Distinguishing First- from Second-order Specifications of *Each*, *Every*, and *All*

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First- & Second-order Quantifiers

- Memory for set cardinality can be used to probe the representational format of quantifier meanings
- Not all quantifiers are specified in second-order terms like *most*
- Not all first-orderizable quantifiers are first-orderized

Overview: First- and Second-order Logic

- **FOL:** Fa → ∃x(Fx) vs. **SOL:** Fa → ∃X(Xa)
  - FOL: relations between individuals, as in (1)
  - SOL: relations between sets, as in (2)
- *Most* requires SOL [1]
- *Each*/*every*/*all* can be expressed with FOL or SOL
  - How are they in fact represented in speakers' minds?

Every dot is red

(1) $\forall x : (Dx \rightarrow Rx)$

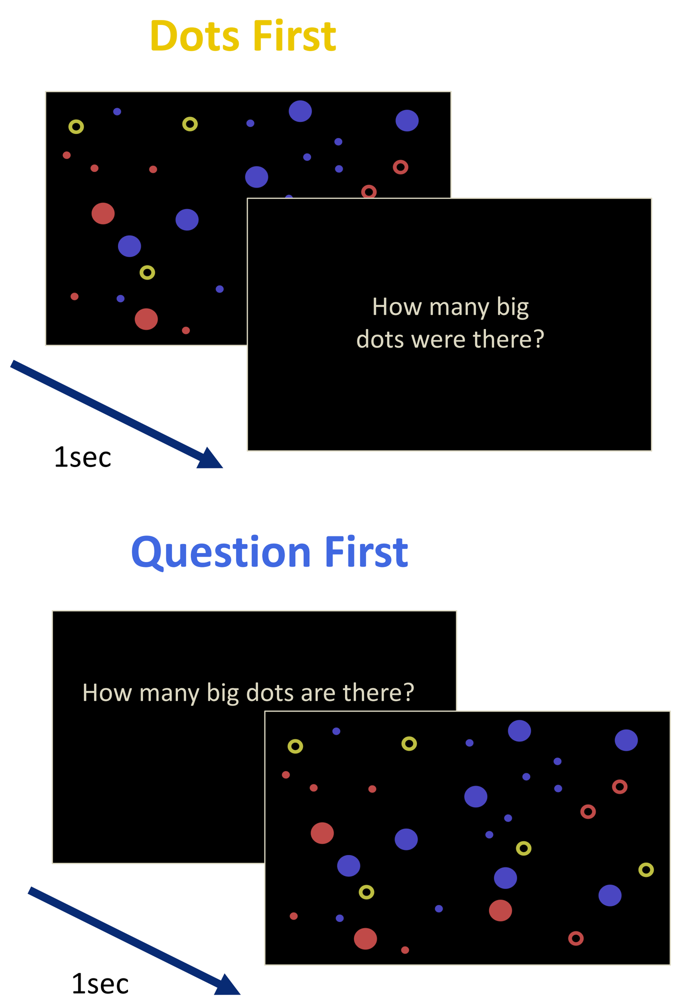
(2) DOT $\subseteq$ RED

Background: Vision, Number, Verification

Linking Hypothesis: Interface Transparency

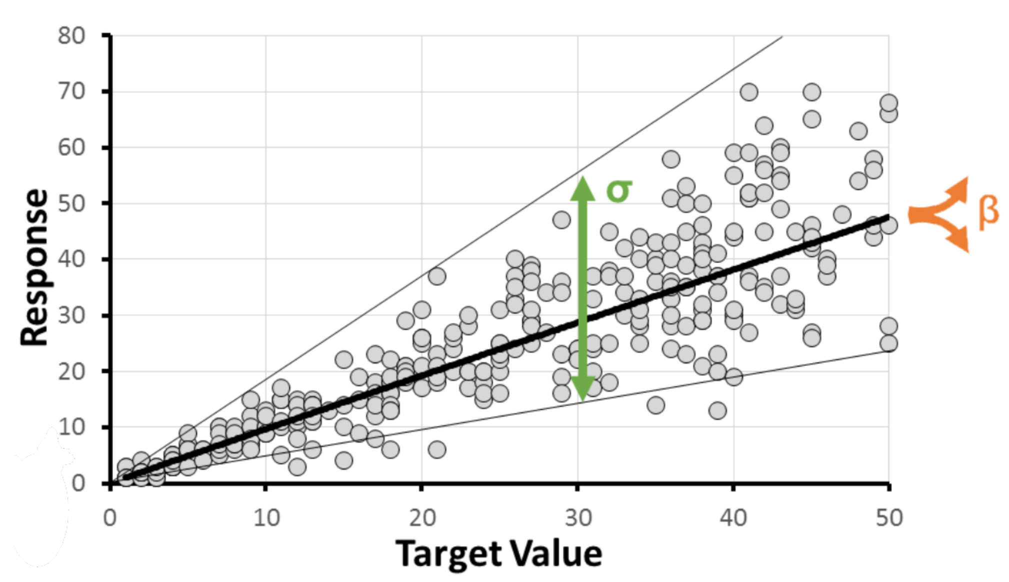
- People are biased toward verification strategies that transparently reflect the meaning under evaluation [2]
  - e.g., A 1-to-1 strategy isn't used to evaluate *most*-statements even when it would be more accurate [3]
- **Methodological strategy**: Variation in verification that can't be otherwise explained is due to the meaning

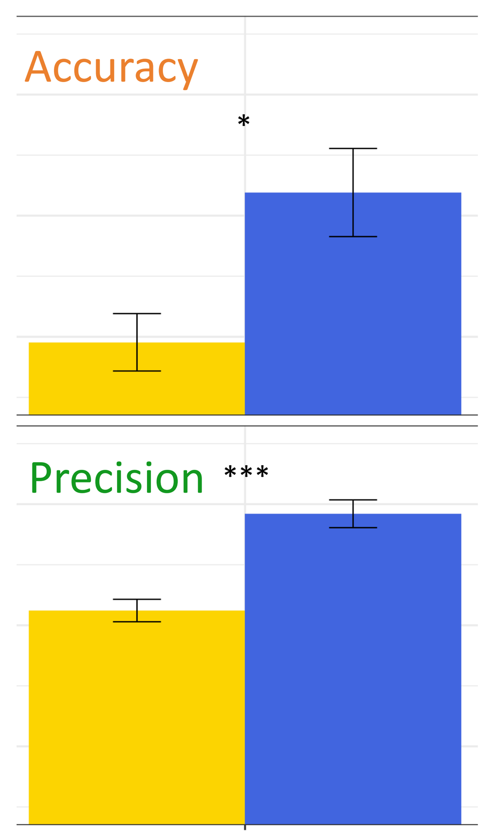
- First-order meaning → strategy: attend to & represent individuals → fail to encode set properties (e.g., #) in memory
- Second-order meaning → strategy: attend to & represent sets → encode those sets' cardinalities in memory [4,5]



***Experiment 1*: Cardinality Knowledge Baseline**

- Task: Answer "how many" question about some subset
  - Either dots come first or question comes first
- Model: accuracy (β) & precision (σ) parameters [6]

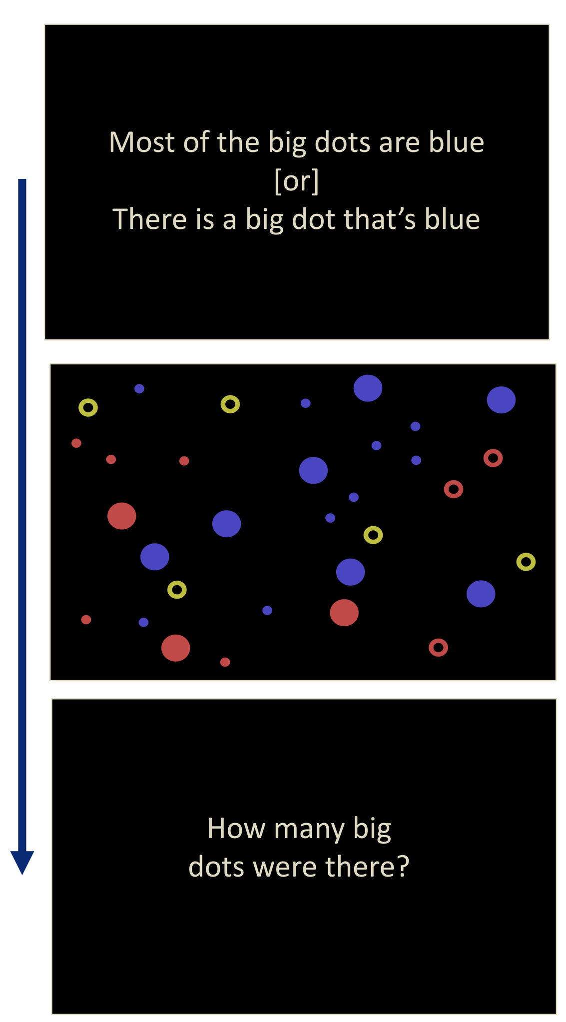


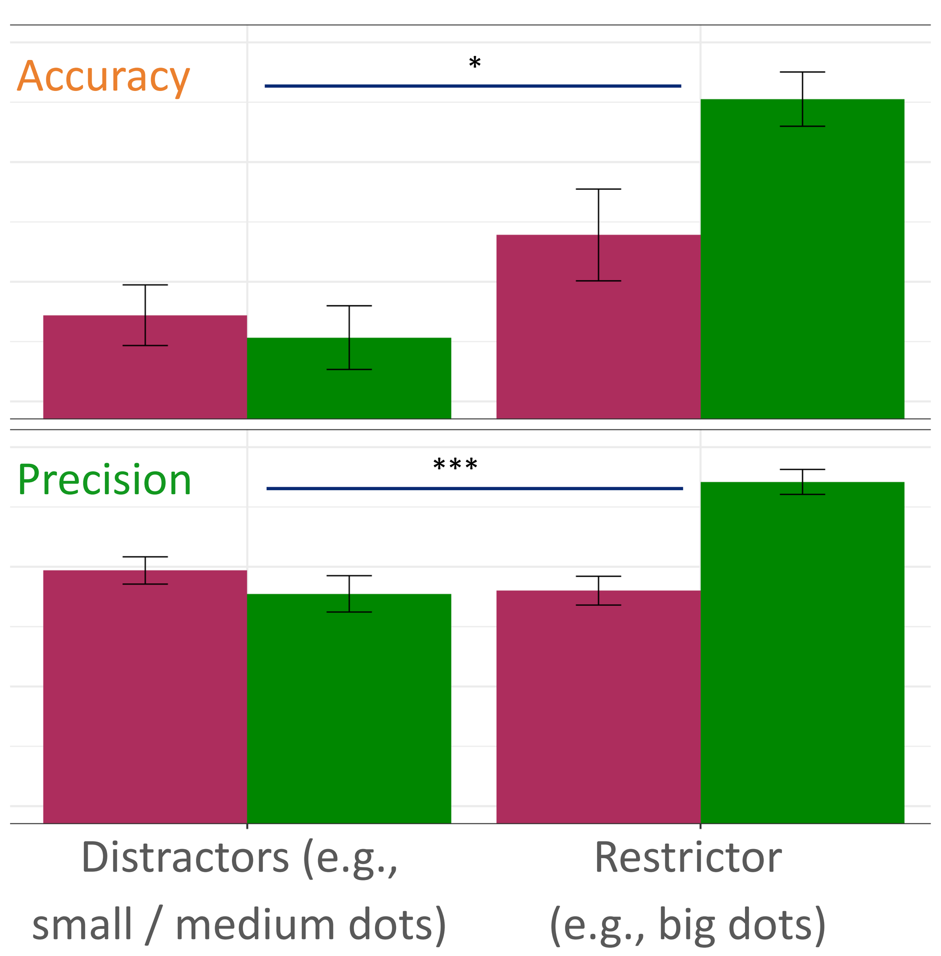


- Improved accuracy/precision when question comes first [7]
- Cardinality knowledge for a set reflects whether it's represented

***Experiment 2*: Developing a Diagnostic**

- Establish that a change in the sentence can yield a change in strategy for visually processing the scene
- Task: T/F evaluation (2 blocks: ***most of the…*** & ***there is a…***); Random "how many" question





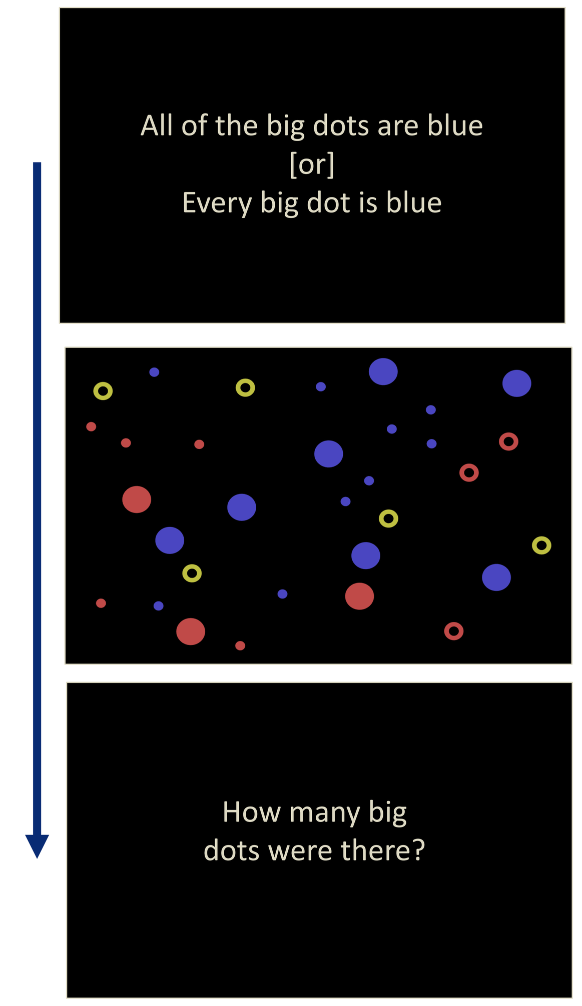
- *Most of the* (decidedly second-order): better memory representation for restrictor set's cardinality
- *There is a* (potentially first-order): worse memory representation for restrictor set's cardinality
  - False trials require looking at each dot, but result is unchanged

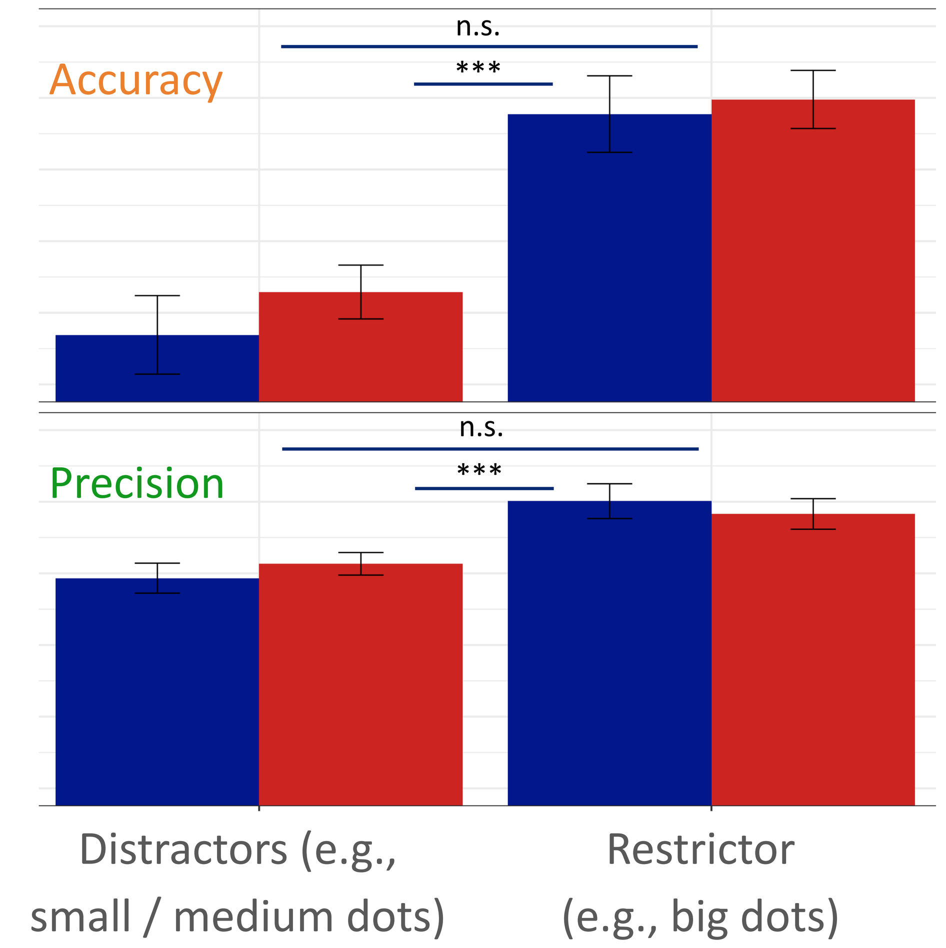
- A follow-up found the same pattern when display times are limited to 1sec
- *There is a* might still be first-order, with relative ease of the individual-based strategy in this case to blame for its use
  - False trials potentially tell against this story

Every vs. All

***Experiment 3*: Pitting Truth-Conditionally Equivalent Quantifiers Against Each Other**

- Task: T/F evaluation (2 blocks: ***all of the…*** & ***every…***); Random "how many" question





- Result: similar memory representation of restrictor set's cardinality following ***all***- and ***every***-statements
  - But knowledge for set denoted by restrictor superior to knowledge for set denoted by complement of restrictor

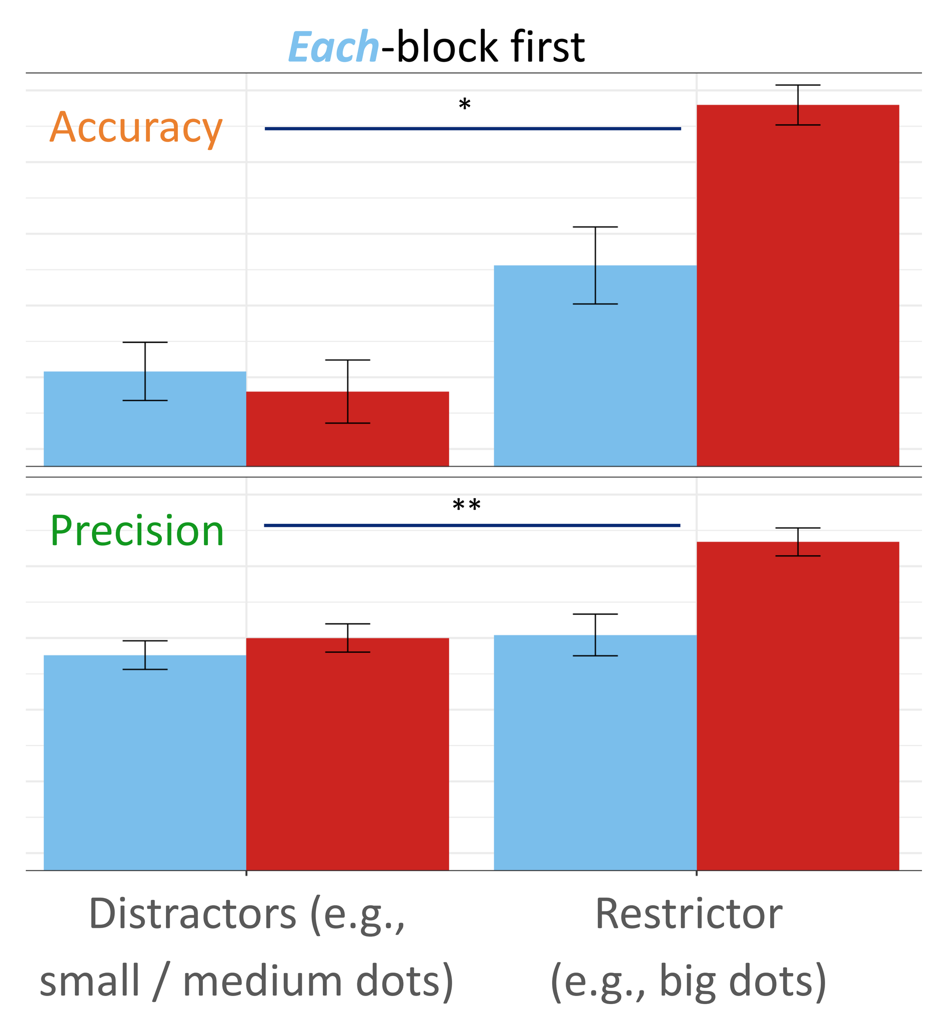
- Both *every* and *all* pattern like *most* (second-order)
- All three bias set-based strategies, suggesting second-order meanings

Each vs. Every

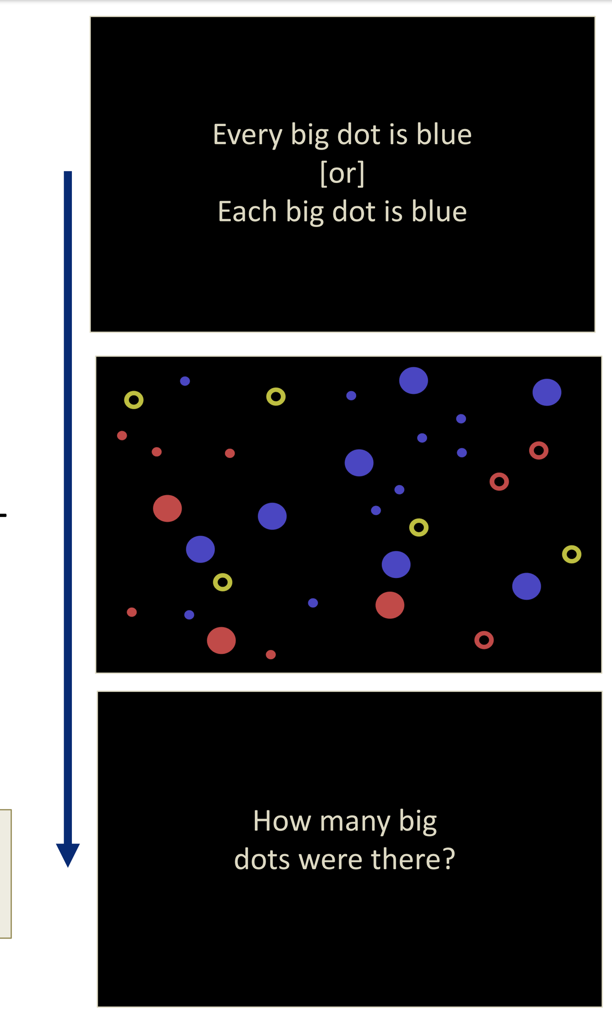
***Experiment 4*: Are All the Universals Second-order?**

- Task: T/F evaluation (2 blocks: ***every…*** & ***each…***); Random "how many" question

Each-block first

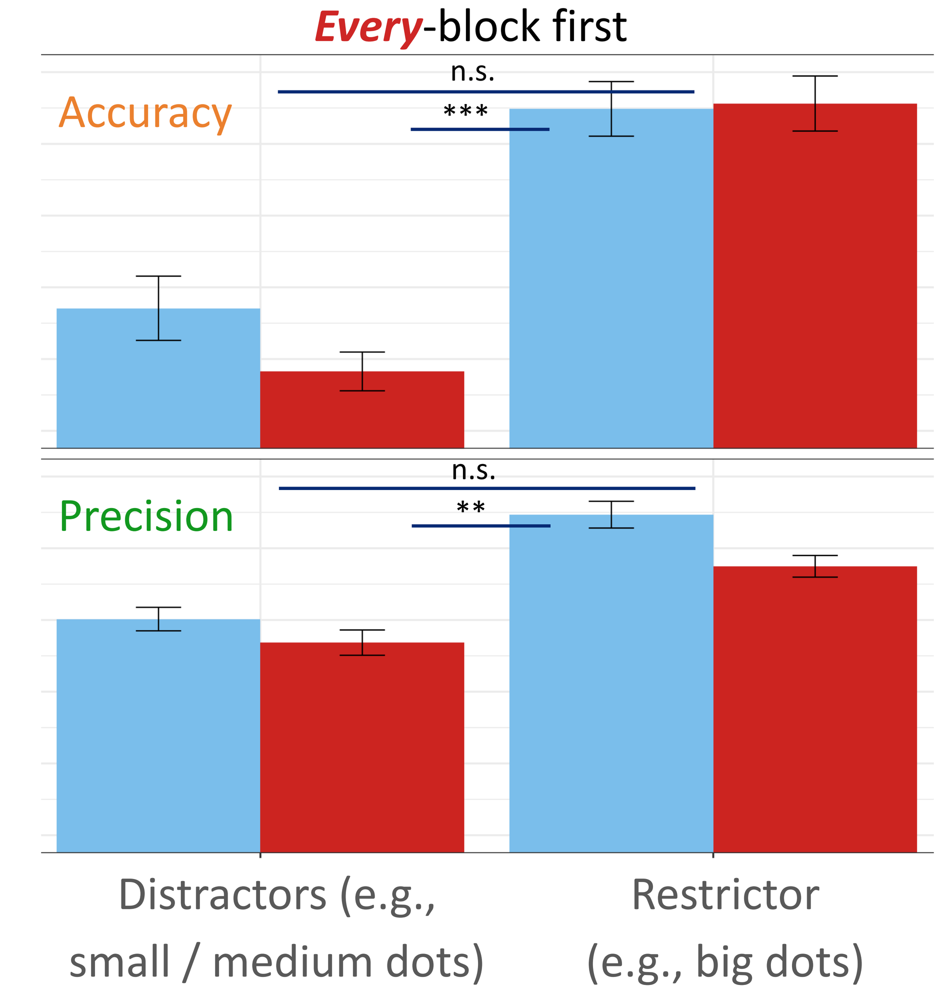


- Result: better memory representation of restrictor set's cardinality following ***every***-statements than ***each***-statements
- Same participants, pictures, & truth-conditions, but different strategies
- Effect driven by participants who started in the *each* condition



- *Each* patterns like *there is a*, suggesting a first-order meaning

***Every*-block first**



- Carryover effects from the set-based strategy in the ***every***-block to the subsequent ***each***-block
  - But ***every*** does not seem to be susceptible to this kind of priming (see above)
- Two possibilities:
  - Meaning pushed around: polysemous *each*
  - Strategy pushed around: participants stick with superior/easier set-based strategy after completing ***every***-block

- Upshot: Despite the truth-conditional equivalence of *each/every/all*, their effects on verification strategy and memory are different, pointing to a first-order meaning for *each*, but not for *every* & *all*.

References: [1] Barwise & Cooper 1981, *Linguistics & Philosophy* [2] Lidz et al. 2011, *Nat. Language Semantics* [3] Pietroski et al. 2009, *Mind & Language* [4] Feigenson et al. 2004, *TICS* [5] Burr & Ross 2008, *Current Biology* [6] Odic et al. 2015 *Behav. Research Methods* [7] Halberda et al. 2006, *Psych. Sci.*

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