Childhood Is Evolution's Way of Performing Simulated Annealing: A life history perspective on explore-exploit tensions.

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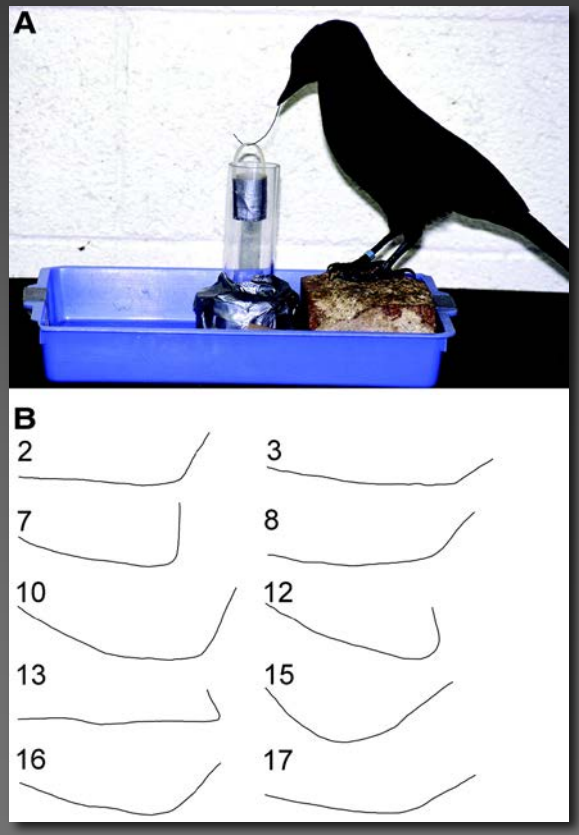
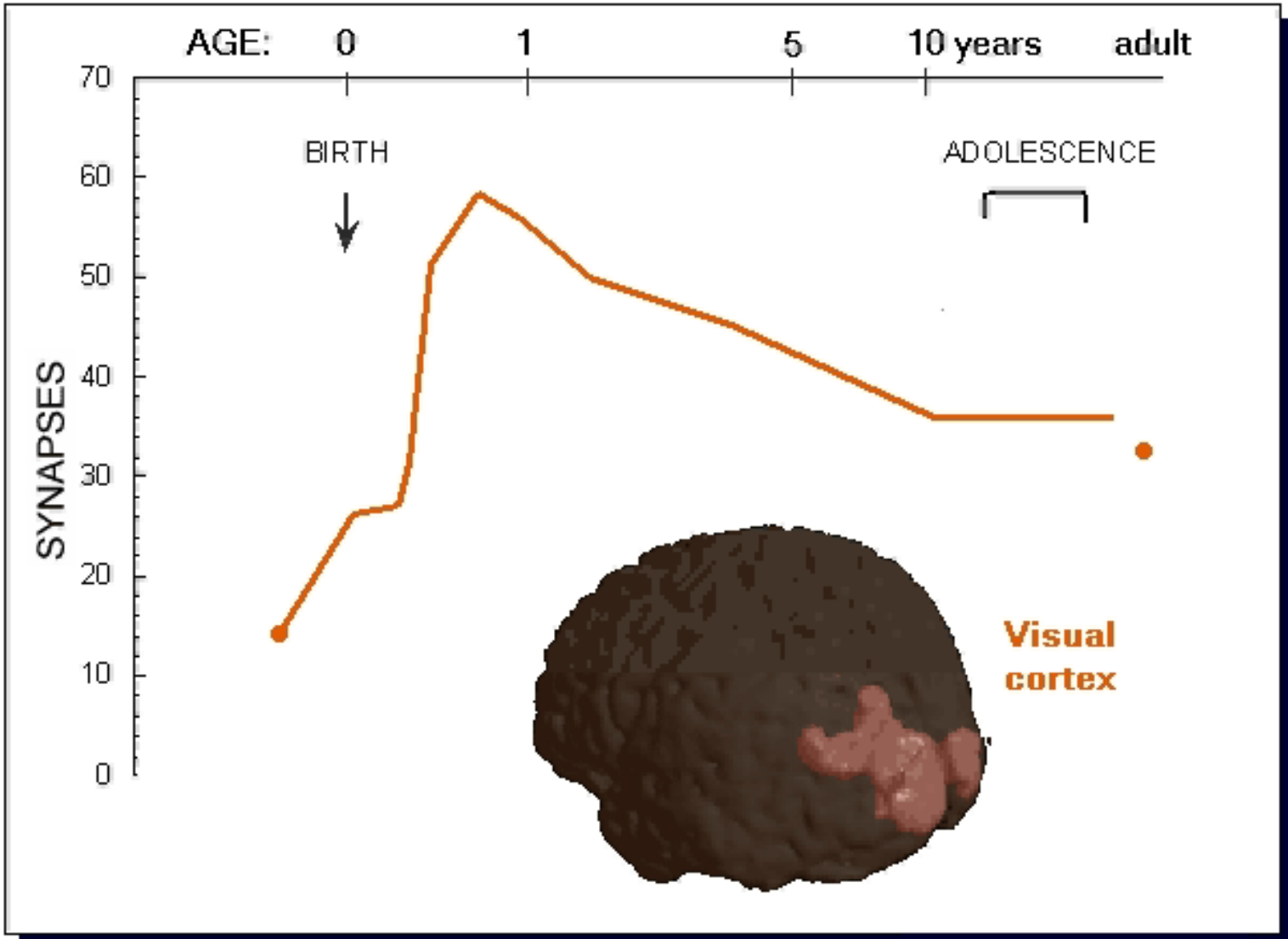
Why Childhood?: Longer Childhood, Bigger Brain, Smarter Animal



Human Brain
Development of Connections (Synapses)



Adapted from P. Huttenlocher et. al. (1979-1997)

THE THEORY THEORY 2.0

Learning Probabilistic Causal Models from Statistical Data

- Gopnik & Wellman, Psychological Bulletin, 2012
- Gopnik, Science, 2012

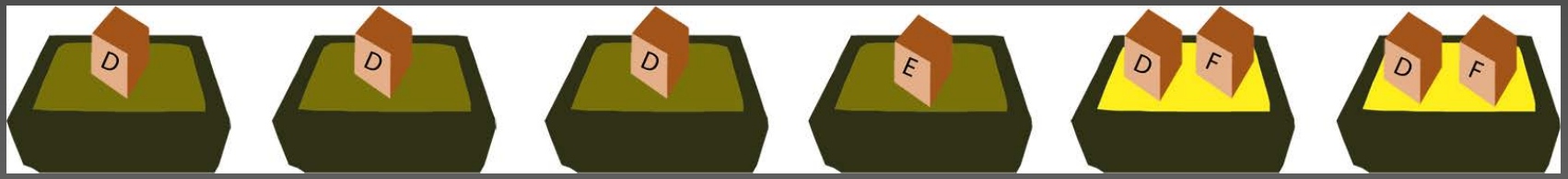
Unanswered Questions

- How do children learn higher-order causal “framework theory” principles as well as specific causal relationships?
- Are there developmental differences?
- How do children search through all the possible hypotheses?

Inferring Abstract Laws
Lucas, Gopnik & Griffiths, 2014, *Cognition*

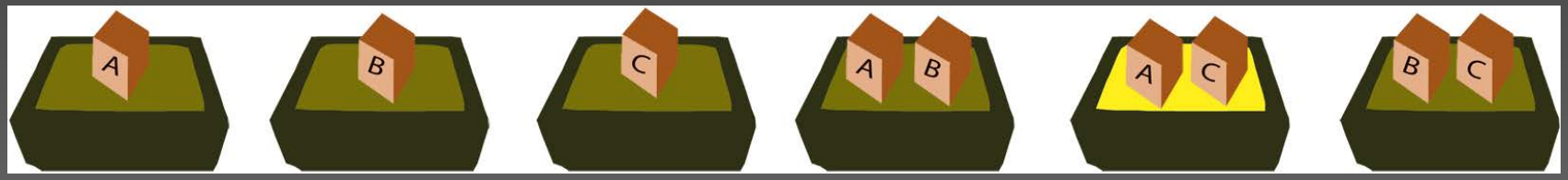
- Framework theories
- Hierarchical Bayes-nets (Griffiths & Tenenbaum, 2007)
- The blessing of abstraction (Goodman, 2010)

Which objects are blickets?



Is D a blicket? Is E a blicket? Is F a blicket?

What if you also saw these events?



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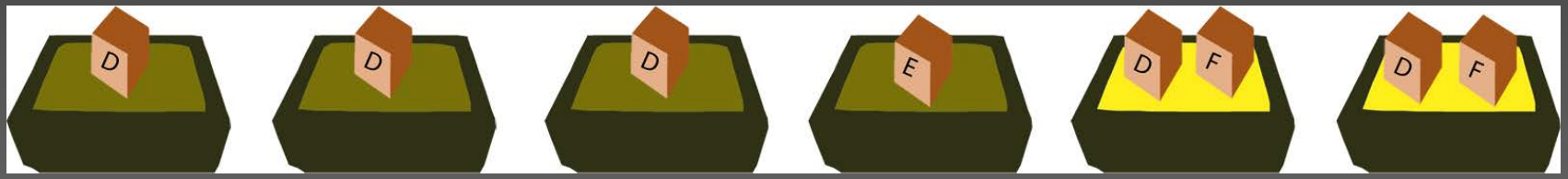
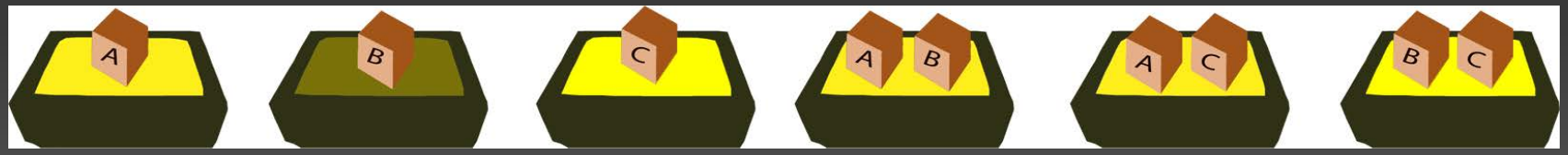
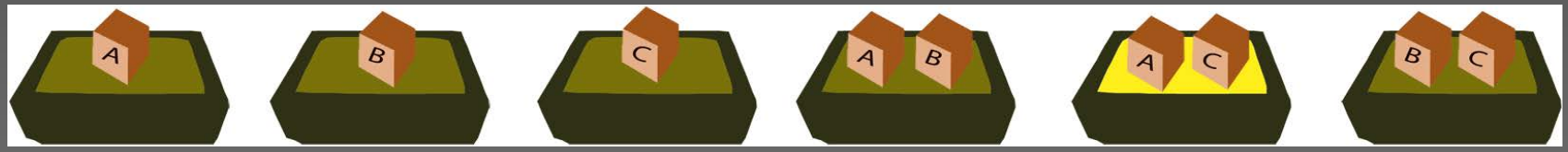


Is D a blicket? Is E a blicket? Is F a blicket?

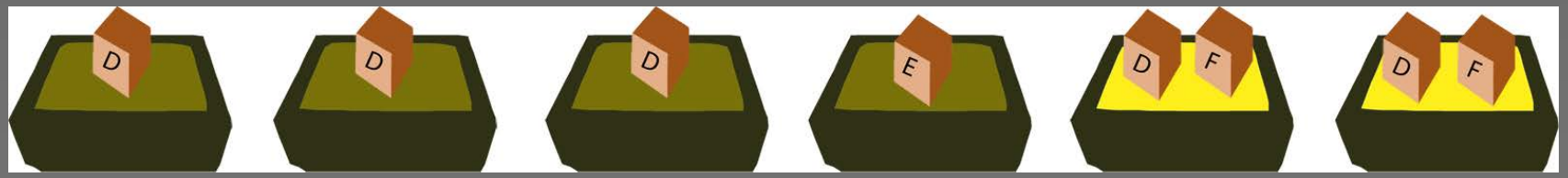
“Or“ Training

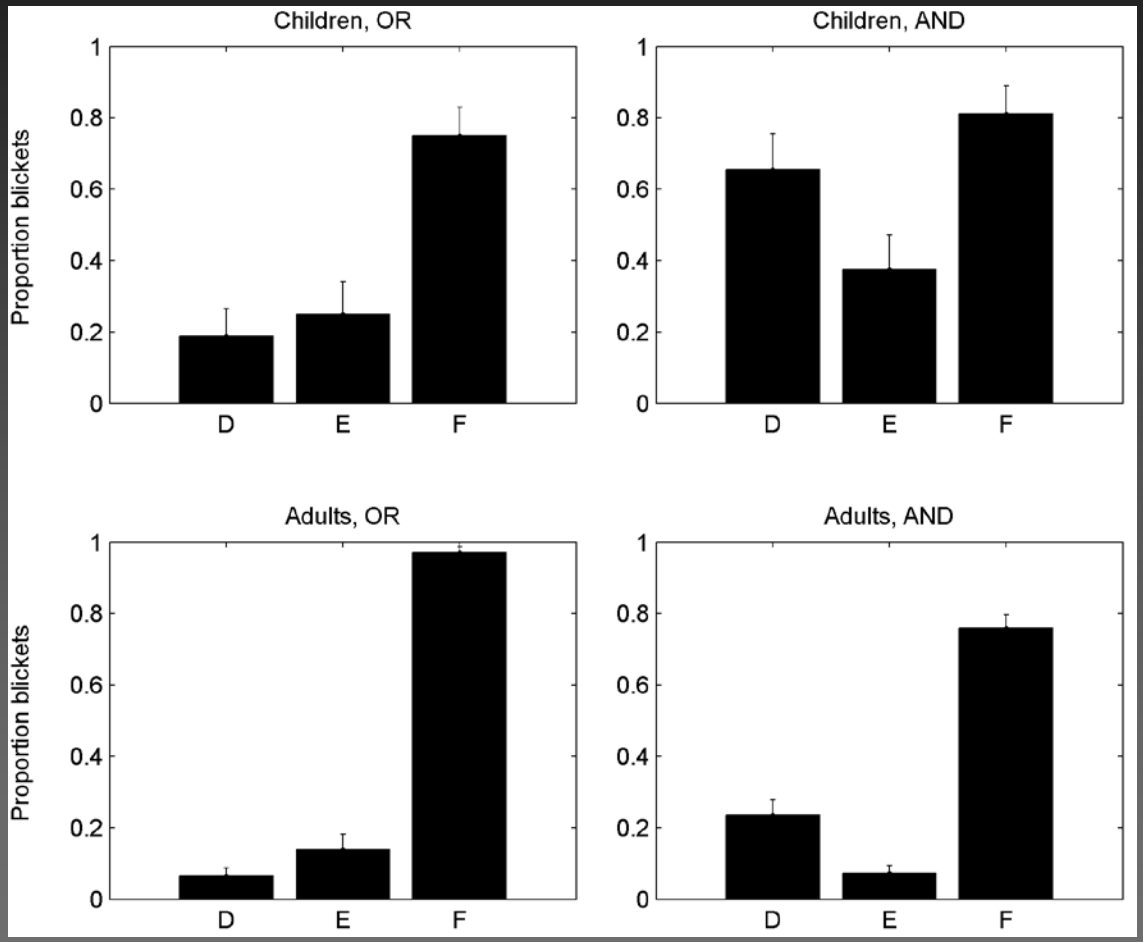


“And” Training

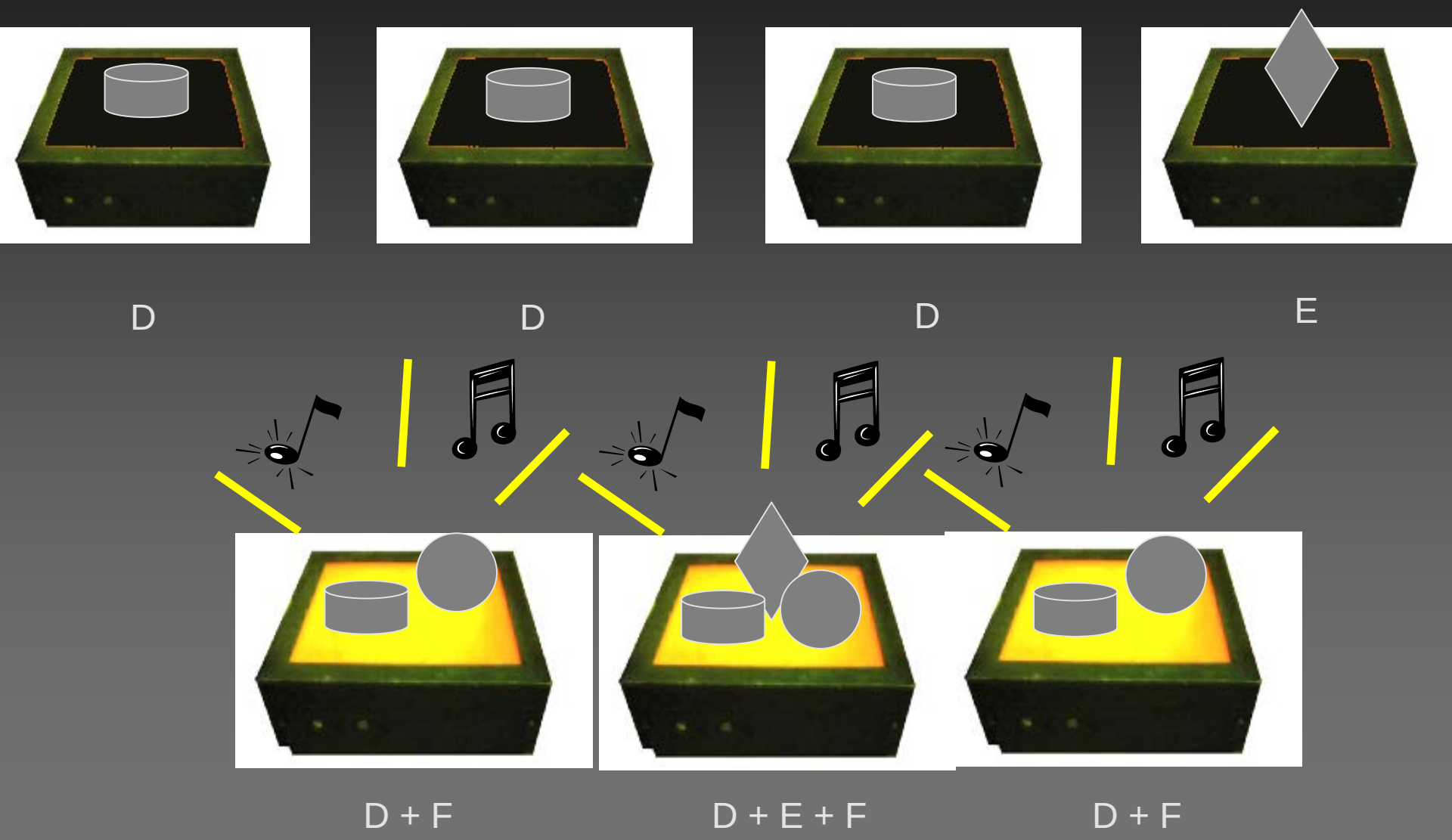


Test



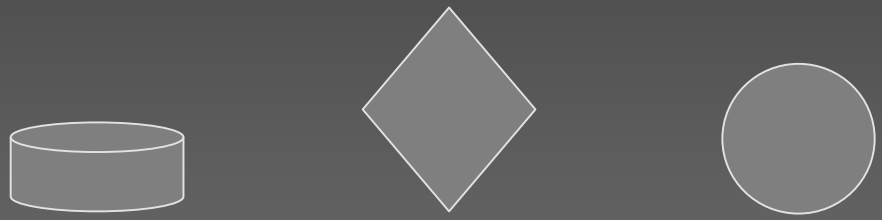

Children, OR
Children, AND
Adults, OR
Adults, AND
Proportion blickets
Proportion blickets
0
0.2
0.4
0.6
0.8
1
D
E
F

Functional Form Procedure: “OR” and “AND” Test Trial



Functional Form Procedure: “OR” and “AND” Conditions

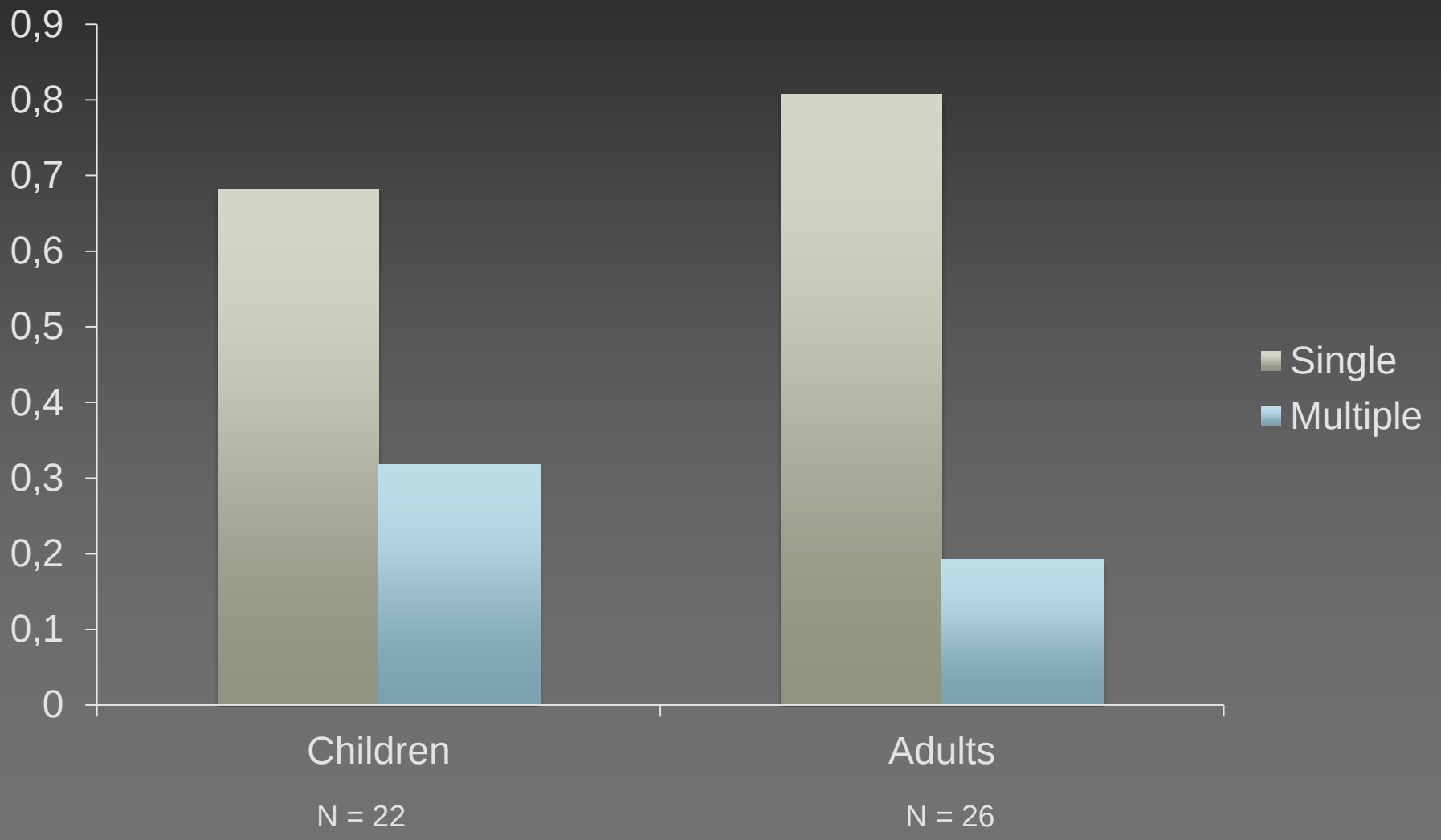
Which of these should we use to make the machine turn on?



Intervention Question

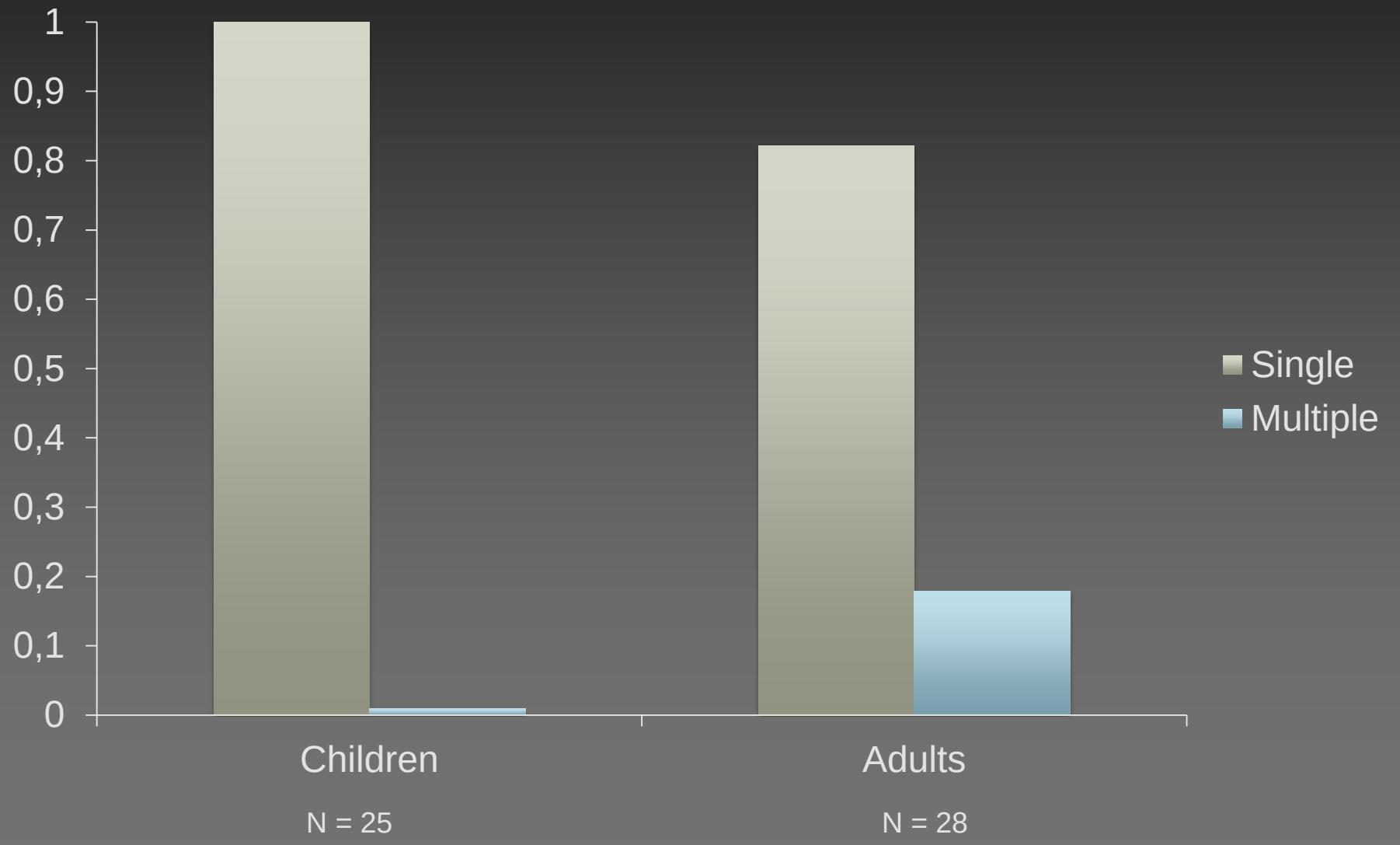
“BASELINE” Intervention Results:

Percentage of Single vs. Multiple Object Interventions



“OR” Intervention Results:

Percentage of Single vs. Multiple Object Interventions



“AND” Intervention Results:

Percentage of Single vs. Multiple Object Interventions

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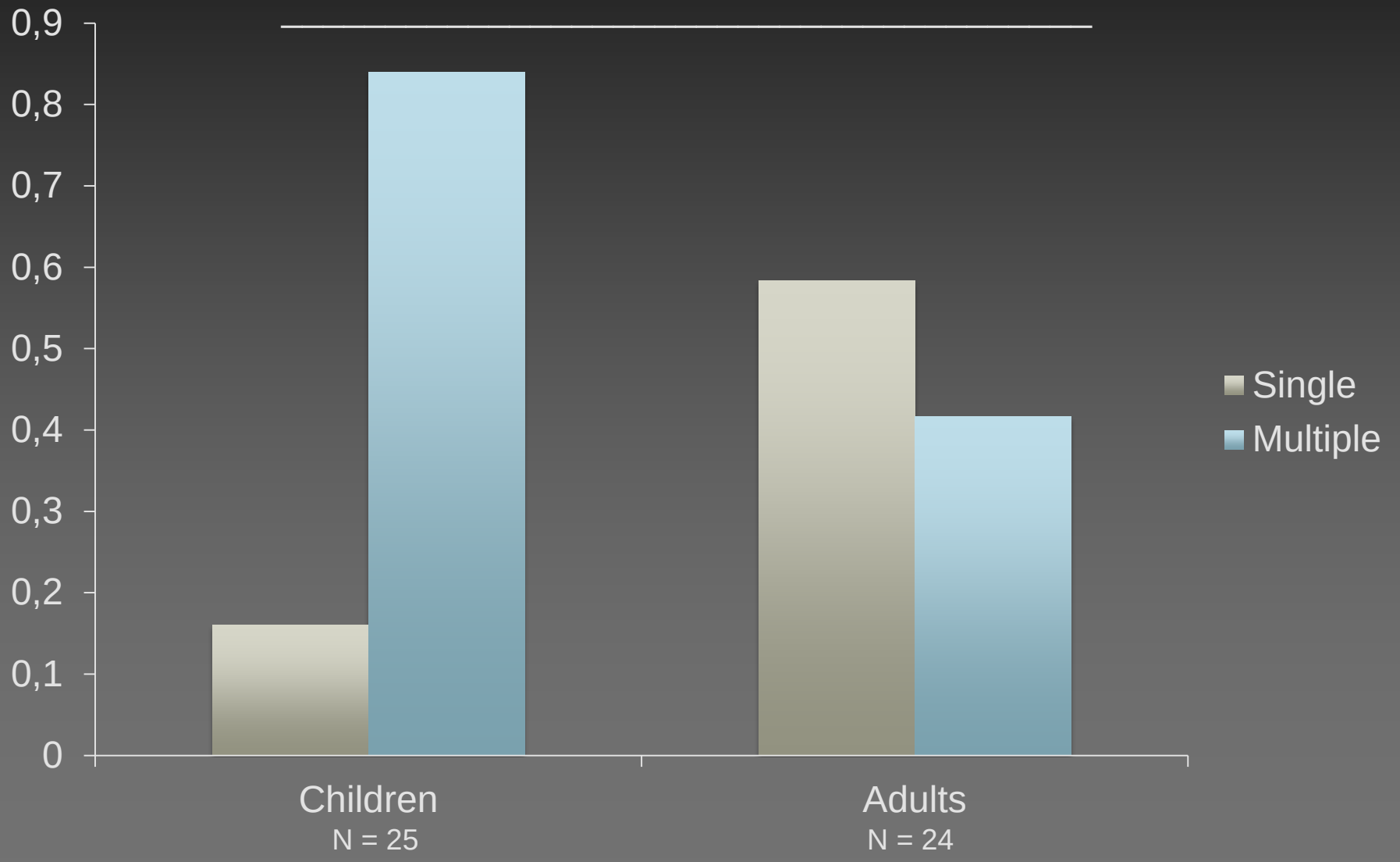
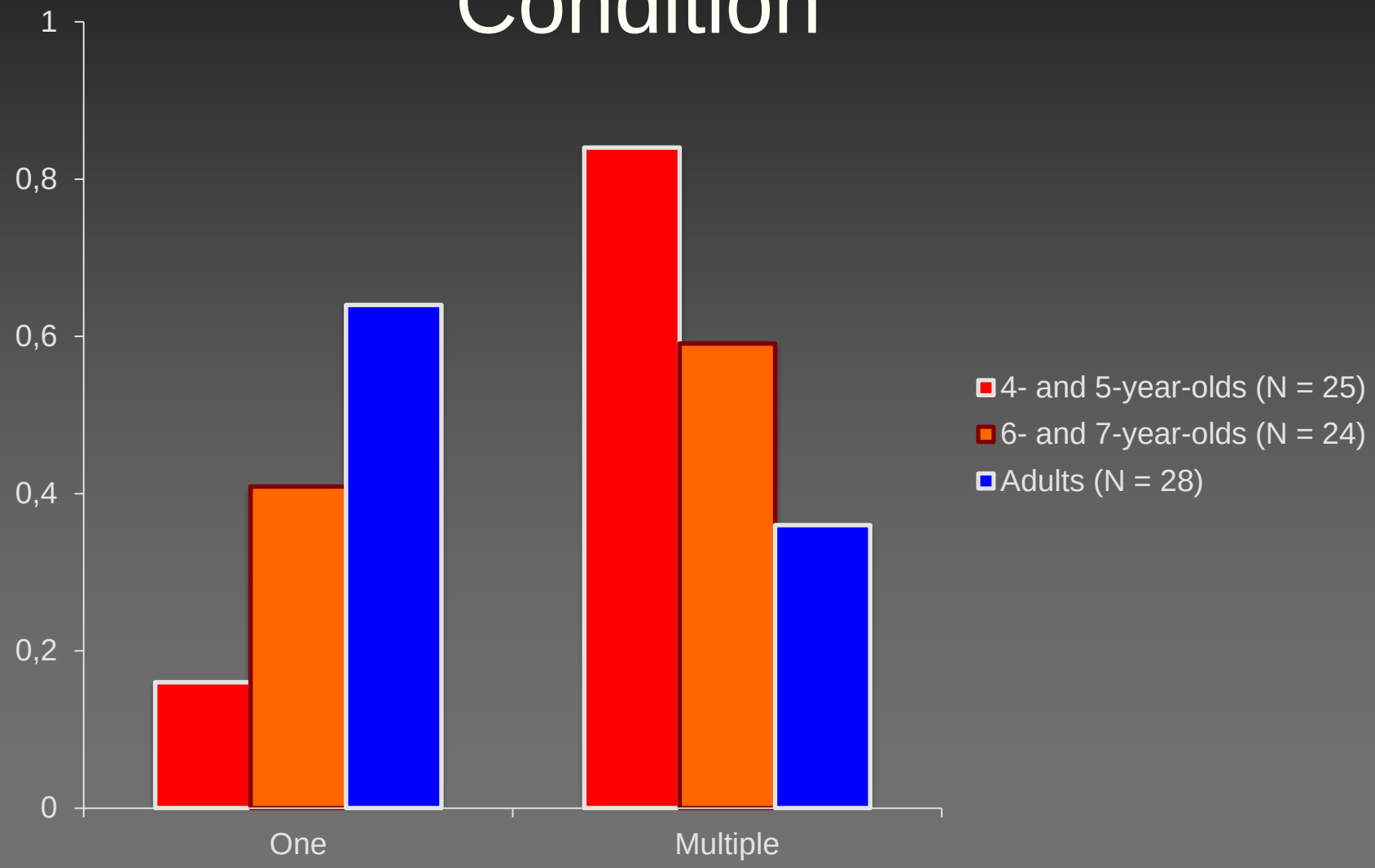


Intervention Choices for 6- and 7-year-olds: “AND” Condition



When Younger Learners Do Better Than Older Ones

- Learning traits versus situations as causes for action (Seiver et al. *Child Development, 2013.)*
- Learning abstract relational causes (same and different). Walker and Gopnik, *Psychological Science, Cog Sci,* 2015
- Learning multiple uses for a tool, Defeyter and German, 2003
- Learning non-native speech contrasts, Kuhl. Werker

Disadvantages of Frontal Control

- Thompson-Schill et al. , 2009

Why the developmental differences?

Two Possibilities

Gopnik, Lucas, & Griffiths, *Current Directions in Psychological Science* (In press).

Different Accumulated Knowledge

- Learned prior for “OR” or “Traits” leads to bias

Different types of search and sampling

- Sampling as a solution to the search problem in computer science: Markov Chain Monte Carlo, Particle Filters

- Sampling in adults: Vul & Pashler, 2008

Sampling in Cognitive Development

Bonawitz, Denison, Griffiths & Gopnik, (2014). *Trends in Cognitive Science*,

Denison et al. *Cognition* (2013).

Win-Stay-Lose-Sample. Bonawitz et al. *Cognitive Psychology* (2014)

Exploitation vs. Exploration

Low-temperature search

Quick to settle on high-probability answer

May miss low-probability answer

High-temperature search

Slow to settle on high-probability answer

More likely to find low-probability answer

Experimentation, Exploration and Explanation

Simulated Annealing

- Early High-Temperature Search followed by later Low-Temperature Search

Conclusion

Childhood is evolution’s way of performing simulated annealing.

Collaborators and Support

- Tom Griffiths
- Caren Walker
- Chris Lucas
- Sophie Bridgers
- Elizabeth Seiver
- Noah Goodman

- NSF
- The James S. McDonnell Foundation Causal Learning Collaborative