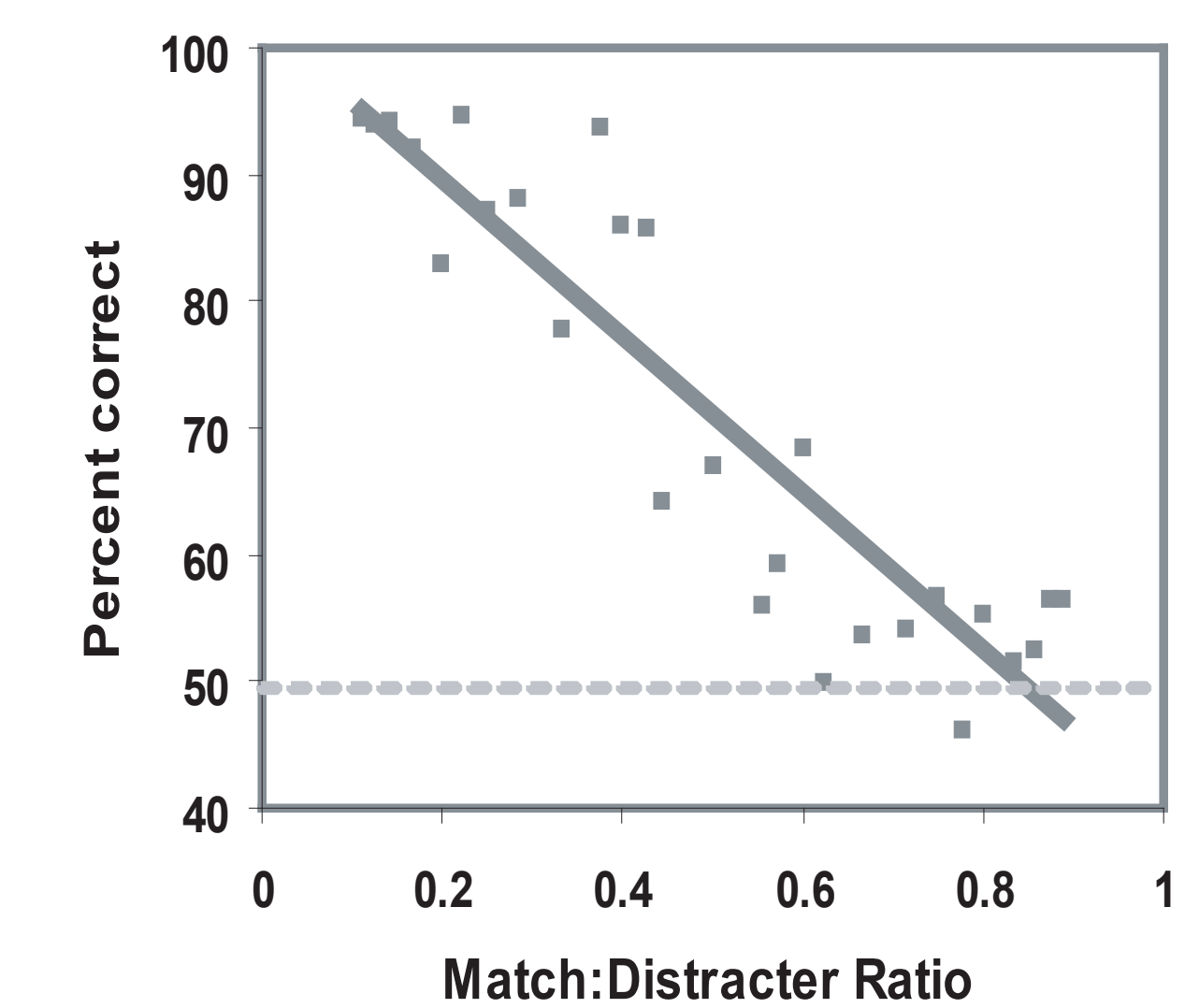
| | PSE | Weber fraction |
|------------|------|----------------|
| Stim set 1 | 4.23 | 0.955 |
| Stim set 2 | 3.45 | 0.579 |

Experiment 3: Choice Requires Precise Numerical Match

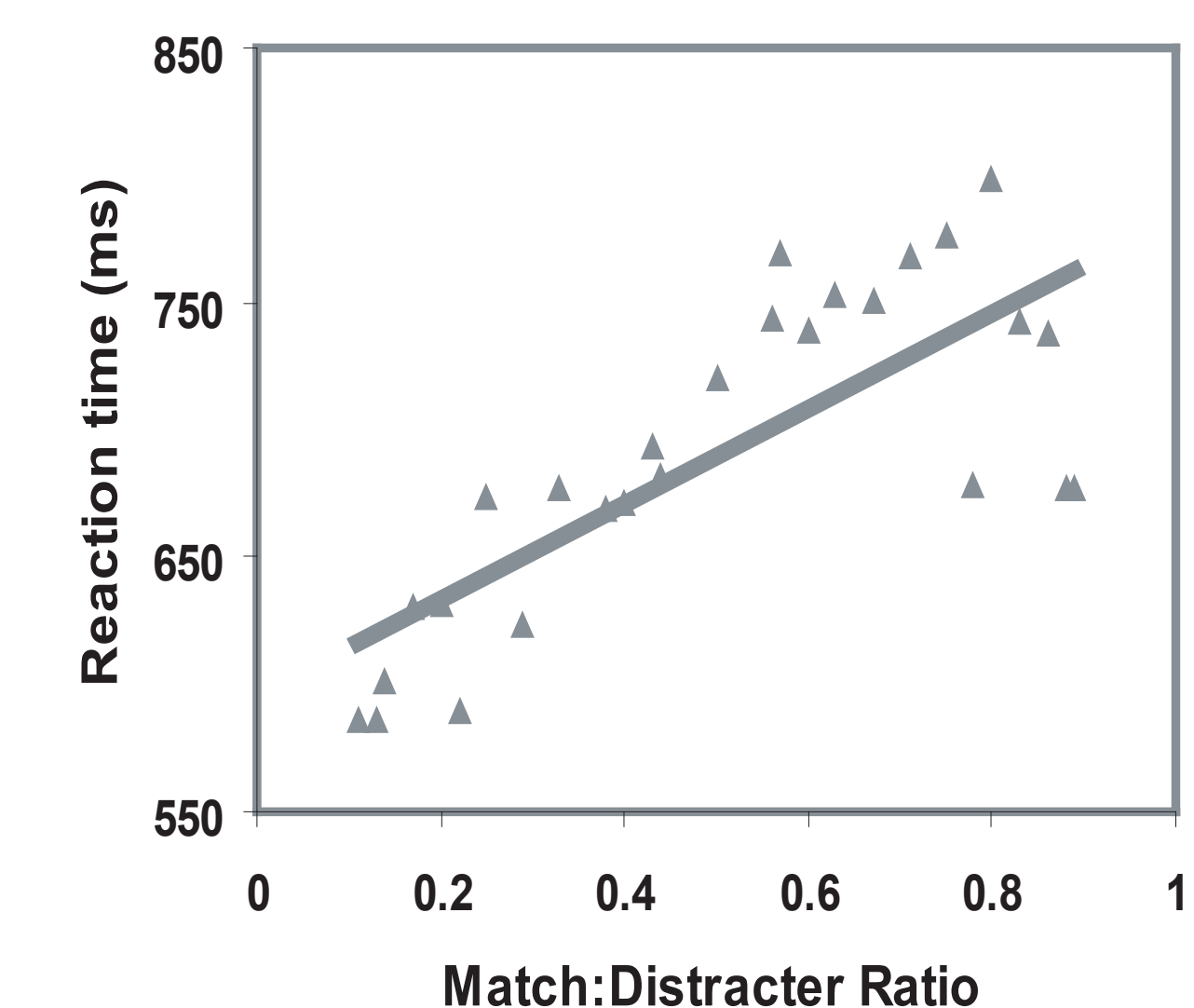
Methods

Subjects: Schroeder and Feinstein
 Sample: numerosities between 1-9
 Test stimuli: numerosities between 1-9
 Full reinforcement

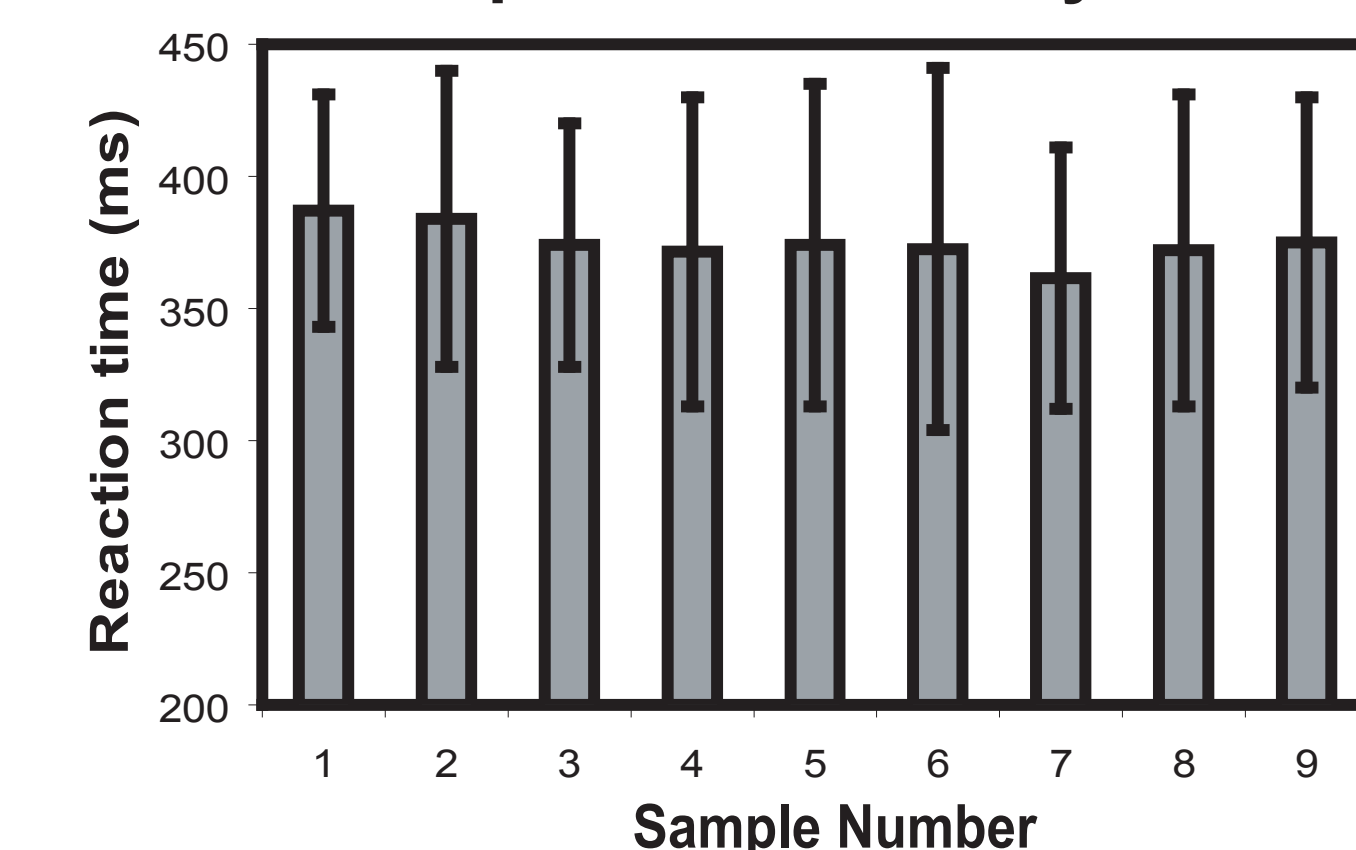
Accuracy decreases as match:distracter ratio increases



Reaction time increases as match:distracter ratio increases



Latency to touch sample does not vary with sample number



Conclusions

Rhesus macaques

- 1) match stimuli based on numerical equivalence, regardless of continuous dimensions
- 2) interpolate novel values along an ordinal continuum
- 3) are sensitive to ratio when making more precise numerical matches

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