The psycho-logic of *each* and *every*

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Slides available at:
tylerknowlton.com/talks/MindCORE.pdf

Linguistic meaning in the mind

- ➡ What sorts of instructions do meanings provide to cognition?
- ➡ What can that relationship tell us about semantic representations?

Why *each* and *every*?

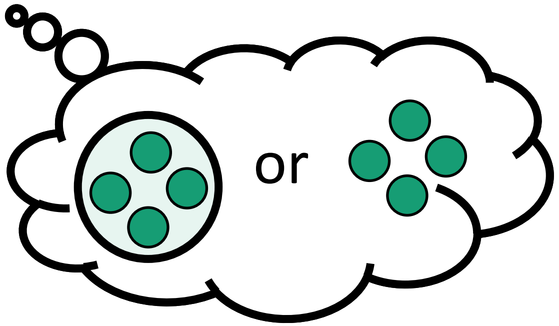
➥ Can state precise hypotheses about their meaning representations

➥ Can leverage an understanding of supporting cognitive systems

➥ Other case studies include: *all, longest,* English & Cantonese *most*

"Every circle is green"

The circles are such that they are all green



How are *each* & *every* mentally represented?

Three hypotheses

➥ Two (psycho)logical distinctions: relational/restricted & first-/second-order

Relational vs. Restricted

➥ Number cognition as a probe

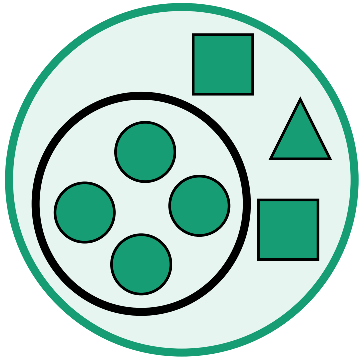
First- vs. Second-order (individual- vs. group- implicating)

➥ Object-files vs. Ensembles as a probe

Each/Every circle is green – possible representations

The circles$_X$ are included in the green-things$_Y$

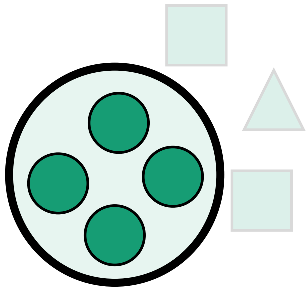
UNIVERSE: TheX:Circle(X) ⊆ TheY:Green(Y)



Unrestricted Second-order

The circles$_X$ are such that all of them$_X$ are green

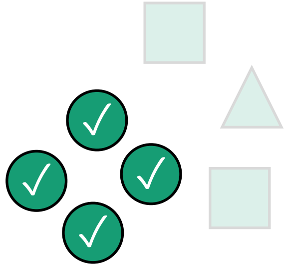
CIRCLES: ∀X[Green(X)]



Restricted Second-order

The individual circles$_x$ are s.t. each one$_x$ is green

CIRCLES: ∀x[Green(x)]



Restricted First-order

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Relational vs. Restricted

➥ Number cognition as a probe

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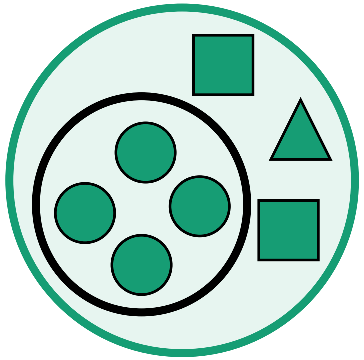
Different representations

"Every circle is green"

Relational (unrestricted)

TheX:Circle(X) $\subseteq$ TheY:Green(Y)

≈The circles$_X$ are included in the green-things$_Y$



Restricted

<u>CIRCLES</u>: ∀X[Green(X)]

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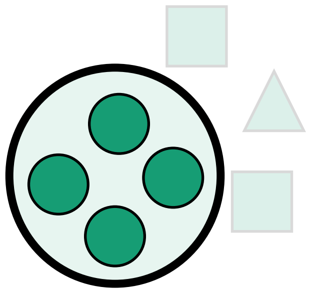
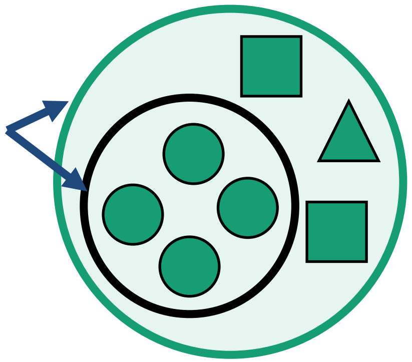


Different behavioral predictions

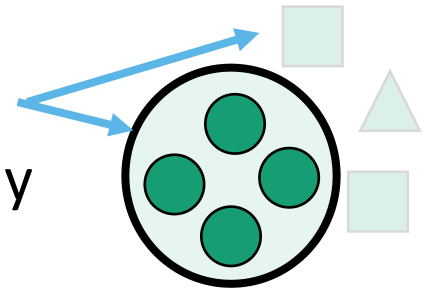
Linking hypothesis: In evaluating a sentence, people are biased toward strategies that directly compute the relations & operations expressed by the semantic representation under evaluation

Relational (unrestricted)	**Restricted**
$\text{TheX:Circle(X)} \subseteq \text{TheY:Green(Y)}$	<u>CIRCLES</u>: $\forall\text{X[Green(X)]}$
≈*The circles*$_X$ *are included in the green-things*$_Y$	≈*The circles*$_X$ *are such that all of them*$_X$ *are green*

Represent & compare both arguments



Treat arguments asymmetrically

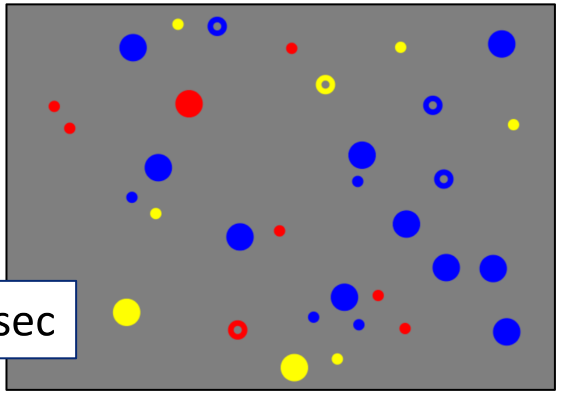


(Linking hypothesis from Lidz et al. 2011)

Every big circle is blue

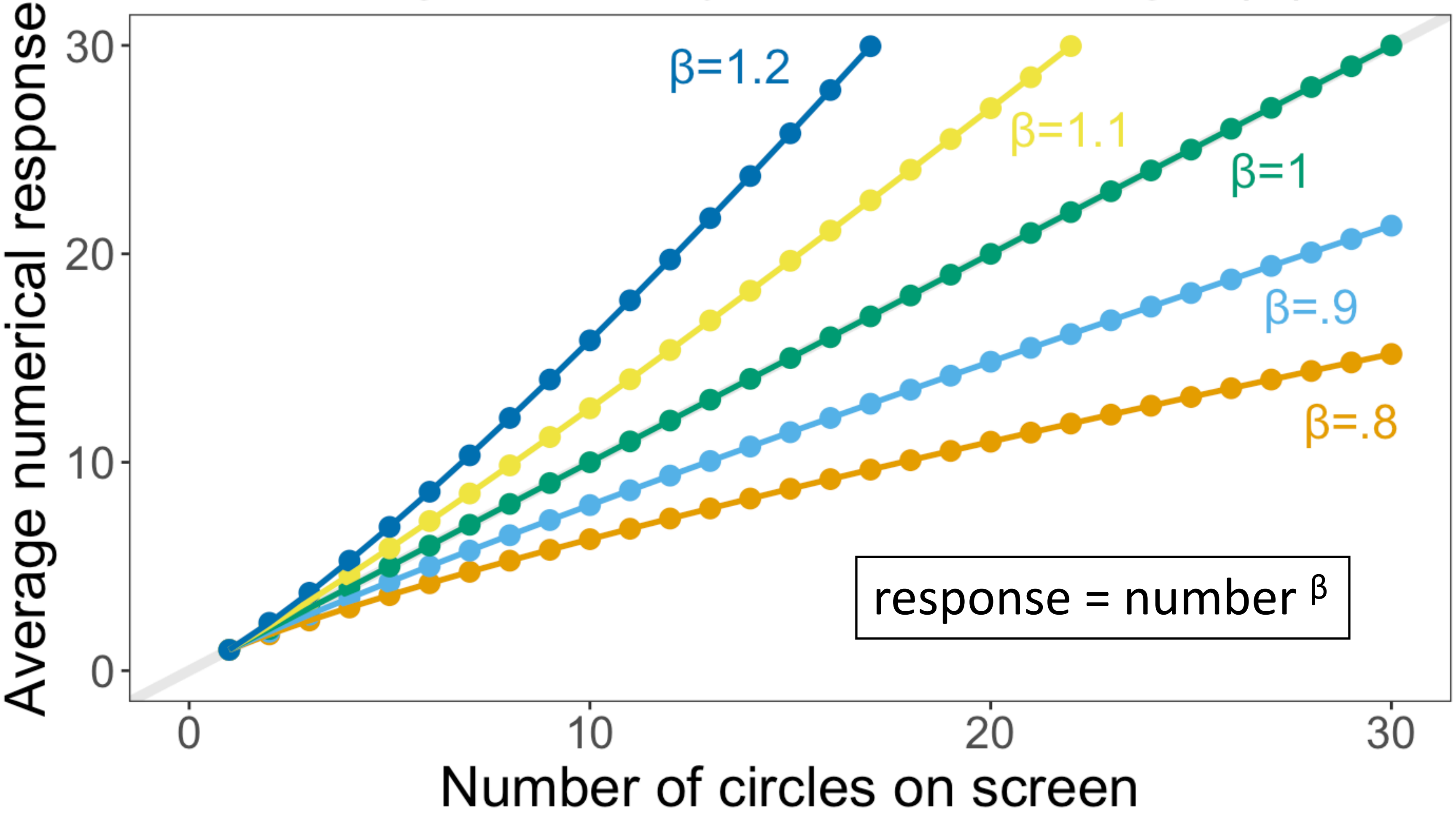
TRUE FALSE

1 sec



How many big circles were there?

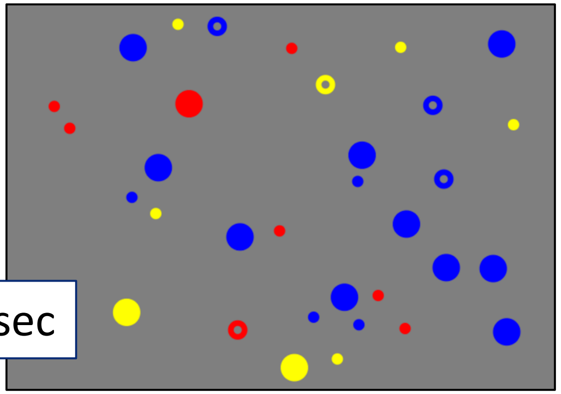
Measuring accuracy of #-knowledge (β)



(e.g., Stevens 1964; Krueger 1984; Halberda, Sires & Feigenson 2006; Odic et al. 2016)

Every big circle is blue

TRUE FALSE



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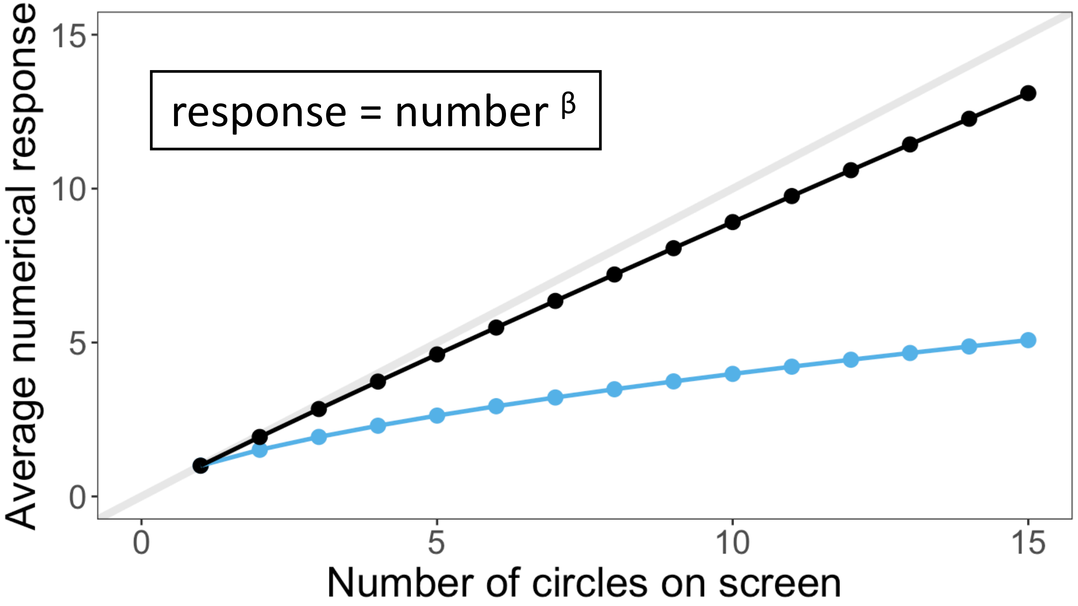
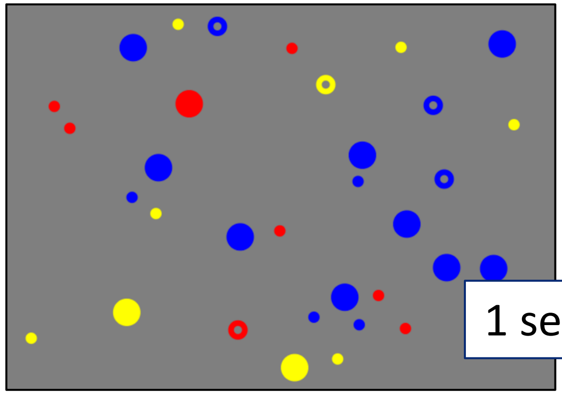


How many big circles are there?



1 sec

How many big circles were there?

#-knowledge following ***every***

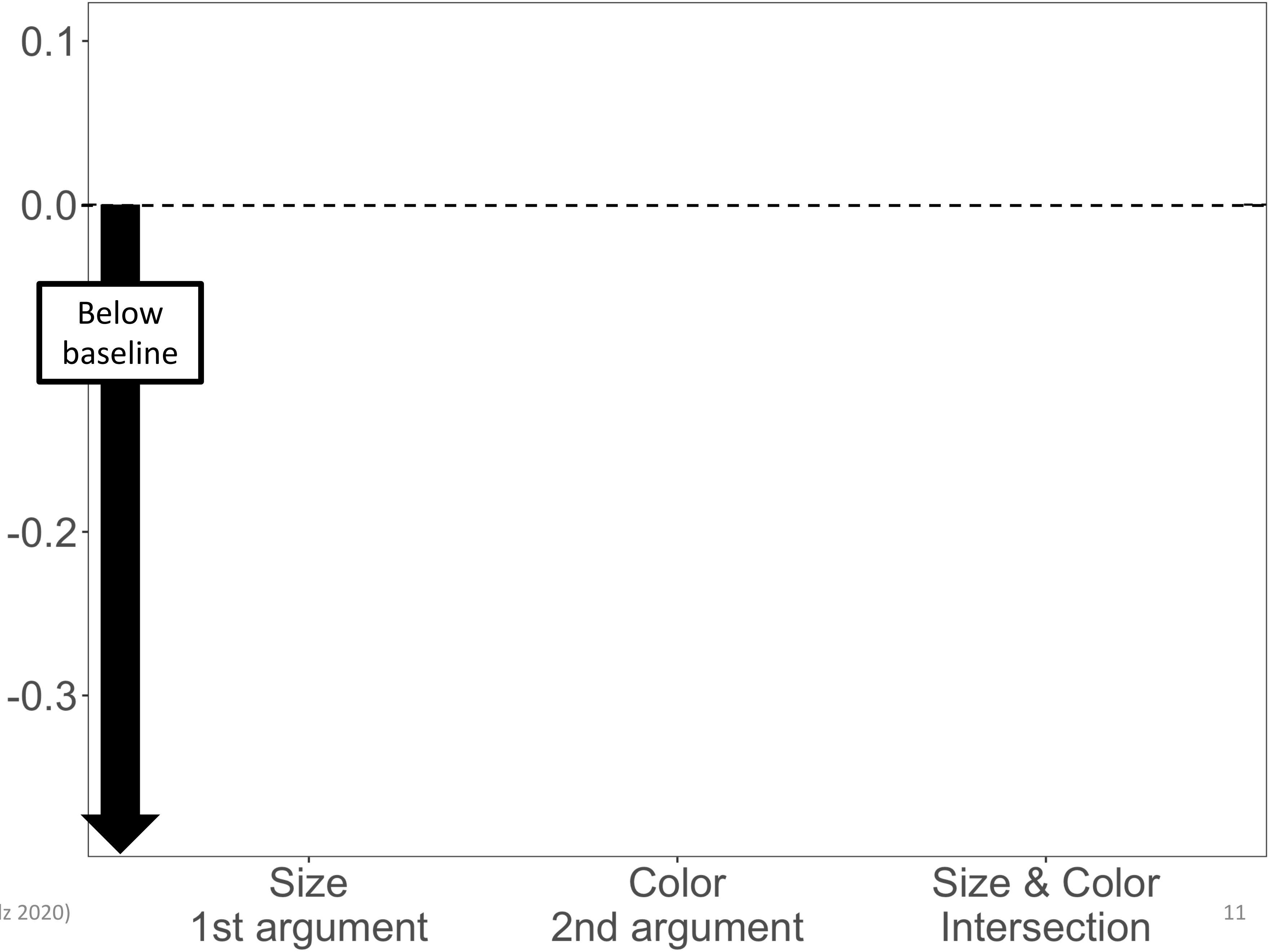
vs.

#-knowledge **baseline**

How many big circles were there?

(Knowlton, Pietroski, Williams, Halberda & Lidz 2020)

Every big circle is blue



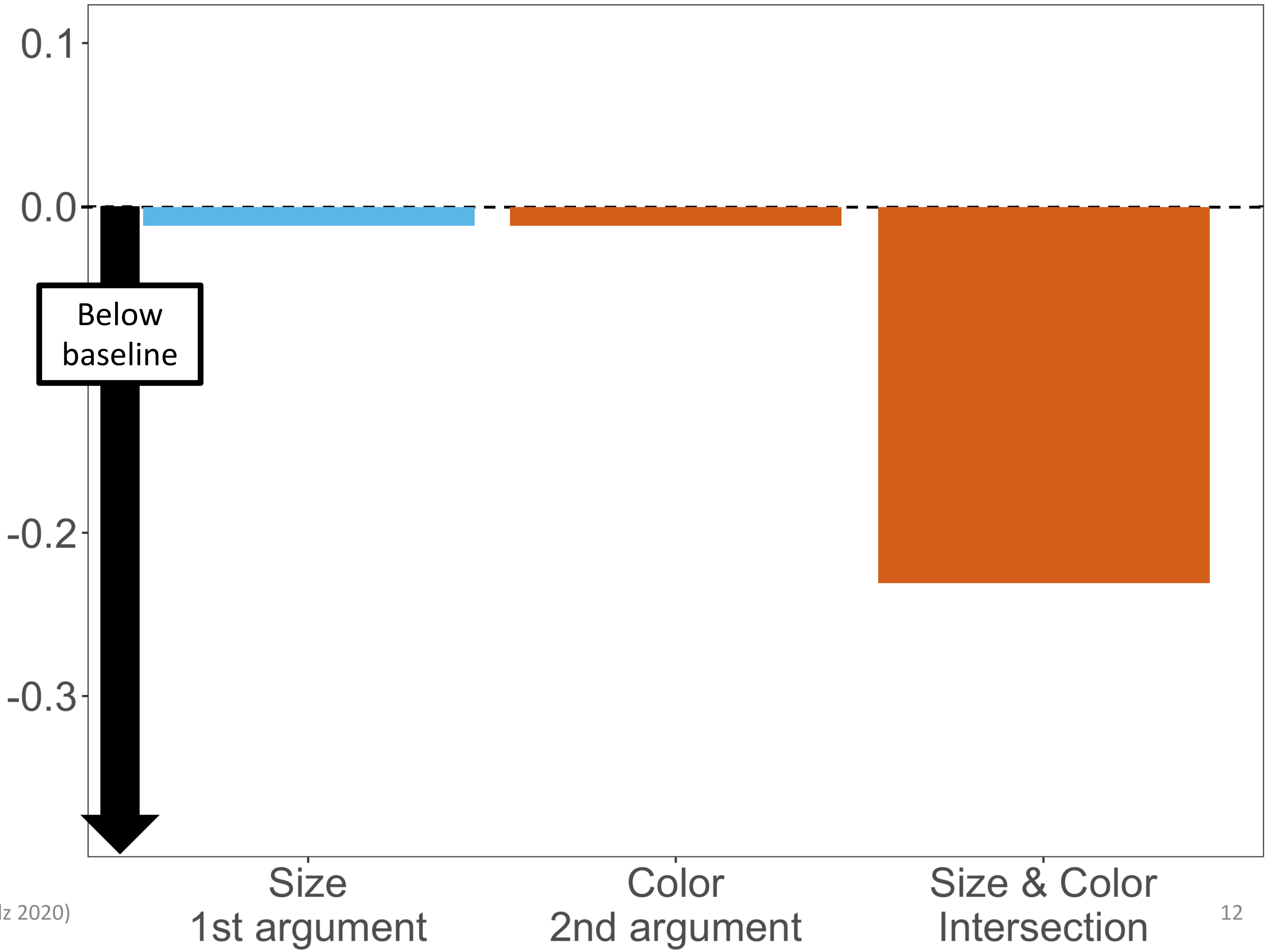
(Knowlton, Pietroski, Williams, Halberda & Lidz 2020)

Every big circle is blue

Relational

The big-circles$_X$ are a subset of the blue-circles$_Y$

Represent both arguments



(Knowlton, Pietroski, Williams, Halberda & Lidz 2020)

Relational

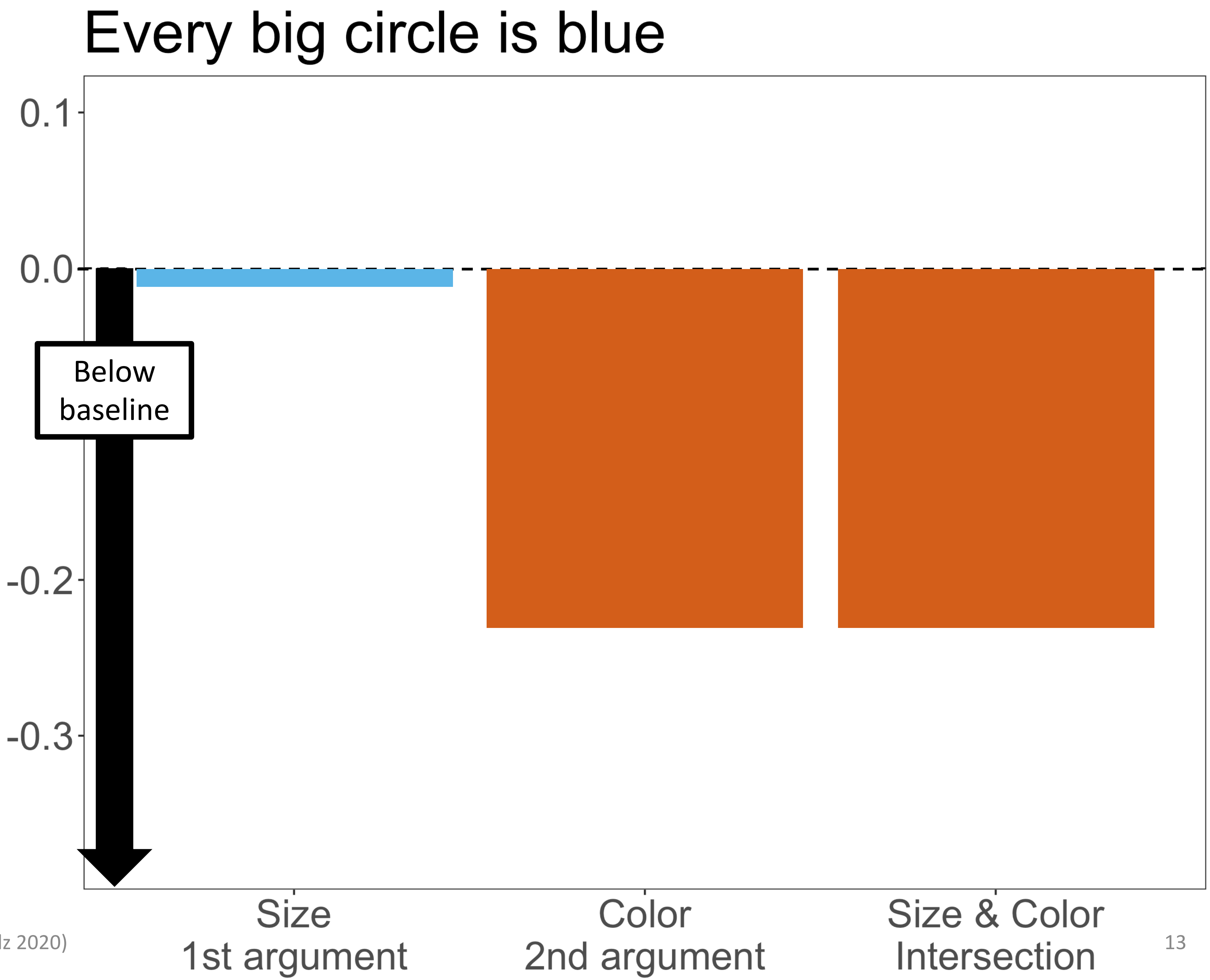
The big-circles$_X$ are a subset of the blue-circles$_Y$

Represent both arguments

Restricted

The big-circles$_X$ are such that all of them$_X$ are blue

Treat arguments asymmetrically



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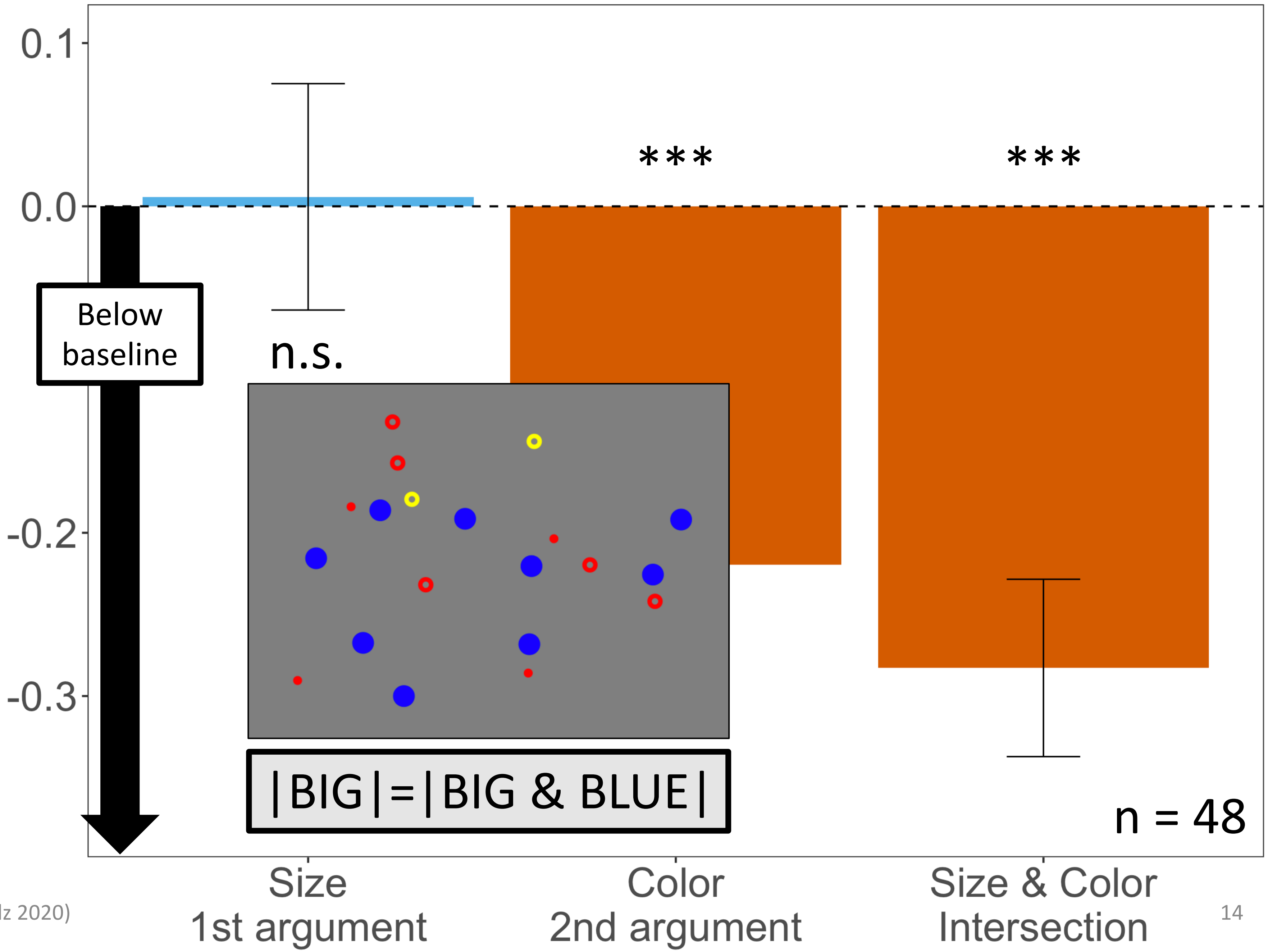
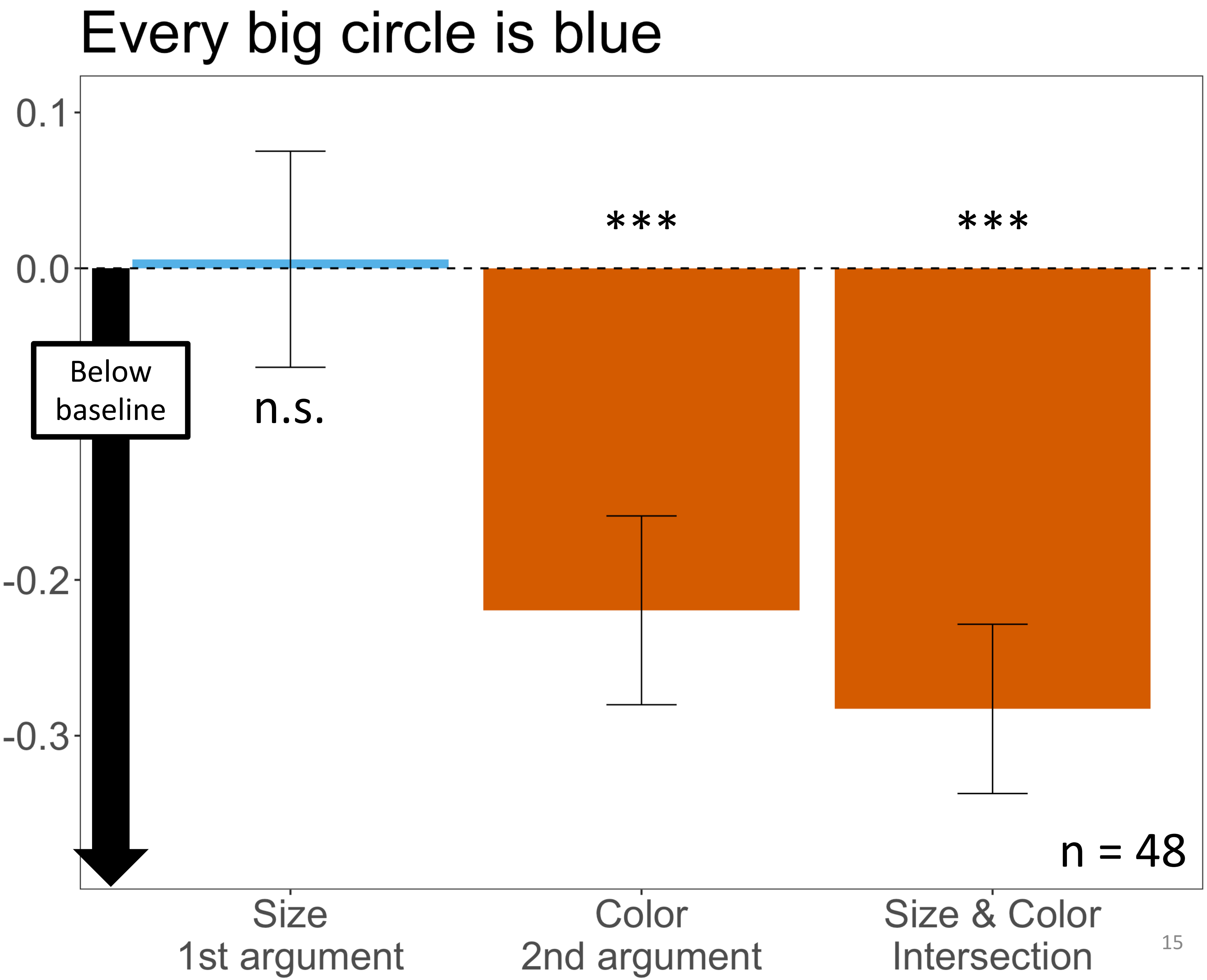


(Knowlton, Pietroski, Williams, Halberda & Lidz 2020)

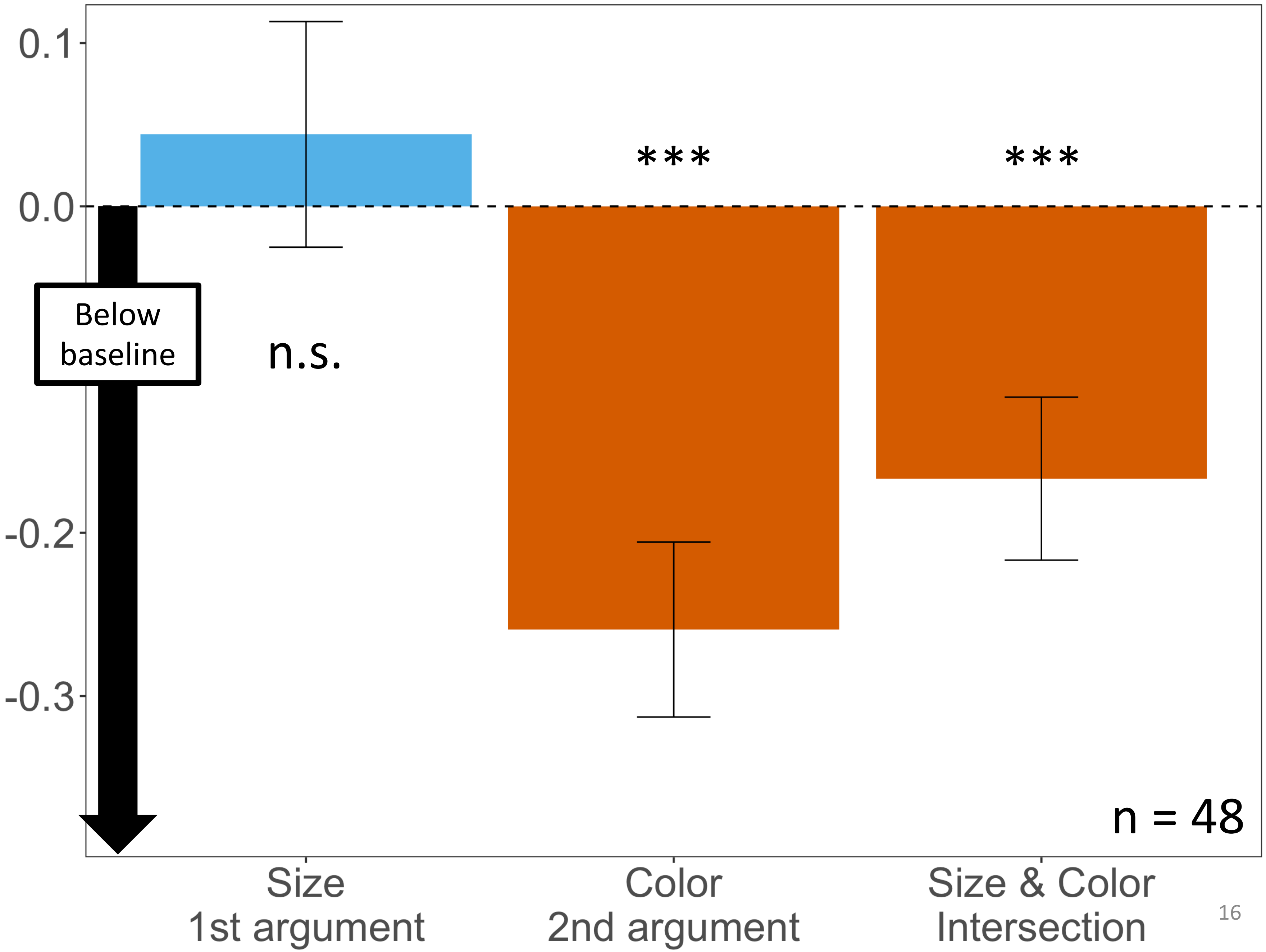
Is the problem that the predicates are introduced in two different ways?



Every circle that is big is blue

Is the problem that the predicates are introduced in two different ways?

No:
both can be introduced with *is*!



How are *each* & *every* mentally represented?

Three hypotheses

Relational vs. Restricted

✓ Number cognition as a probe into which arguments are represented

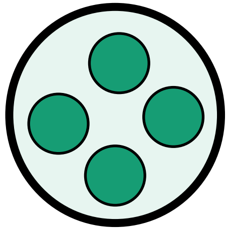
First- vs. Second-order (individual- vs. group-implicating)

➥ Object-files vs. Ensembles as a probe into how arguments are encoded

Different representations: groups or individuals?

Second-order representations (*every*)

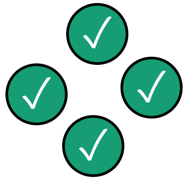
<u>CIRCLES</u>: $\forall X[\text{Green}(X)]$ ≈The circles$_X$ are such that all of them$_X$ are green



take on ≥1 value at a time

First-order representations (*each*)

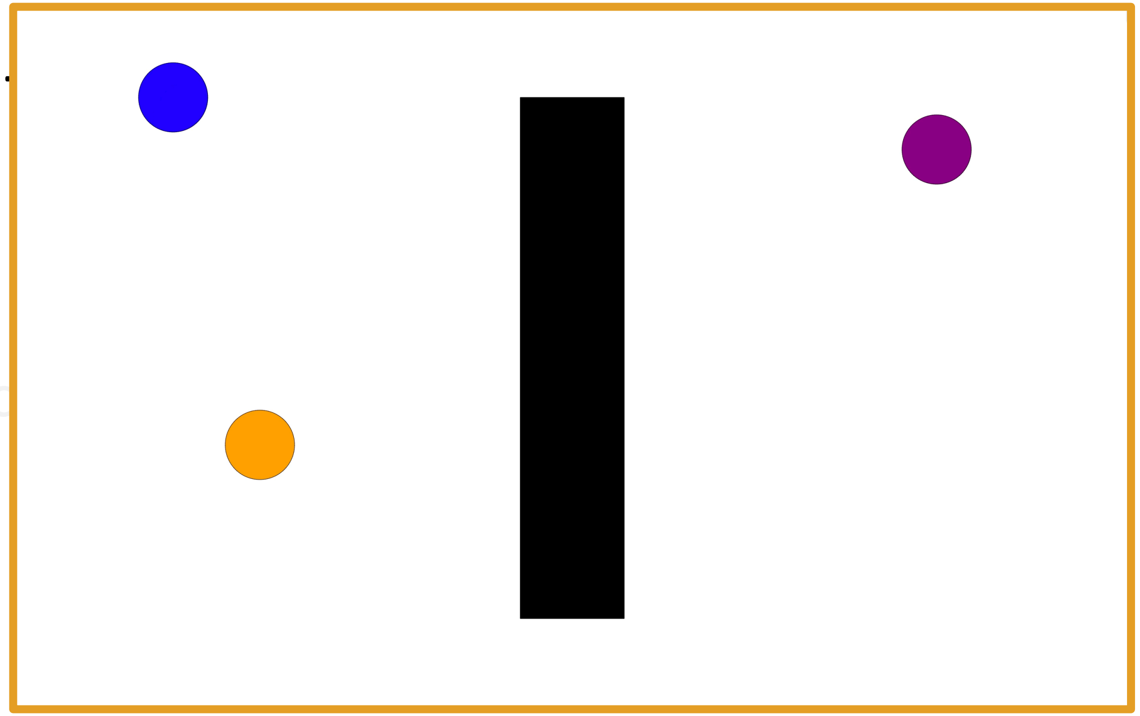
<u>CIRCLES</u>: $\forall x[\text{Green}(x)]$ ≈The individual circles$_x$ are s.t. each one$_x$ is green



take on only 1 value at a time

(Boolos 1984, 1985, 1998; Schein 1993; Pietroski 2018)

Different underlying cogni



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First-order representations (*each*) rely on object-files

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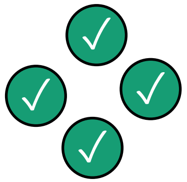
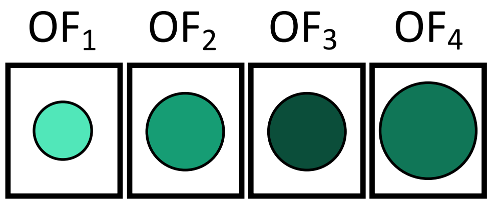


take on only 1
value at a time

Objects individuated
individual properties encoded



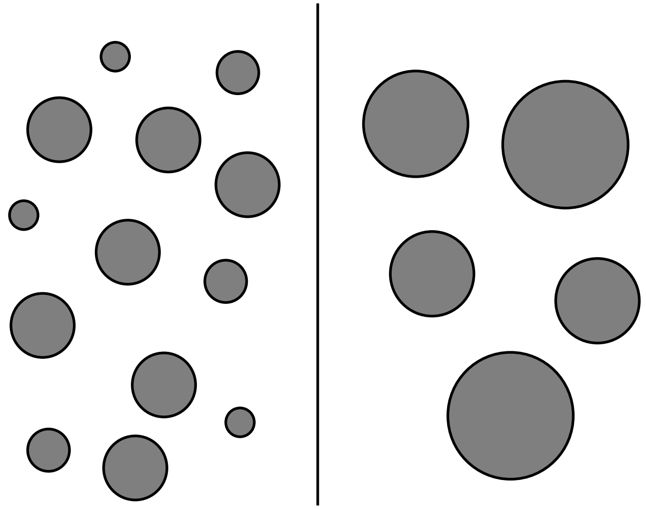
(e.g., Kahnemann et al. 1992; Pylyshyn & Storm 1998; Scholl, Pylyshyn & Feldman 2001; Scholl 2002; Feigenson, Dehaene & Spelke 2004; Carey 2009)

Different underlying cognitive systems

Second-order representations (*every*) rely on ensembles

CIRCLES: ∀X[Green(X)] ≈The circles$_X$ are such that all of them$_X$ are green

Which side has **bigger** circles?



Objects abstracted away from **summary statistics** encoded

Ensemble$_1$

Center: (x,y)
Cardinality: 4
Avg. Size:

each) rely on object-files

ndividual circles$_x$ are s.t. each one$_x$ is green

Objects individuated **individual properties** encoded

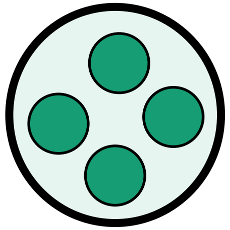
OF$_1$ OF$_2$ OF$_3$ OF$_4$

(e.g., Ariely 2001; Feigenson, Dehaene & Spelke 2004; Alvarez 2011; Haberman, Brady & Alvarez 2015; Ward, Bear & Scholl 2016; Whitney & Leib 2018)

Different representations & cognitive systems

Second-order representations (*every*) rely on ensembles

CIRCLES: $\forall X[\mathrm{Green}(X)]$ ≈The circles$_X$ are such that all of them$_X$ are green



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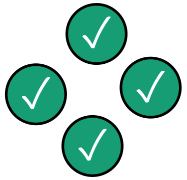

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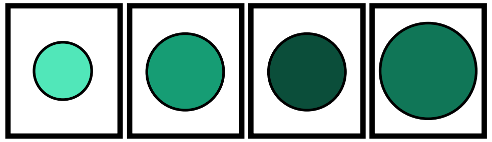
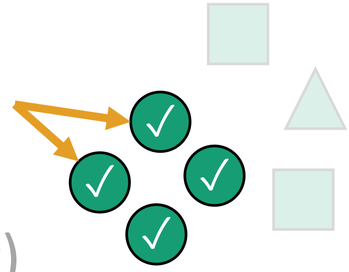


Different behavioral predictions

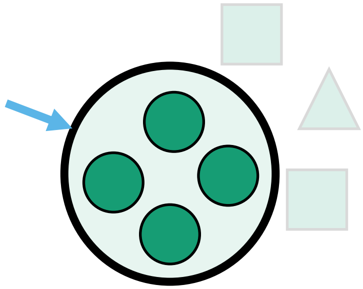
Linking hypothesis: In evaluating a sentence, people are biased toward strategies that directly compute the relations & operations expressed by the semantic representation under evaluation

First-order (*each*)	**Second-order (*every*)**
CIRCLES: $\forall x[\text{Green}(x)]$	CIRCLES: $\forall X[\text{Green}(X)]$
≈*The individual circles$_x$ are such that each one$_x$ is green*	≈*The circles$_X$ are such that all of them$_X$ are green*

Encode individual properties (e.g., color)



Encode summary statistics (e.g., #)

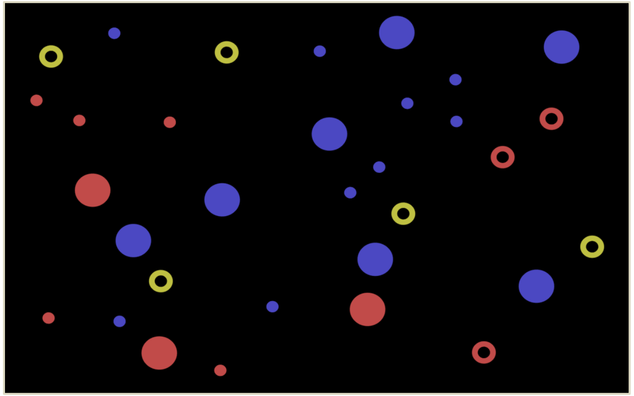


Abstract away from individual properties

(Linking hypothesis from Lidz et al. 2011)

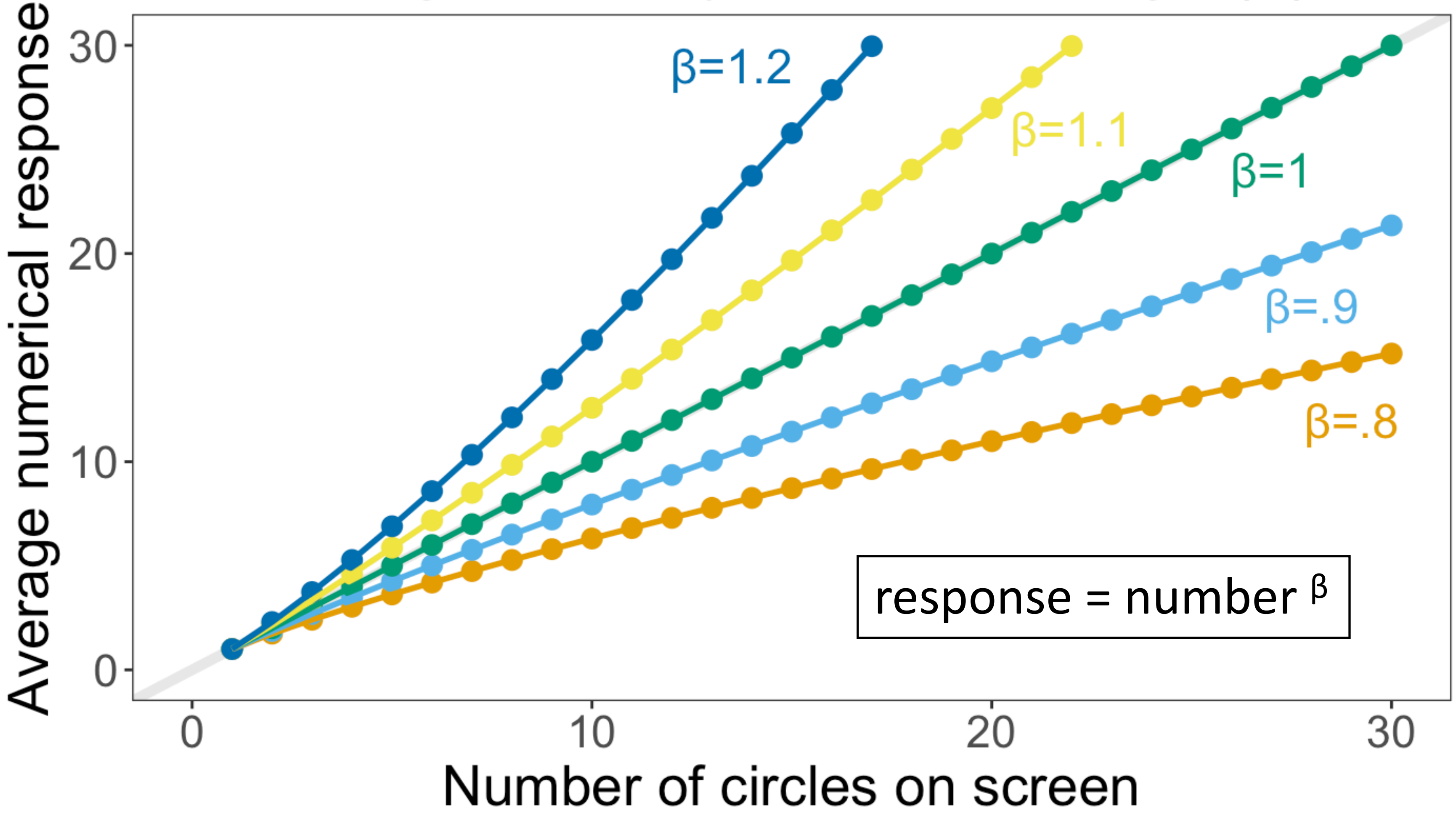
{Each/Every} big circle is blue

TRUE FALSE



How many {big/medium/small} circles were there?

Measuring accuracy of #-knowledge (β)



#-knowledge accuracy - Bayesian estimates

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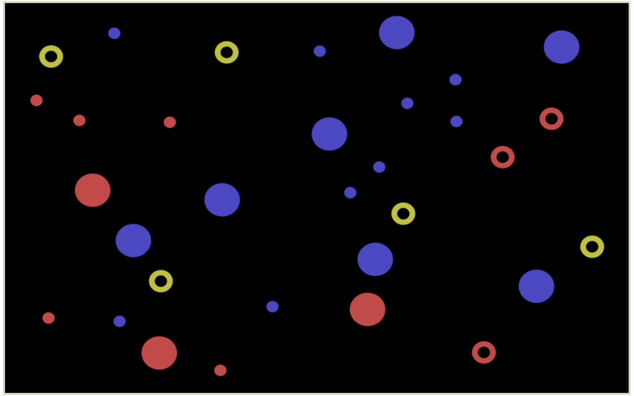
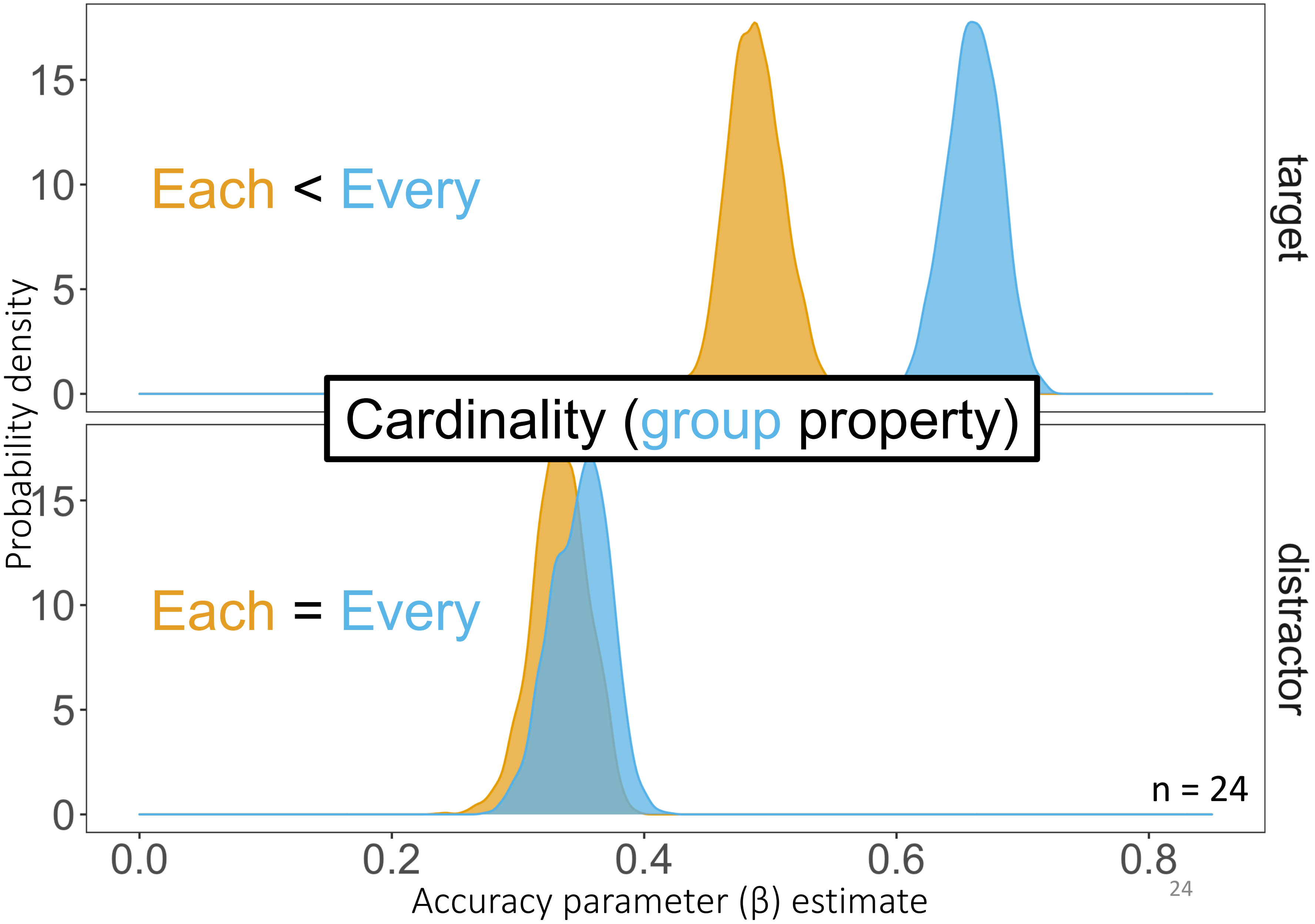
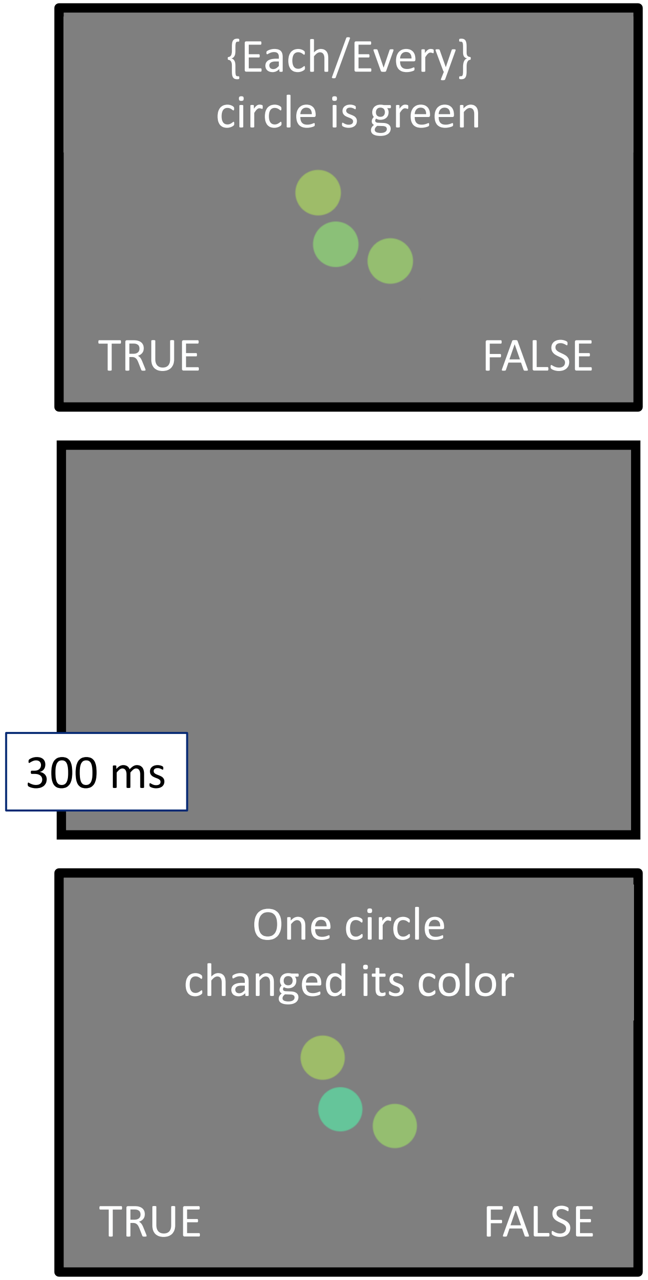


How many
{big/medium/small}
circles were there?

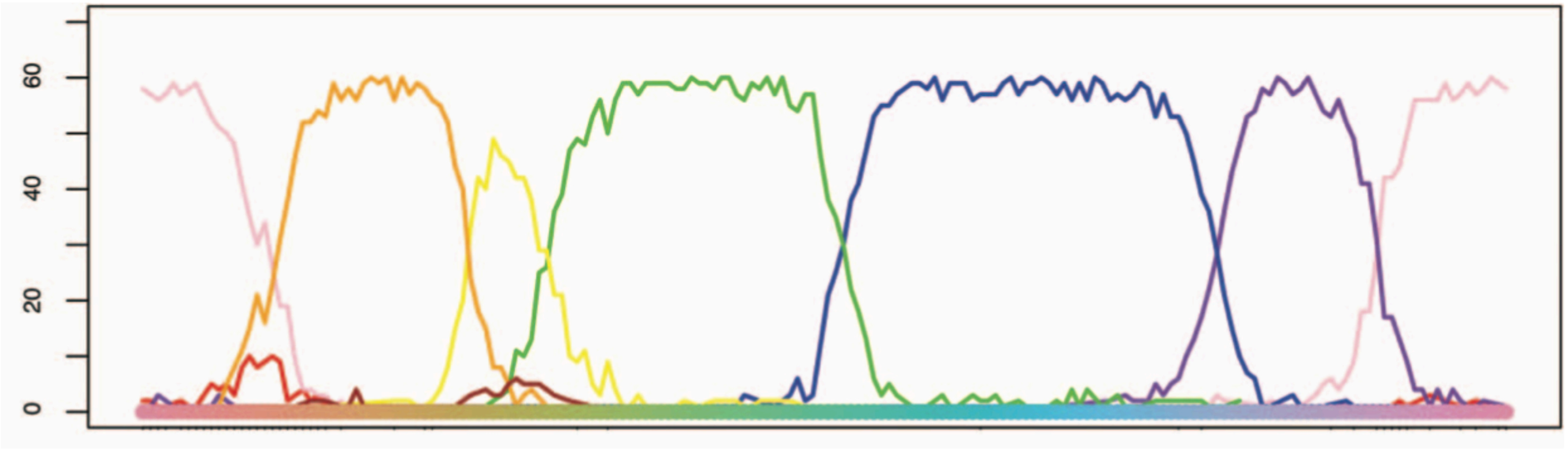
(Knowlton et al. *under review*)



Color (individual property)

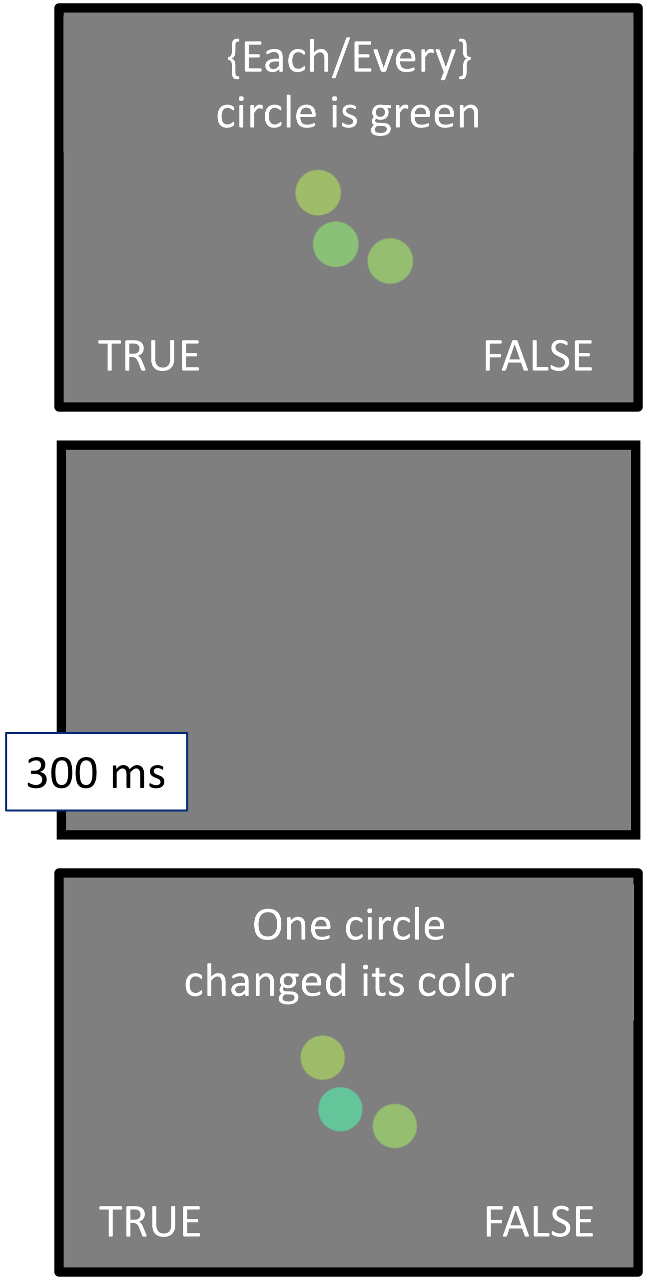


Color category naming task

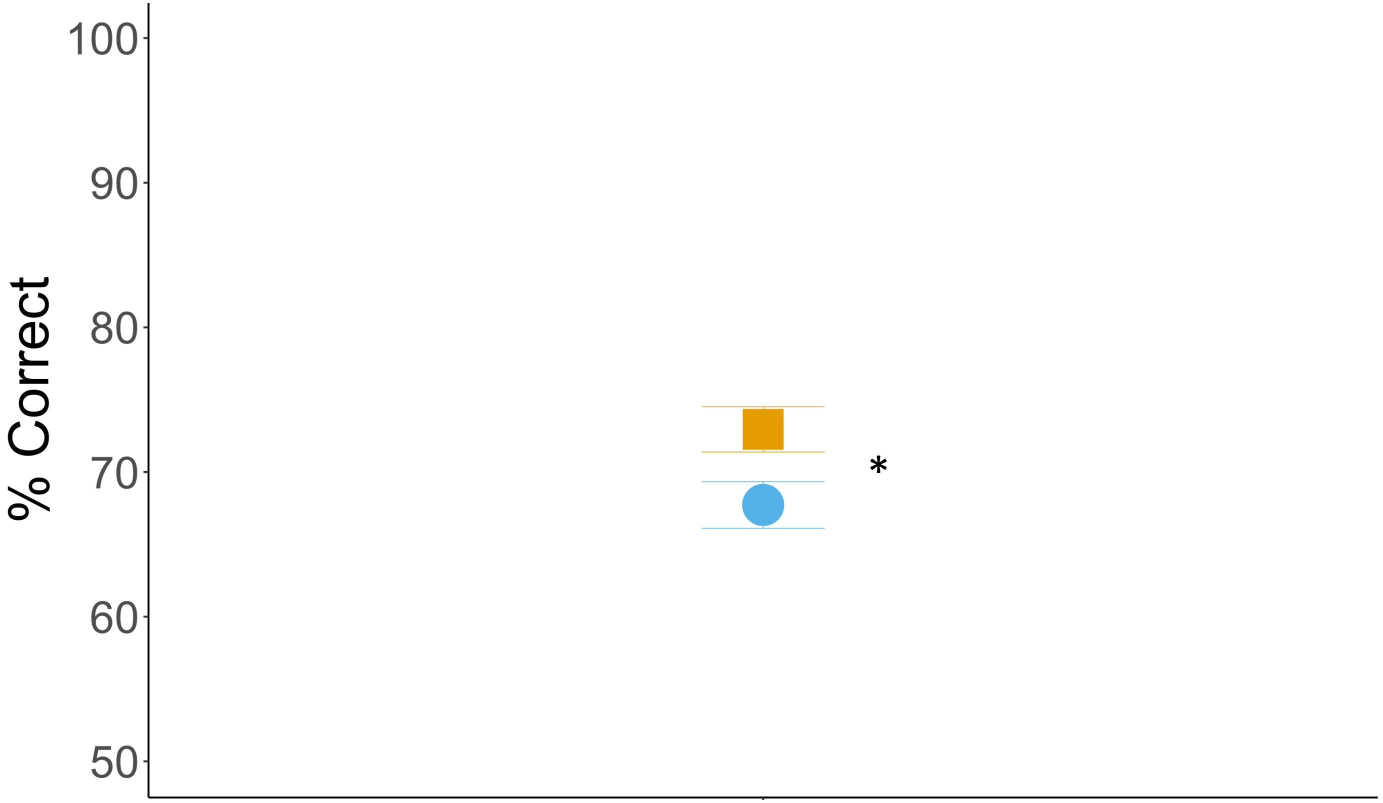


(Bae, Olkkonen, Allred & Flombaum 2015)

Color (individual property)

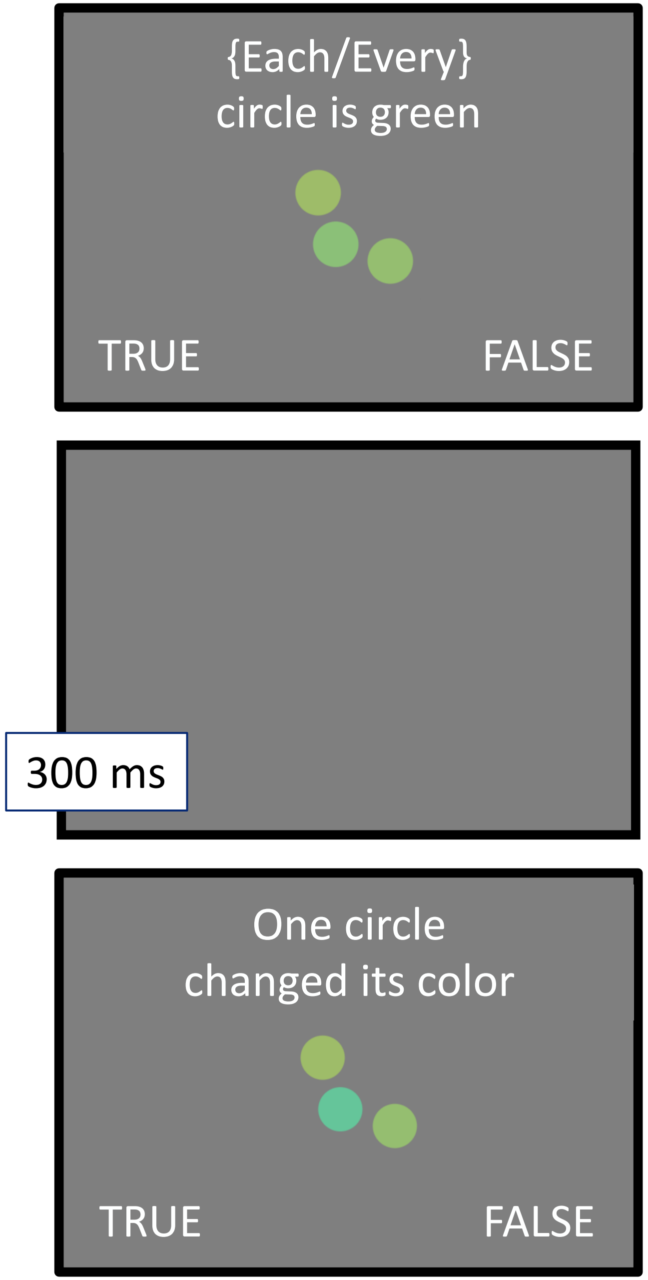


Change detection accuracy

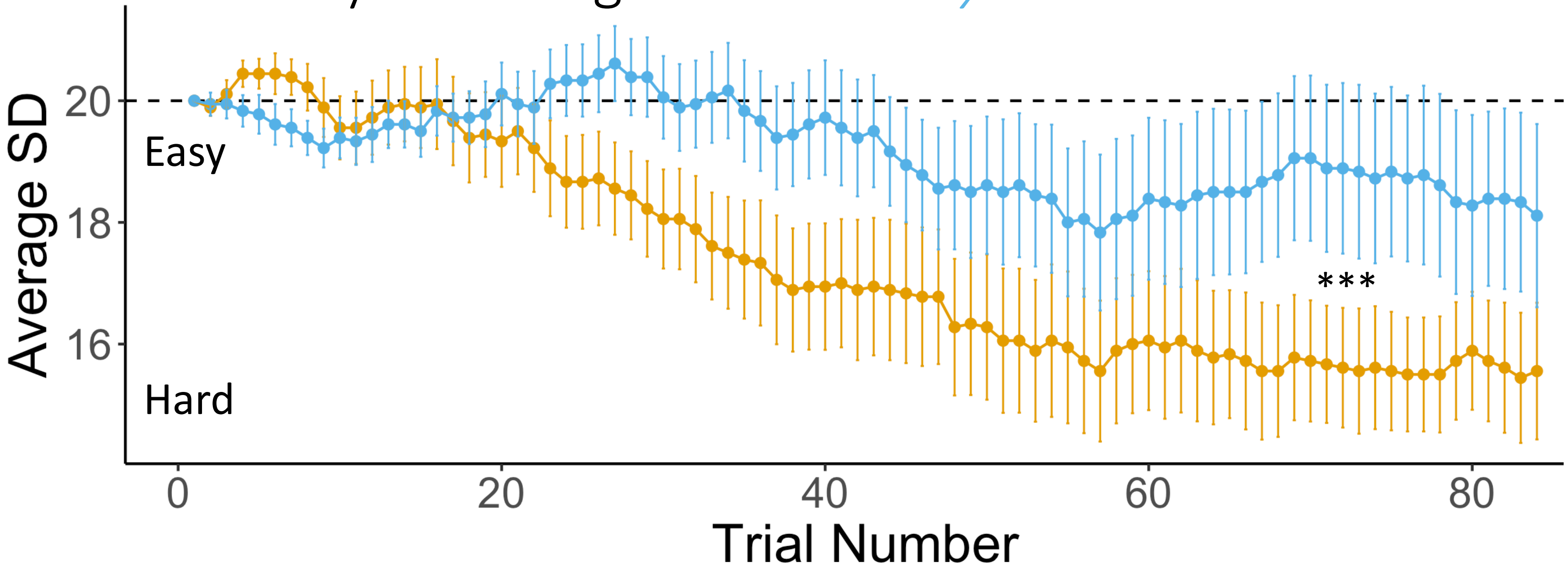


n = 36

Color (individual property)



Color change detection: difficulty required for 70% accuracy following *each* or *every*



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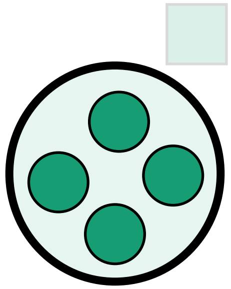
How are *each* & *every* mentally represented?

***Every*: restricted second-order**

The circles$_X$ are such that all of them$_X$ are green

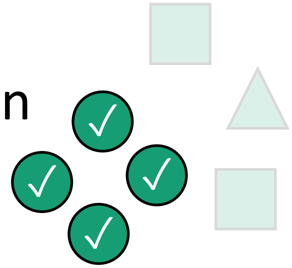


CIRCLES: $\forall X[\mathrm{Green}(X)]$

➥ Ensemble representations

***Each*: restricted first-order**

The individual circles$_x$ are such each one$_x$ is green



CIRCLES: $\forall x[\mathrm{Green}(x)]$

➥ Object-file representations

How are *each* & *every* acquired? (Future direction)

Differences in child-directed speech

Each – generalize over local domain

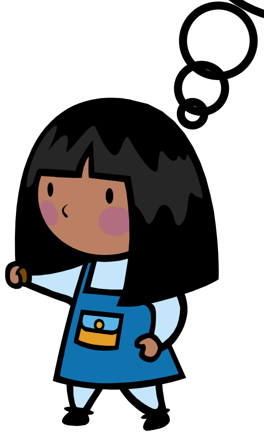
"You have to ring up each thing"
"Could you put a flower on each plate?"
"Put sugar in each coffee"

Every – project beyond the local domain

"Every time I ask a question, you say you don't know"
"You turn into a wild man every time we get out"
"She watches every movie they make"

Acquisition question:

What leads learners to pair "each" and "every" with the right concepts?



(Knowlton & Lidz *forthcoming*)

Thanks!

Slides available at: tylerknowlton.com/talks/MindCORE.pdf

Special thanks to:

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Language at Maryland

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