Representational Format and Universal Quantifiers

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Introduction: First- & second-order meanings

Big Picture Question: How are universal quantifiers – *each*, *every*, and *all* – mentally represented?
- Finding: Despite truth-conditional equivalence, *each* biases representing individuals; *every*/*all* bias representing groups
- Conclusion: Even though all three universals are first-orderizable, only *each* has a first-order representation

First- vs. second-order quantification

- There are infinitely many ways to formally specify the relation expressed by universal quantifiers, including (1)-(4)

"**every** dot is blue" –
- (1) $\lambda D.\lambda B.\forall x{:}Dx[Bx]$
- (2) $\lambda D.\lambda B.\neg\exists x{:}Dx[\neg Bx]$
- (3) $\lambda D.\lambda B.D \subseteq B$
- (4) $\lambda D.\lambda B.D = D \cap B$
- (5) …

(1)–(2): **First-order**: domain=individuals; assignment=one value per variable

(3)–(4): **Second-order**: genuine relation between two groups / sets

- Are the universals equally-well described by (1)-(4)? Or are meanings specified at a finer grain-size in the mind?

Linking Hypothesis:

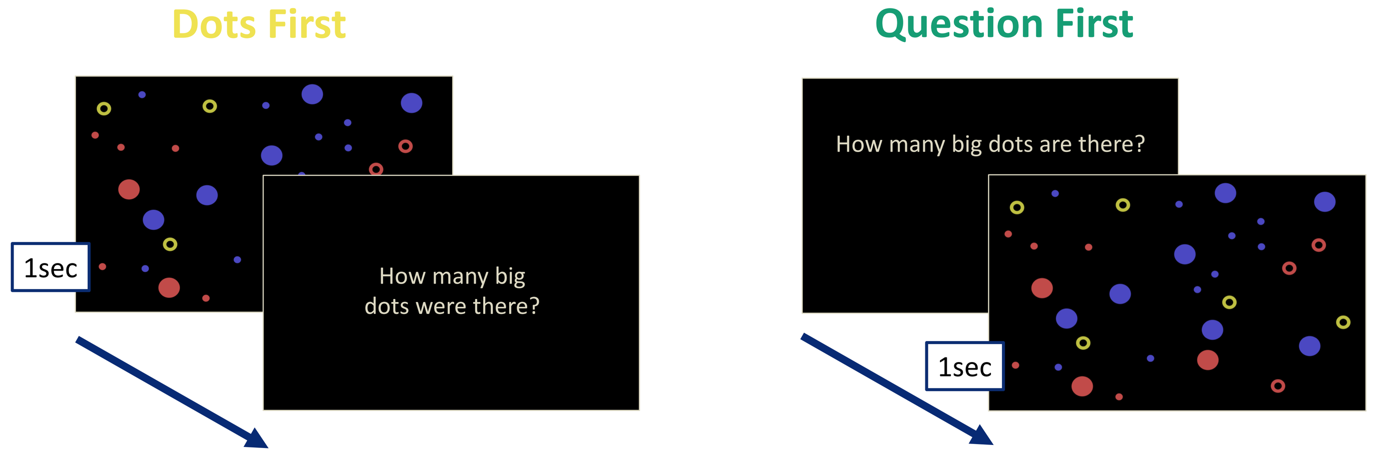
- People are biased toward verification strategies that transparently reflect the meaning under evaluation [1-3]
  - Methodological strategy: Variation in verification that can't be otherwise explained is due to the meaning

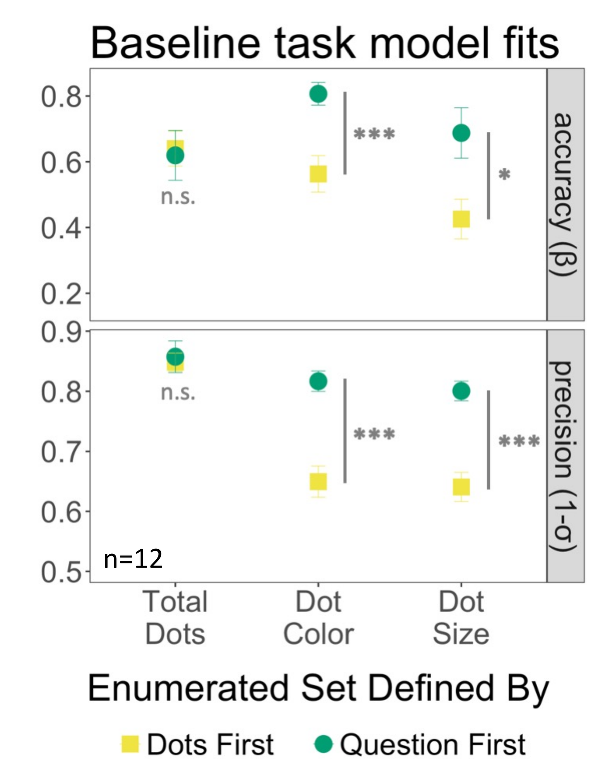
Second-order meaning → attend to & represent sets → encode those sets' cardinalities in memory [4,5]
First-order meaning → attend to & represent individuals → fail to encode set-based properties (e.g., #) in memory

Background: Measuring cardinality knowledge

Baseline task

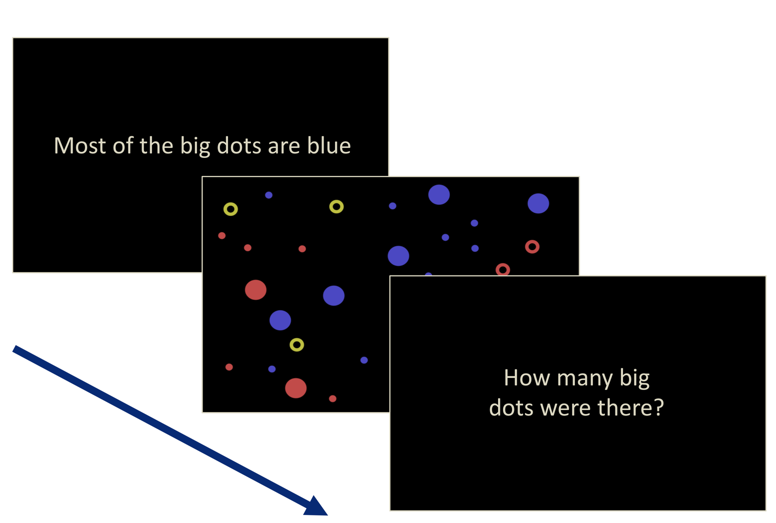
- When asked to estimate the cardinality of some subset, participants can be fit with an accuracy (β) and precision parameter (1-σ) [6-9]
  - **Result**: Better accuracy & precision when given the question first

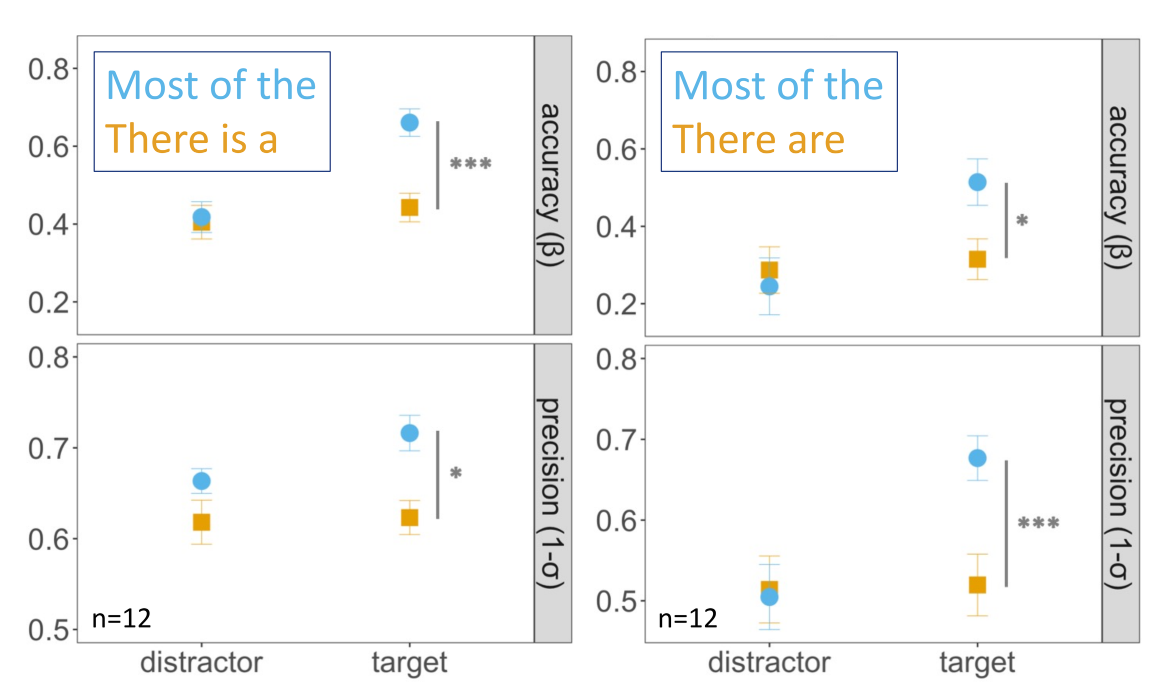




Adding language: *most*- vs. existential-statements

- Participants biased to attend to groups or not based on the statement under evaluation:
  - A decidedly second-order *most*-statement or a plausibly first-order existential-statement
  - Follow-up questions probed the restrictor set (target) or a random set (distractor)





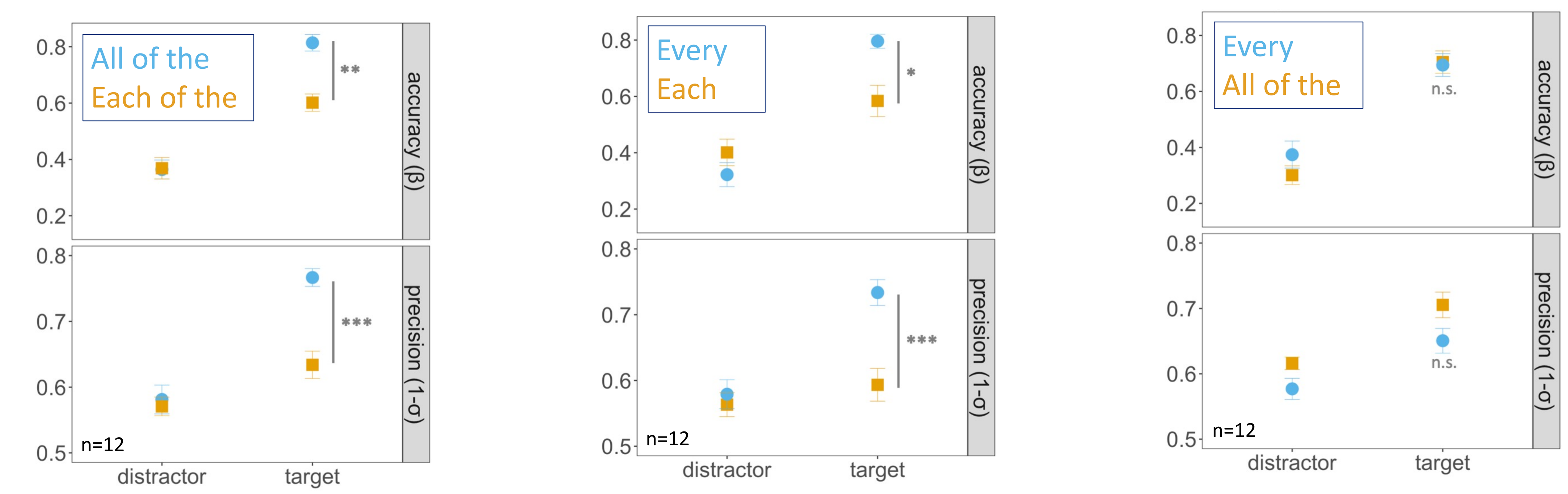
- **Result:** Participants know the restrictor set's cardinality better following *most*-statements

Most's second-order meaning leads participants to represent groups

Comparing the universals

Testing truth-conditionally equivalent statements

- Same task, but both conditions were matched in syntax, truth-conditions, and images
  - **Result**: Participants know the restrictor set's cardinality better following *every*- and *all*-statements than following *each*-statements; *every*- and *all*-statements still pattern together when tested within subjects



Each-statements lead participants to represent individuals (thanks to their first-order meaning)
Every- and *all*-statements lead participants to leading participants to represent groups (thanks to their second-order meaning)

Linguistic consequences of first-order *each*

Distributivity

- While *every* and *all* can give rise to distributive interpretations, ***each* mandatorily does** [10,11]:

(6) a. Each student sang happy birthday
(well as a solo piece / #in perfect harmony)
b. Every student/all the students sang happy birthday
(well as a solo piece / in perfect harmony)

(7) a. Determine whether each dragon is dangerous
('for each dragon, figure out whether **it's** dangerous')
b. Determine whether every dragon is dangerous
('figure out if it's true that every dragon is dangerous')

- *Each* is sometimes said to be a pronunciation of the distributive operator, D (e.g., [12])
  - If *each*/D is first-order, the predicate must to apply to the elements in the domain individually

Genericity

- While *every* and *all* can be used to express generic thoughts, ***each* cannot** [13,14]:

(8) a. #Each bird lays eggs
b. Every bird lays eggs
c. All birds lay eggs

(9) Usually you complain every/#each time we shop

- Generic statements abstract away from individual entities / events and describe group properties
  - FOL considers individuals and their properties
- The # of exceptions tolerated changes with the domain size; hard to capture in FOL (though see [15])
  - The same problem arises for statements with proportional quantifiers, like *most* [16]

Takeaway: *each*, *every*, and *all* are represented in different formats in speakers' minds
- *Each* is represented in a first-order format; *every* and *all* are represented in second-order formats
- Knowledge of group-based properties (e.g., #) following evaluation reflects this subtle difference in meaning

References: **[1]** Pietroski, Lidz, Hunter, & Halberda (2009) The meaning of 'most': Semantics, numerosity and psychology **[2]** Lidz, Pietroski, Halberda, & Hunter (2011) Interface transparency and the psychosemantics of most **[3]** Tomaszewicz (2011) Verification strategies for two majority quantifiers in polish **[4]** Ariely (2001) Seeing sets: Representation by statistical properties **[5]** Alvarez (2011) Representing multiple objects as an ensemble enhances visual cognition **[6]** Stevens (1964) Concerning the psychophysical power law **[7]** Laming (1997) The measurement of sensation **[8]** Odic, Im, Eisinger, Ly, & Halberda (2016) Psimle: A maximum-likelihood estimation approach to estimating psychophysical scaling and variability more reliably, efficiently, and flexibly **[9]** Halberda, Sires, & Feigenson (2006) Multiple spatially overlapping sets can be enumerated in parallel **[10]** Vendler (1962) Each and every, any and all **[11]** Dowty (1987) Collective predicates, distributive predicates, and all **[12]** LaTerza (2014) Distributivity and plural anaphora **[13]** Beghelli & Stowell (1997) Distributivity and negation: The syntax of each and every **[14]** Gil (1992) Scopal quantifiers: some universals of lexical effability **[15]** Asher & Morreau (1995) What some generic sentences mean **[16]** Rescher (1962) Plurality Quantification

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