



Monkeys Count Up and Count Down: Conditional Numerical Ordering in Rhesus Monkeys

Jessica Cantlon, Kerrie Lewis, & Elizabeth M. Brannon



Psychological and Brain Sciences & Center for Cognitive Neuroscience, DUKE UNIVERSITY

Introduction

This research investigates the abstract nature of ordinal numerical concepts in non-human primates. Previous research has shown that rhesus monkeys can use ordinal rules to seriate numerosities. Subjects trained to order a subset of numerical values ordered novel numerical values with non-differential reinforcement (Brannon & Terrace 1998, 2000). Thus, rhesus monkeys learn ordinal numerical rules and represent numerosity as an ordered dimension. The level of abstraction at which subjects appreciate ordinal numerical relations, however, is still not known.

Here we address three questions regarding monkeys' ordinal numerical abilities:

- 1) Can monkeys learn to flexibly order numerosities with both ascending and descending ordinal rules?
- 2) Can subjects who are trained to perform a conditional ordinal rule on the numerosities 1 to 9 transfer the ordinal rule to large numerical values?
- 3) To what degree do monkeys use density and perimeter as cues to discriminate and order numerosity?

Method

Subjects & Training Procedure

Two rhesus macaques (Feinstein and Mikulski)

Red background: respond **ascending**

Blue background: respond **descending**

Training Phase 1 (differed between monkeys)

Feinstein trained on 3-item subsets 1-3-5 and 9-7-5

Mikulski trained on 2-items subsets 1-9 and 9-1

Training Phase 2

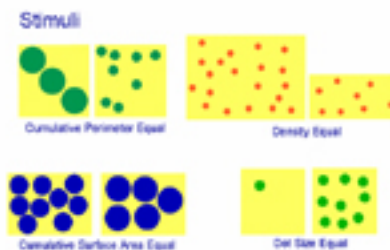
Subjects trained on odd 2-item pairs between 1 and 9

Training Phase 3

Subjects trained on all 2-item pairs between 1 and 9

Stimulus Controls

After subjects learned to order the numerosities 1 to 9, density, perimeter, and surface area were controlled.



Transfer

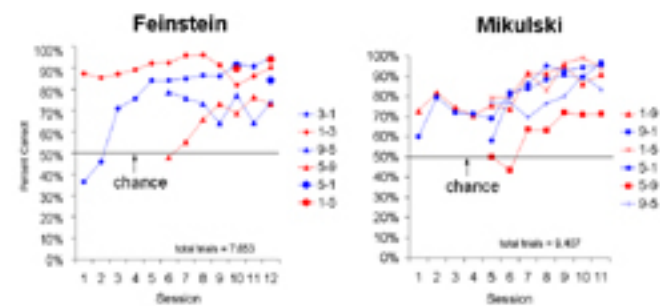
Pairwise test of large, novel numerical values (10-20, 10-30, 10-40, 20-30, 20-40, 30-40)

Pairs consisting of one or two novel values were non-differentially reinforced.

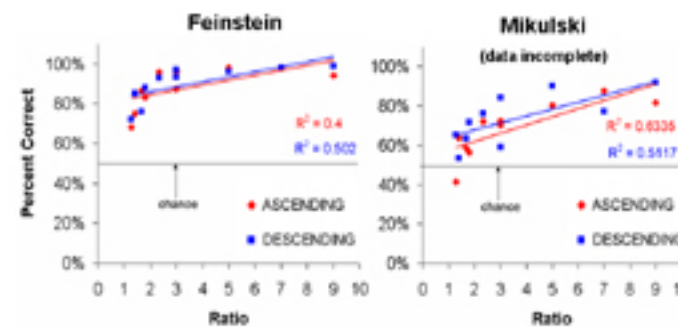
Results

Acquisition

Accuracy on first sessions in which **ascending** and **descending** trials were randomized for a subset of numerical pairs.

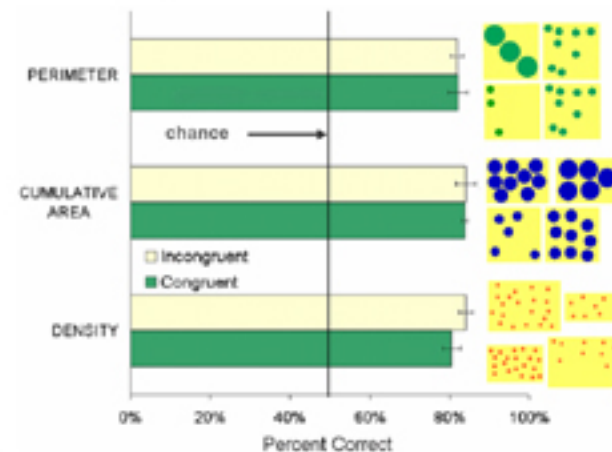


Accuracy on all odd pairs between 1 and 9 by ratio



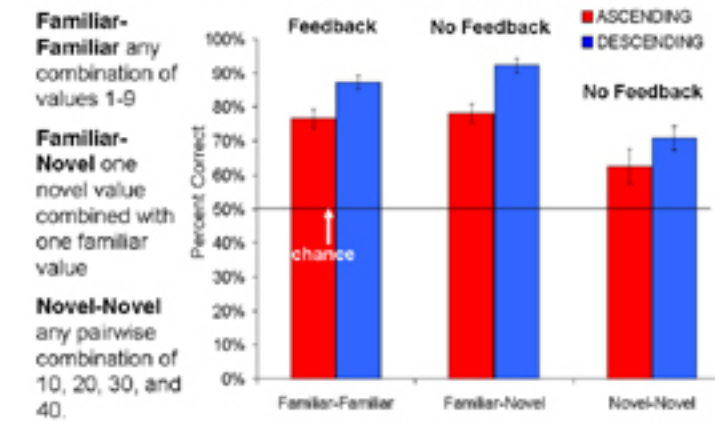
Stimulus Controls

Subject's accuracy is unaffected by stimulus controls
Note: From this point on, data is from Feinstein only

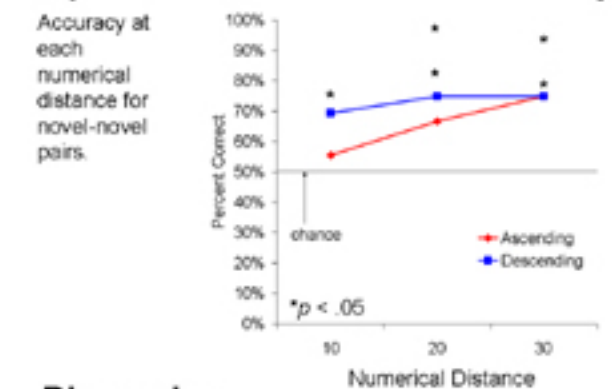


Transfer

Subject transfers ordinal rule to large, novel numbers



Subject shows numerical distance effect on large numbers



Discussion

- 1) Both monkeys were successful in learning to perform conditional ascending and descending ordinal rules.
- 2) After training on values ranging from 1 to 9, one subject was able to order the novel numerosities 10, 20, 30, and 40 consistent with the conditional ordinal rules.
- 3) Cumulative perimeter and density did not influence numerosity discrimination in this task.

This suggests that rhesus monkeys have a rich appreciation of numerosity and ordinality and that they appreciated large novel numerosities as a continuous extension of smaller, familiar numerosities.

References

Brannon, E. and Terrace, H. (1998). Ordering of the numerosities 1-9 by monkeys. *Science*, 282: 746-749.

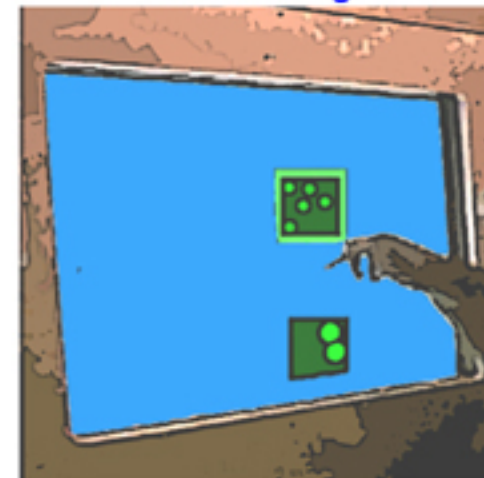
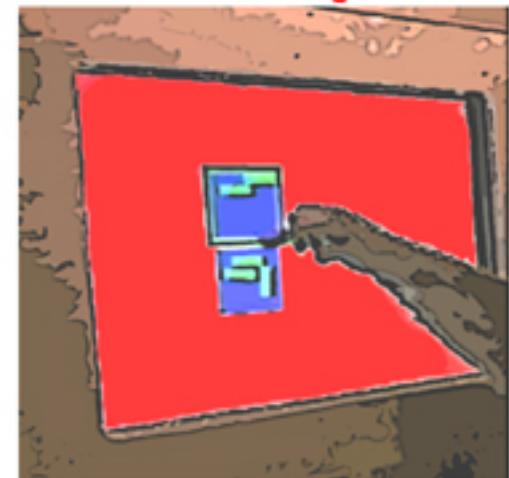
Brannon, E. and Terrace, H. (2000). Representation of the numerosities 1-9 by Rhesus Monkeys. *JEP-ASP* 26 (1), 31-49.

Acknowledgements

We would like to thank Kerry Jordan, Jessica Ward, and Pierre Rojas for participating in data collection. This project was funded by the John Merck Scholars Program to EMB.

Ascending

Descending



When the background color of the monitor was **red**, subjects were rewarded with fruit juice for touching the stimuli in an ascending direction and when the background color was **blue**, subjects were rewarded for touching stimuli in a descending direction.