The psycho-logic of universal quantifiers

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

Meaning in mental grammar

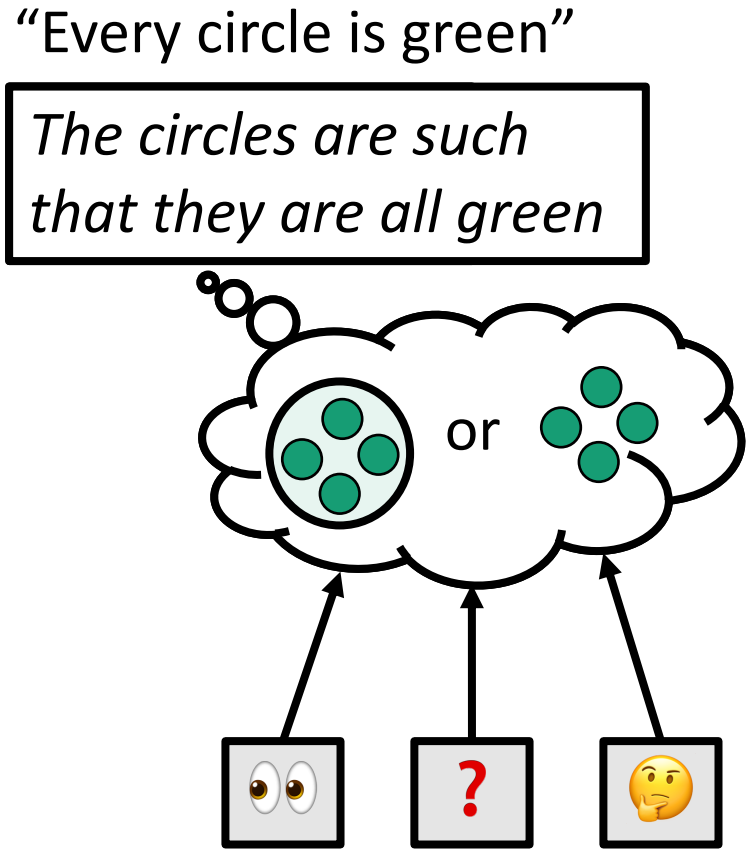
➥ What sorts of instructions do meanings provide to cognition?
➥ What can that relationship tell us about semantic representations?

Methodological strategy

Ask which cognitive systems are engaged

➥ e.g., systems for group vs. individual representation

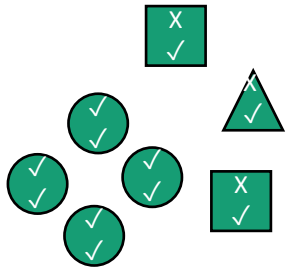
Isolate the contribution of the semantic representation



Many ways to describe “every circle is green”

For each individual$_x$, if it$_x$ is a circle, it$_x$ is green

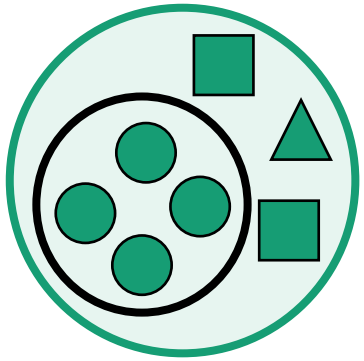
UNIVERSE: ∀x[Circle(x) → Green(x)]



Unrestricted First-order

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

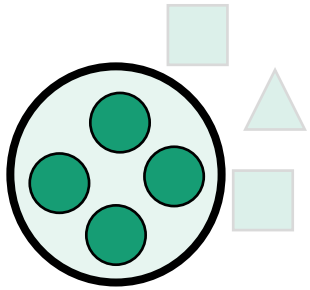
UNIVERSE: TheX:Circle(X) ⊆ TheY:Green(Y)



Unrestricted Second-order

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

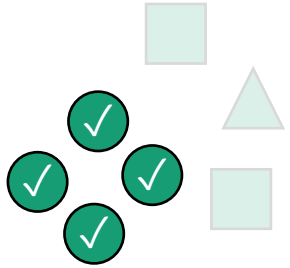
CIRCLES: ∀X[Green(X)]



Restricted Second-order

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

CIRCLES: ∀x[Green(x)]



Restricted First-order

How are universal quantifiers mentally represented?

Relational vs. Restricted (*every*)

➥ Number cognition as a probe into which arguments are represented

➥ Explanation of the "conservativity" universal

First- vs. Second-order (*each* vs. *every*)

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

Consequences for language acquisition (*each* vs. *every*)

➥ Precursors of quantification in infants

➥ Differences in child-directed speech

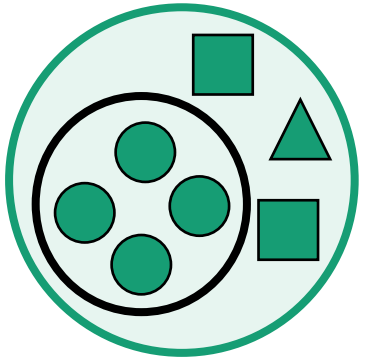
Different representations

"Every circle is green"

Relational (unrestricted)

TheX:Circle(X) ⊆ TheY:Green(Y)

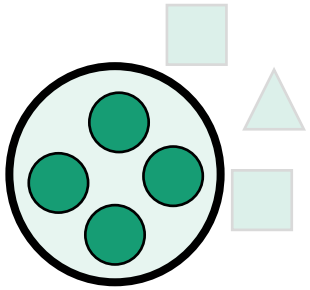
≈*The circles$_X$ are included in the green-things$_Y$*



Restricted

CIRCLES: ∀X[Green(X)]

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



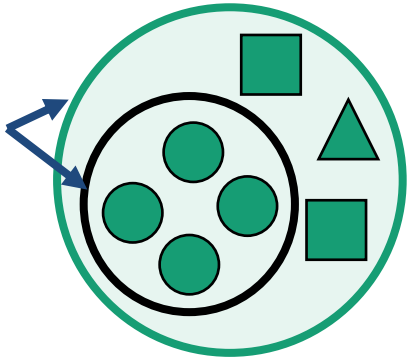
Different behavioral predictions

Linking hypothesis: people are biased toward verification strategies that directly compute the relations & operations expressed by the semantic representation under evaluation

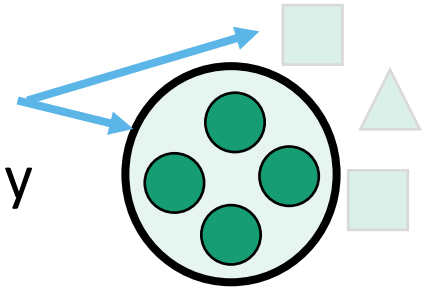
Relational (unrestricted)
TheX:Circle(X) ⊆ TheY:Green(Y)
≈*The circles$_X$ are included in the green-things$_Y$*

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

Represent & compare both arguments



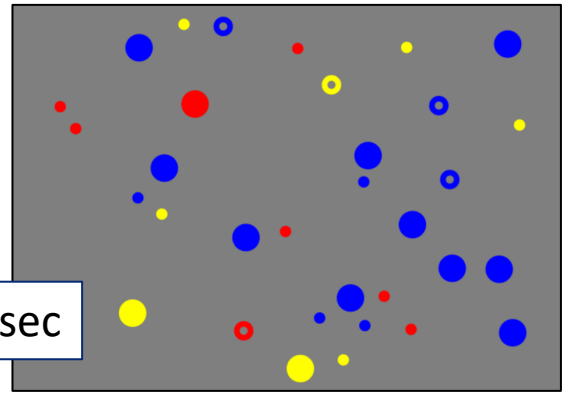
Treat arguments asymmetrically



(Lidz et al. 2011)

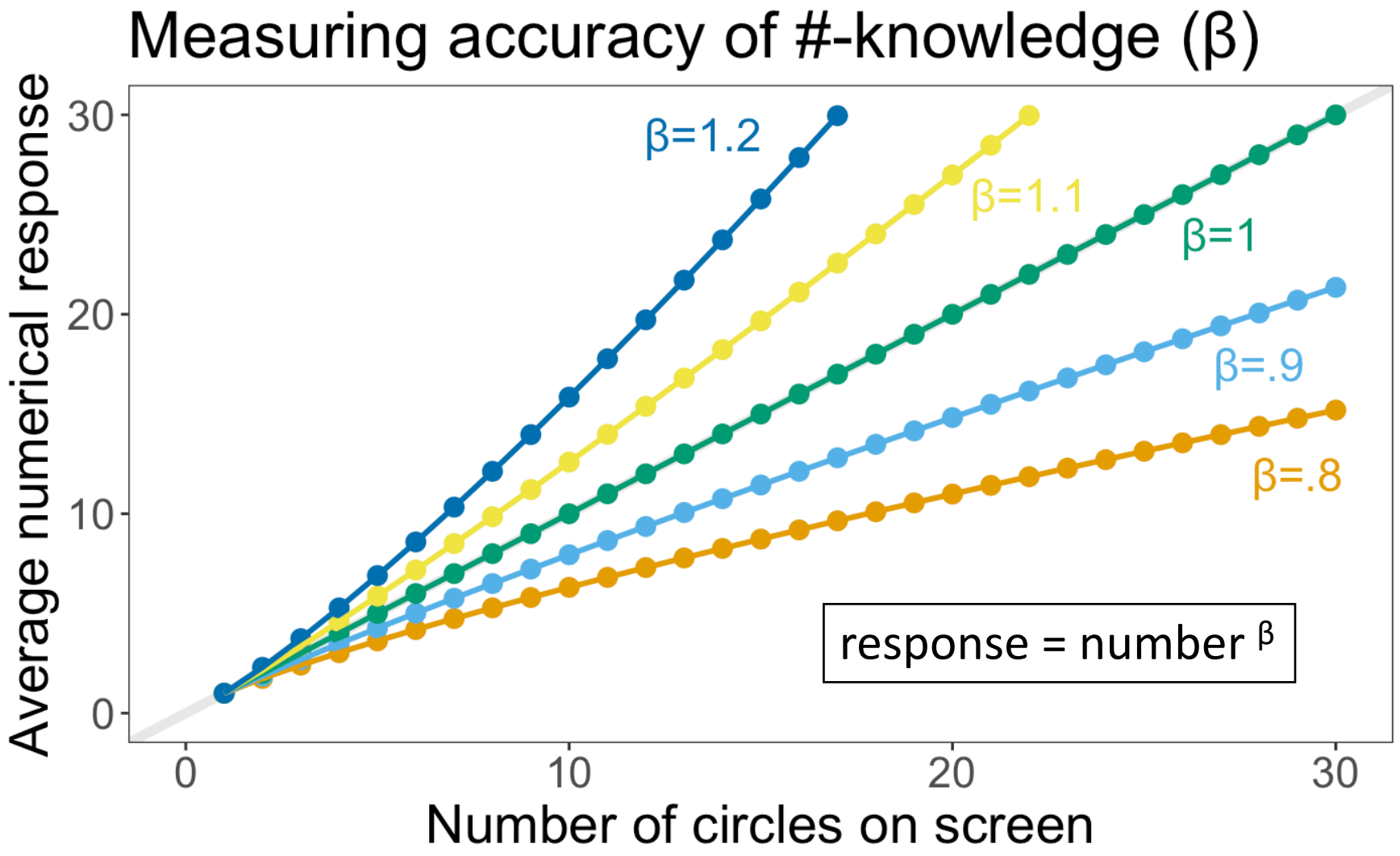
Every big circle is blue

TRUE FALSE



1 sec

How many big circles were there?



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

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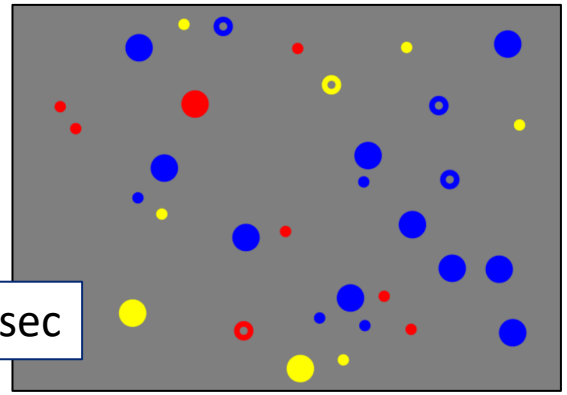

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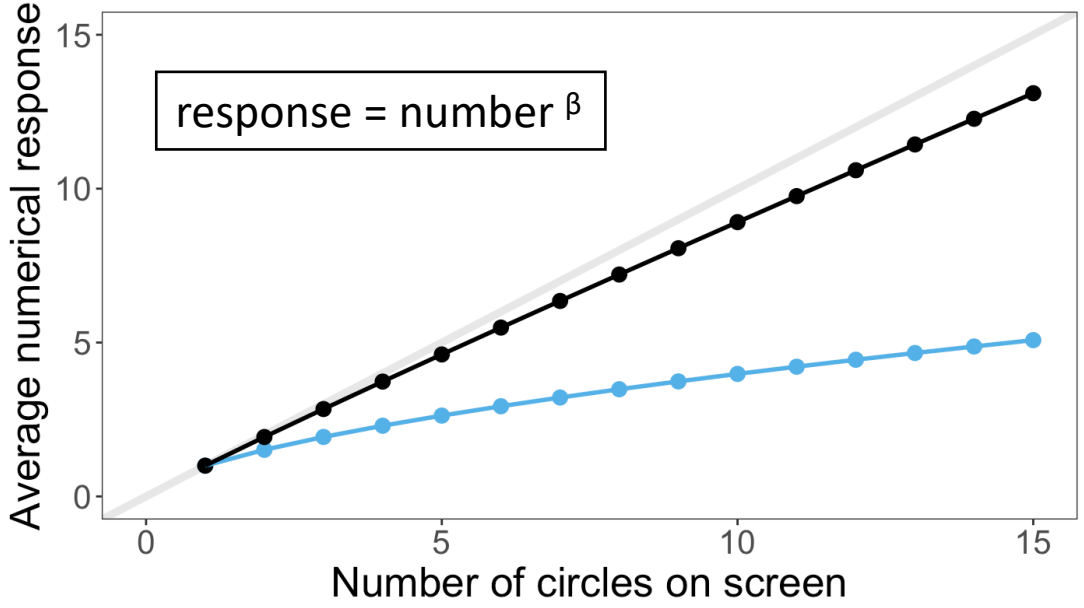

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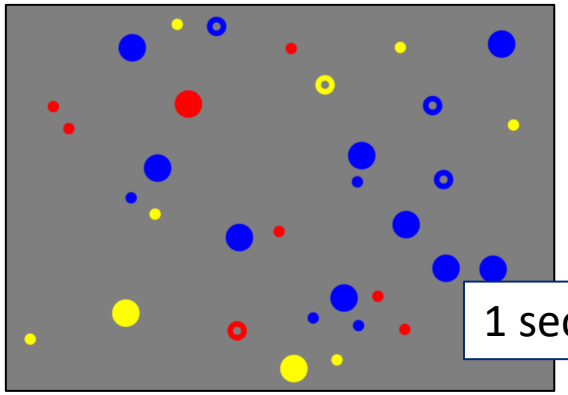


1 sec

How many big circles were there?

#-knowledge following ***every***

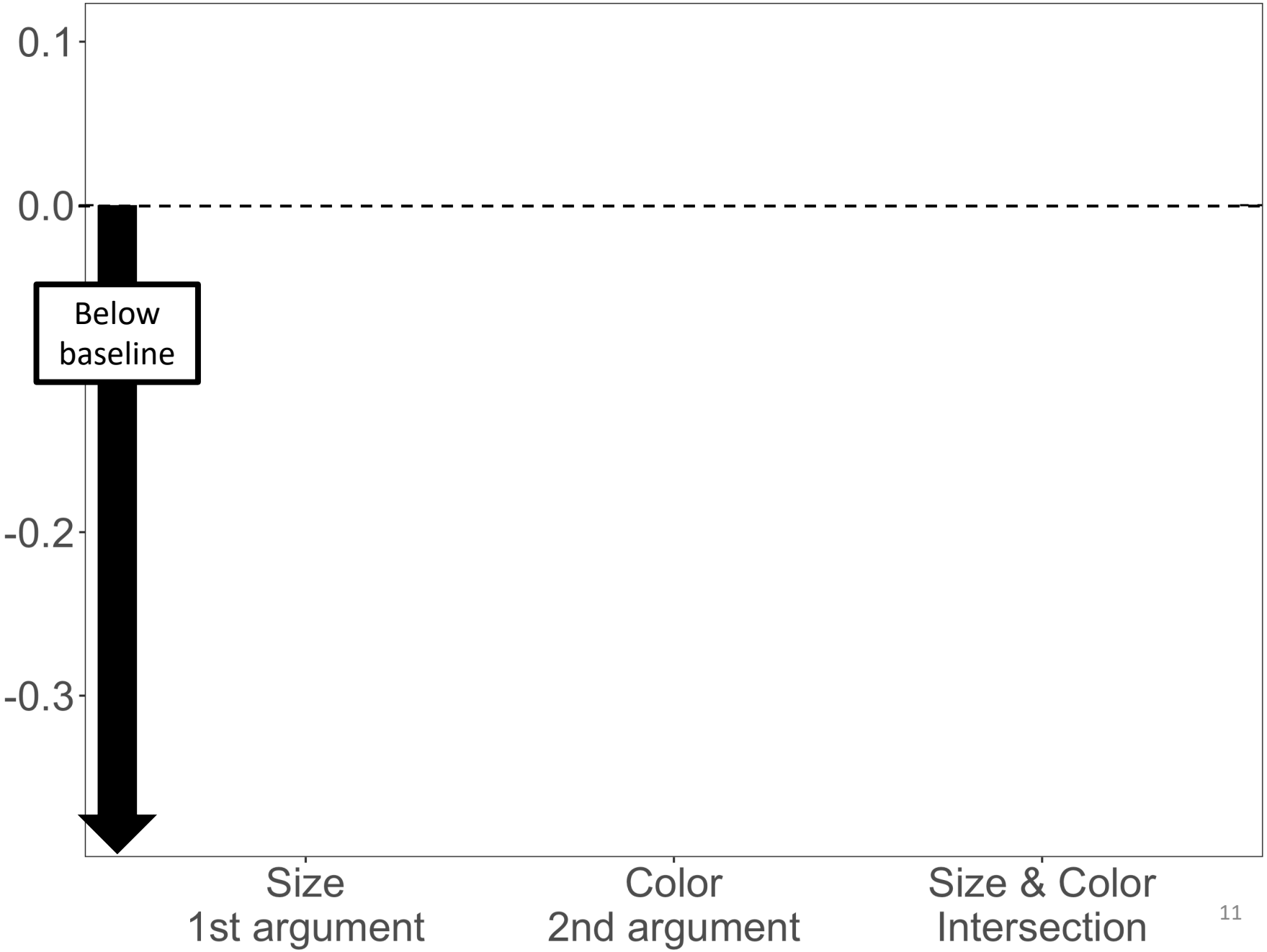
vs.

#-knowledge **baseline**

How many big circles were there?

(Knowlton, Pietroski, Williams, Halberda & Lidz *forthcoming*)

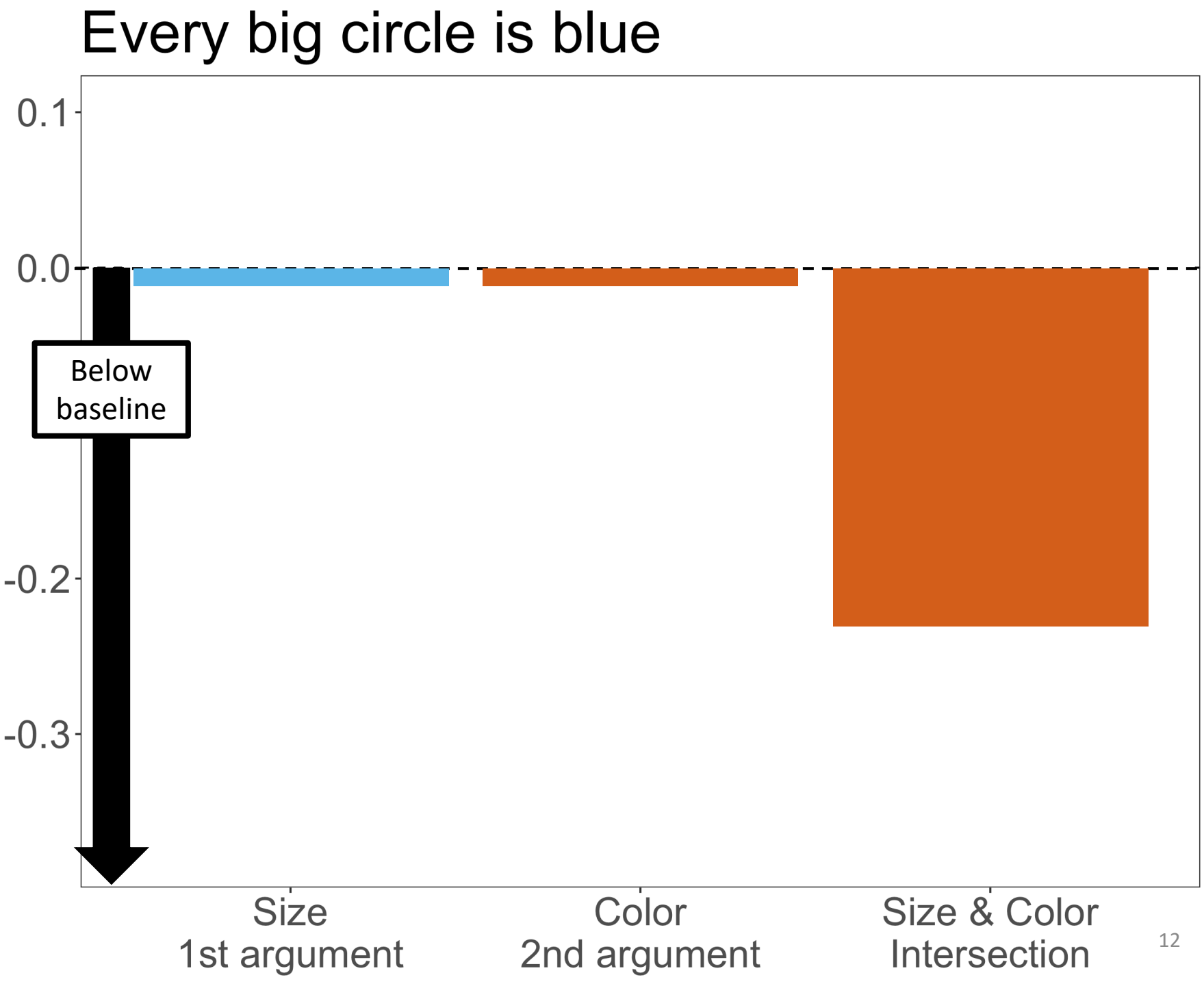
Every big circle is blue



Relational

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

Represent both arguments



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Restricted

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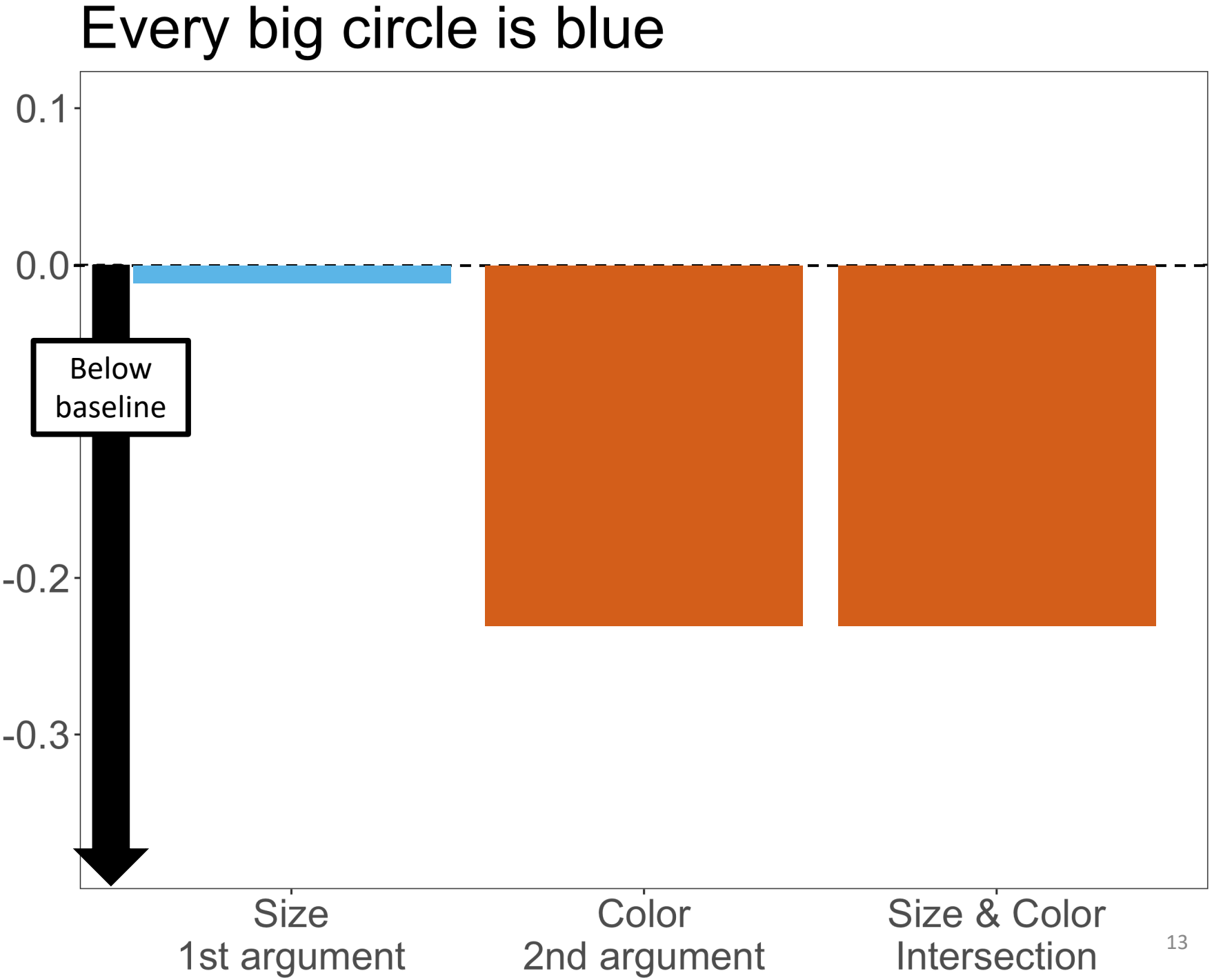
Treat arguments asymmetrically



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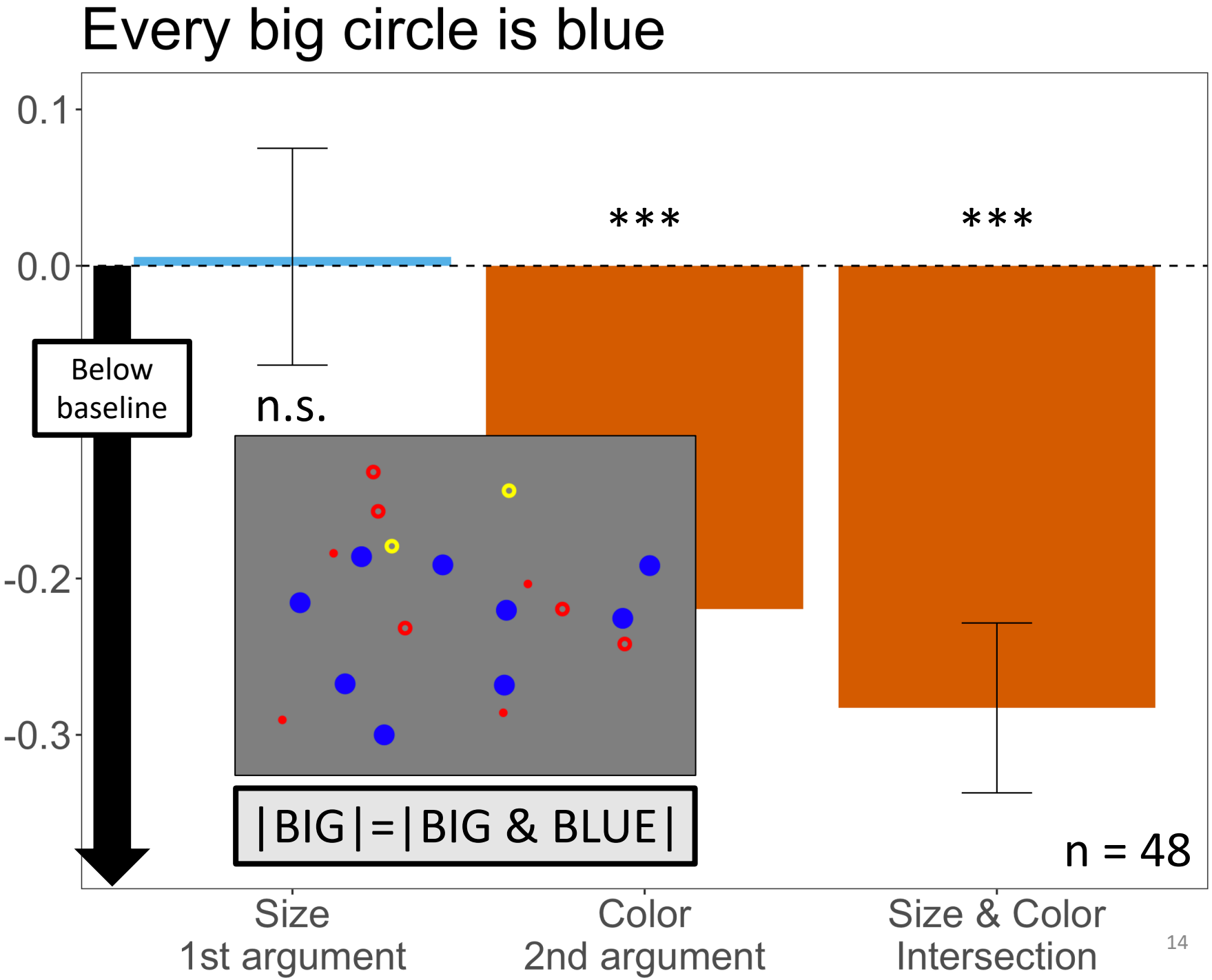
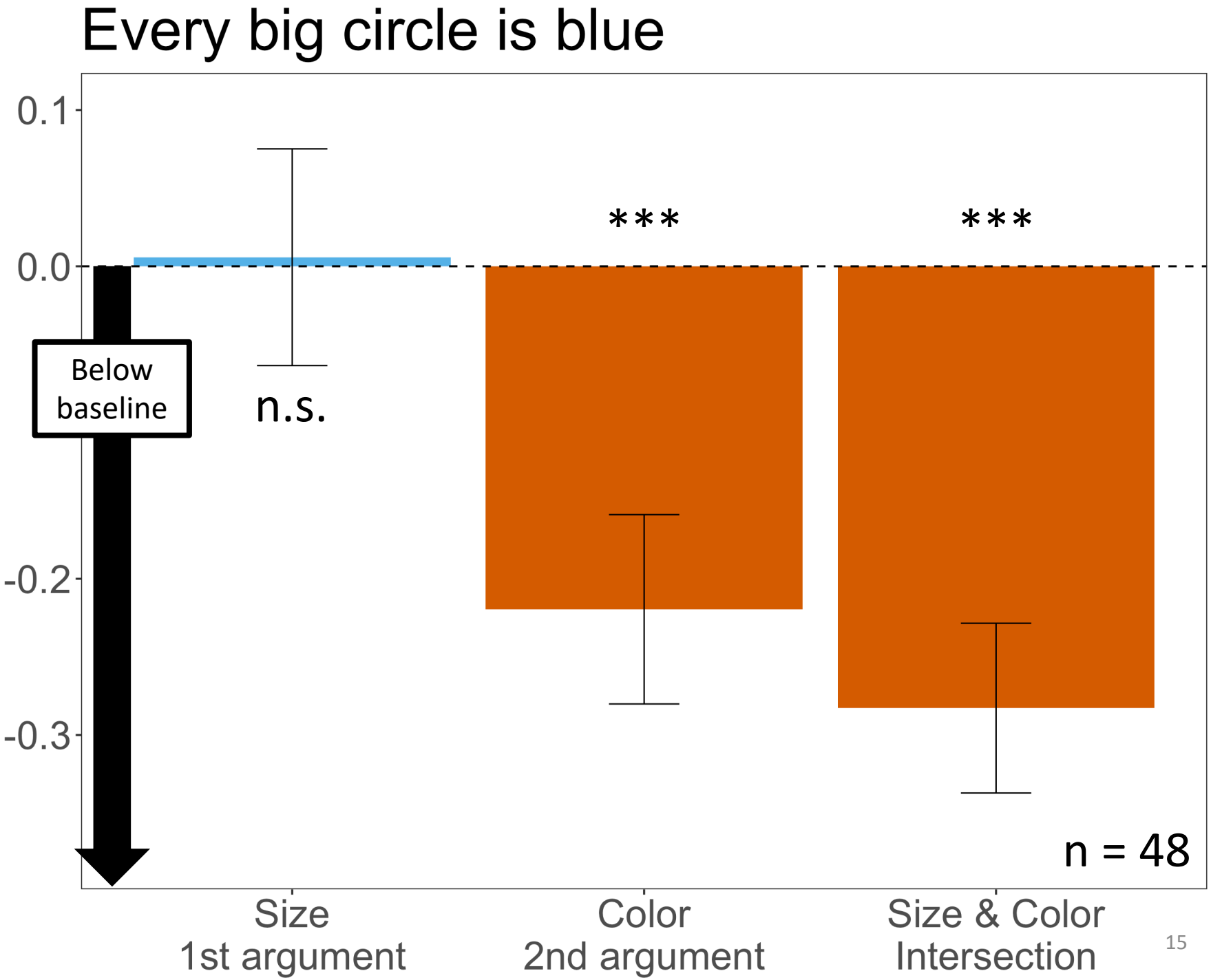
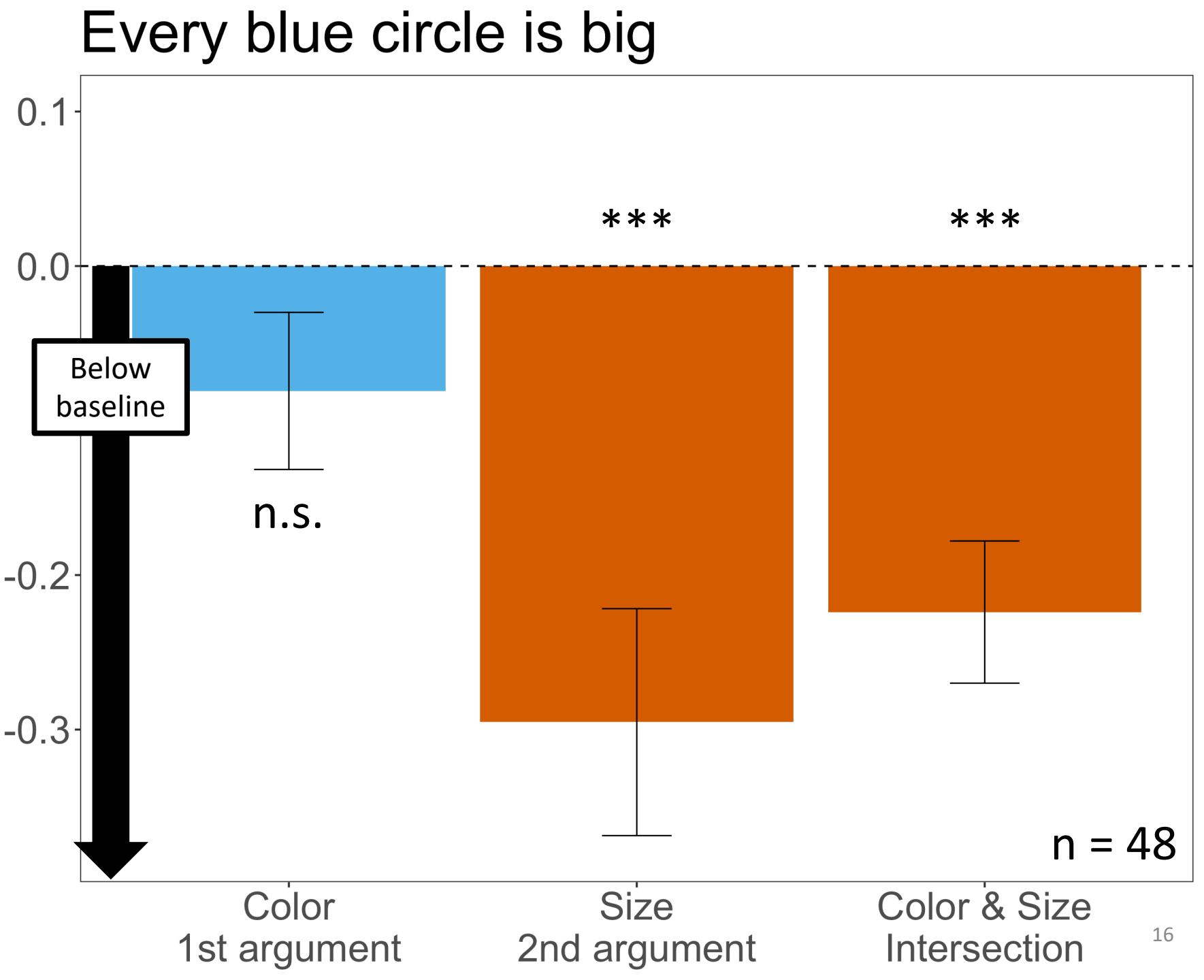


Is there something special about size?

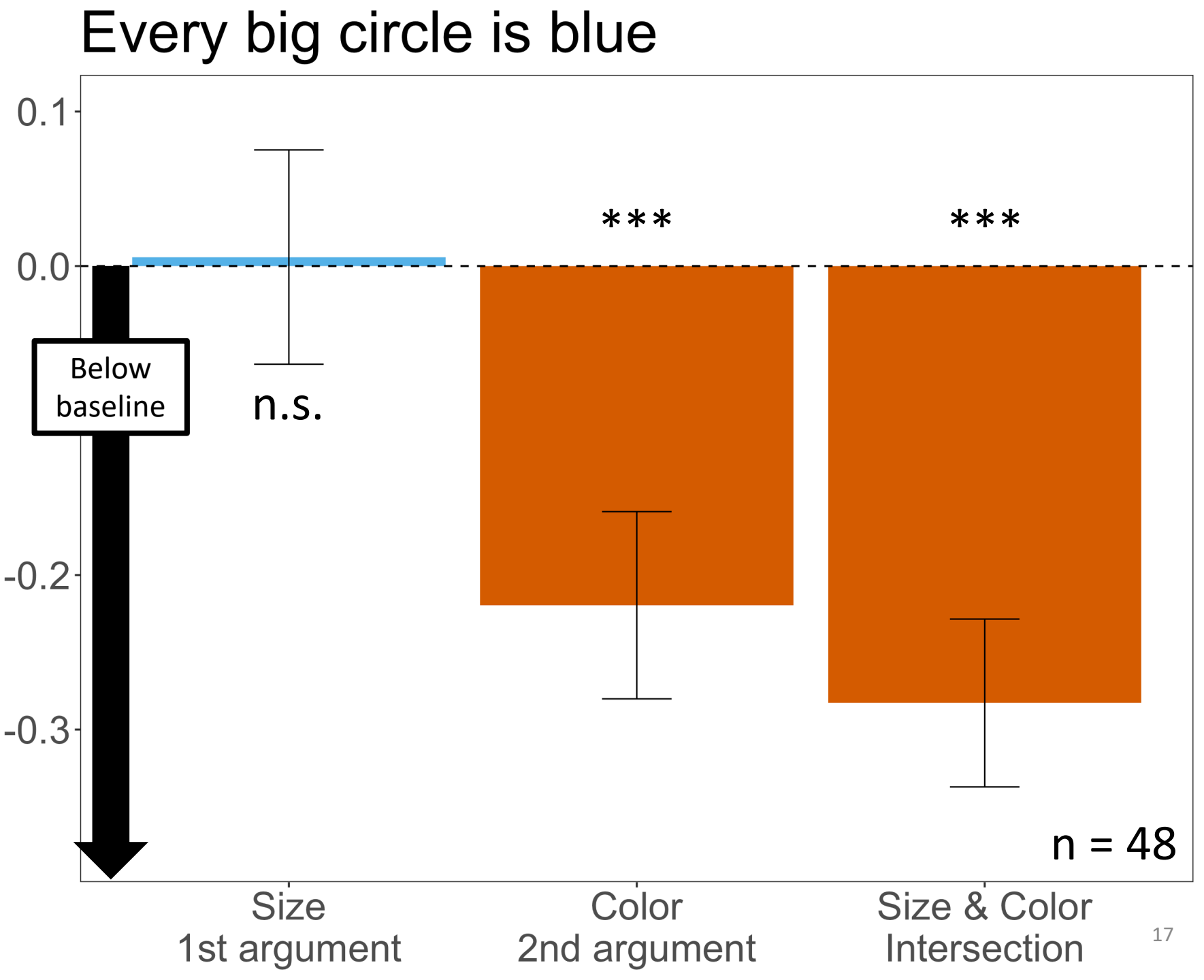


Is there something special about size?

No:
swap arguments, same result!

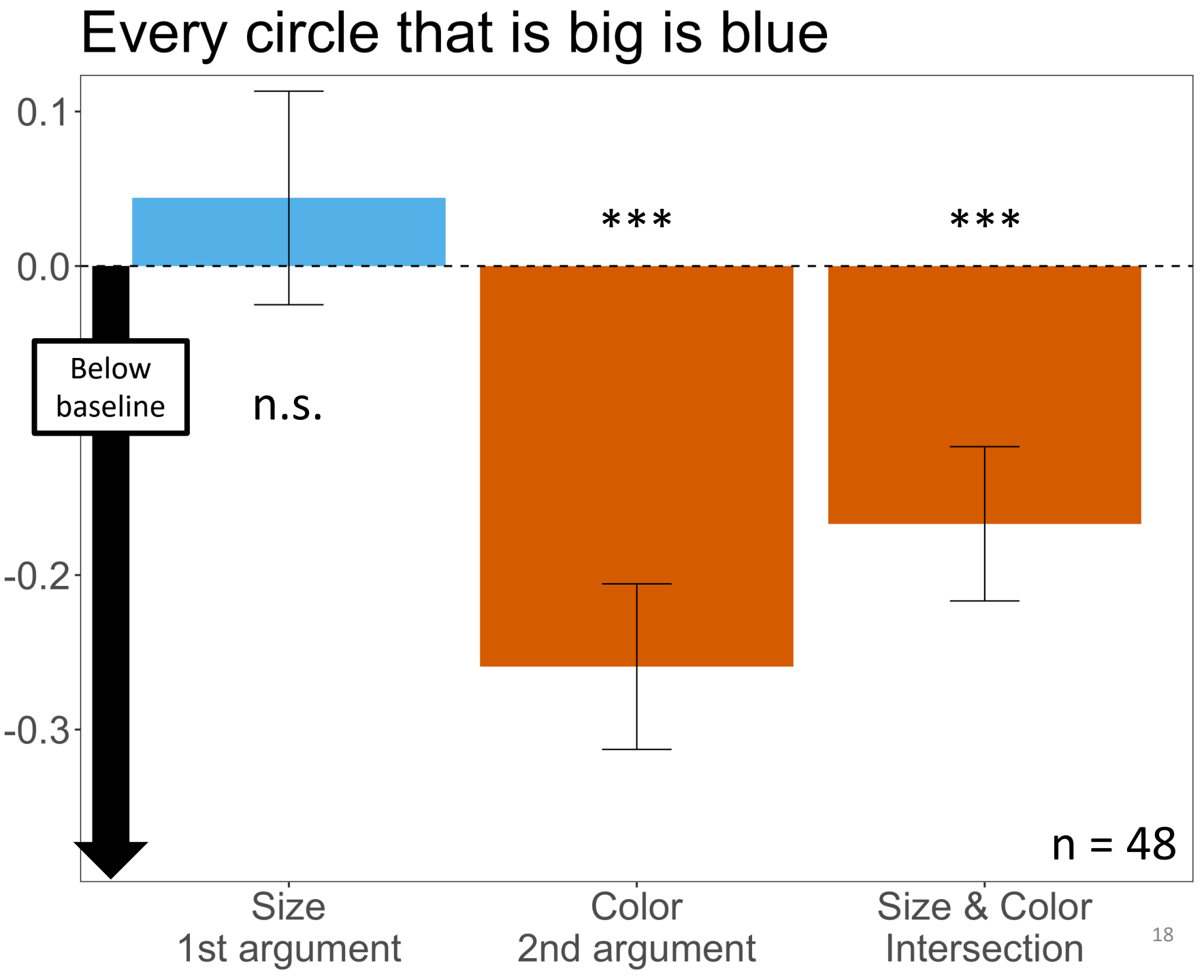


Is the problem that the predicates are introduced in two different ways?



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

No:
both can be introduced with *is*!

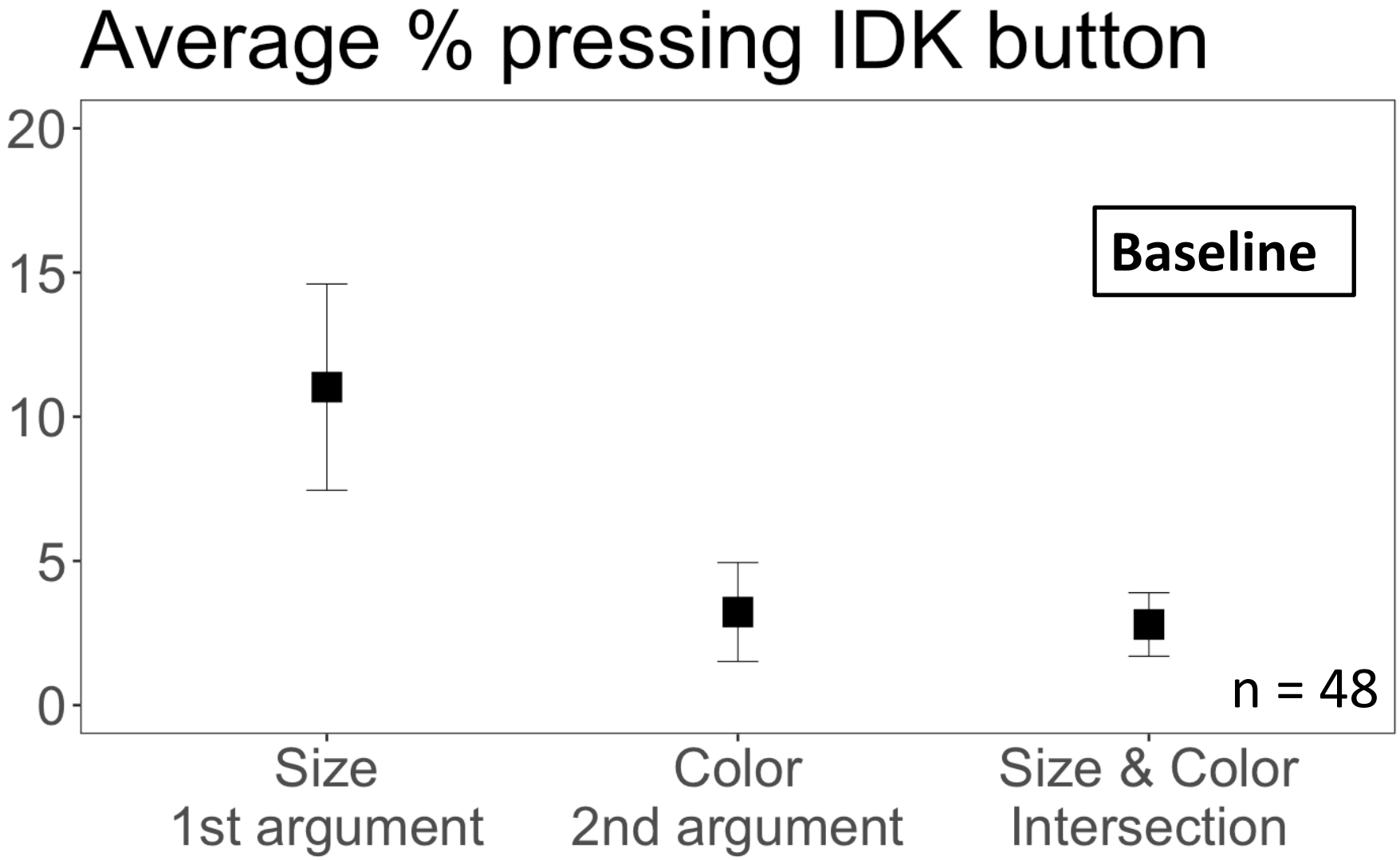


Is there another signature of the asymmetry?

Yes:
rate of opting not to answer

How many {big/blue} circles were there?

I don't know!



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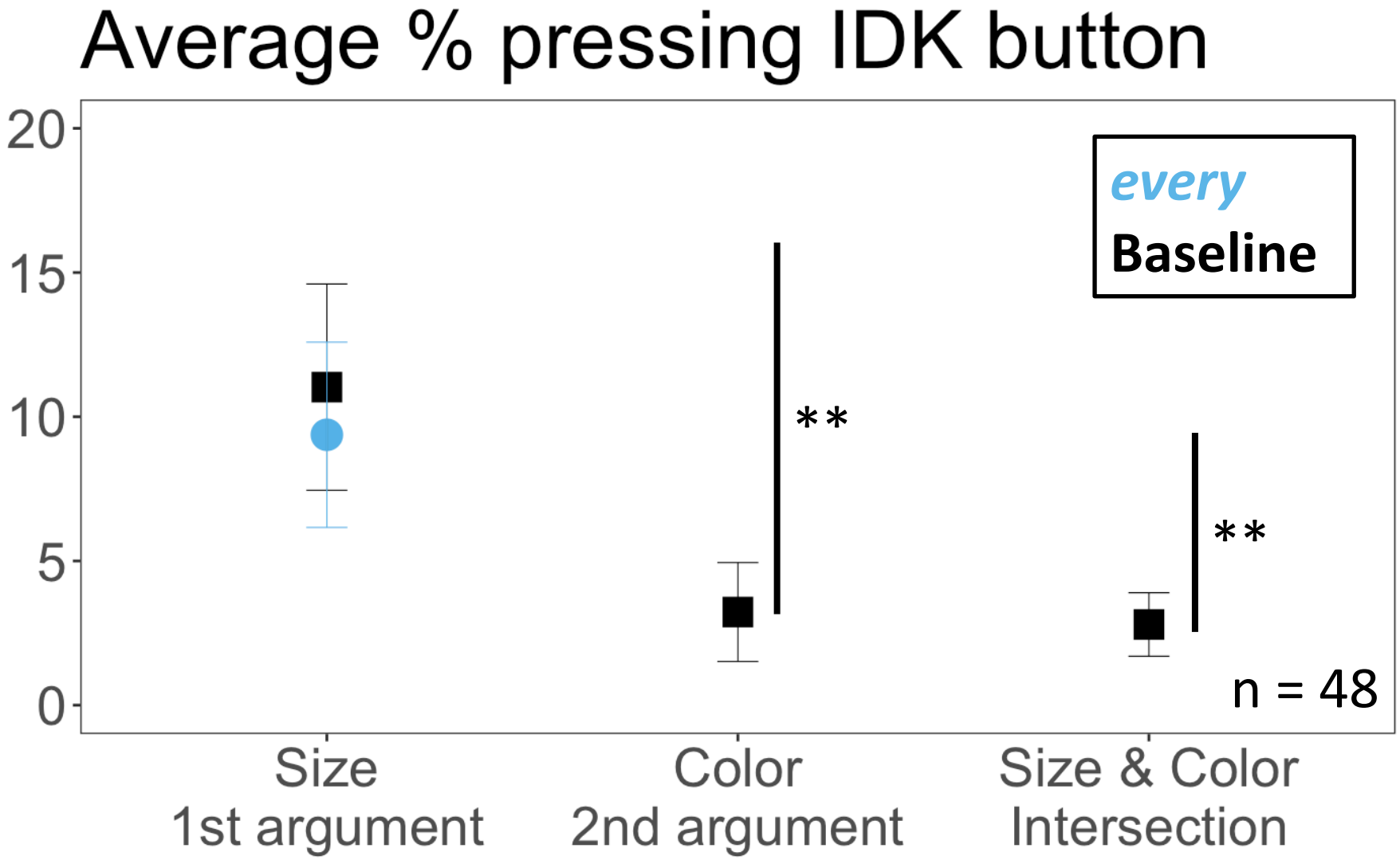
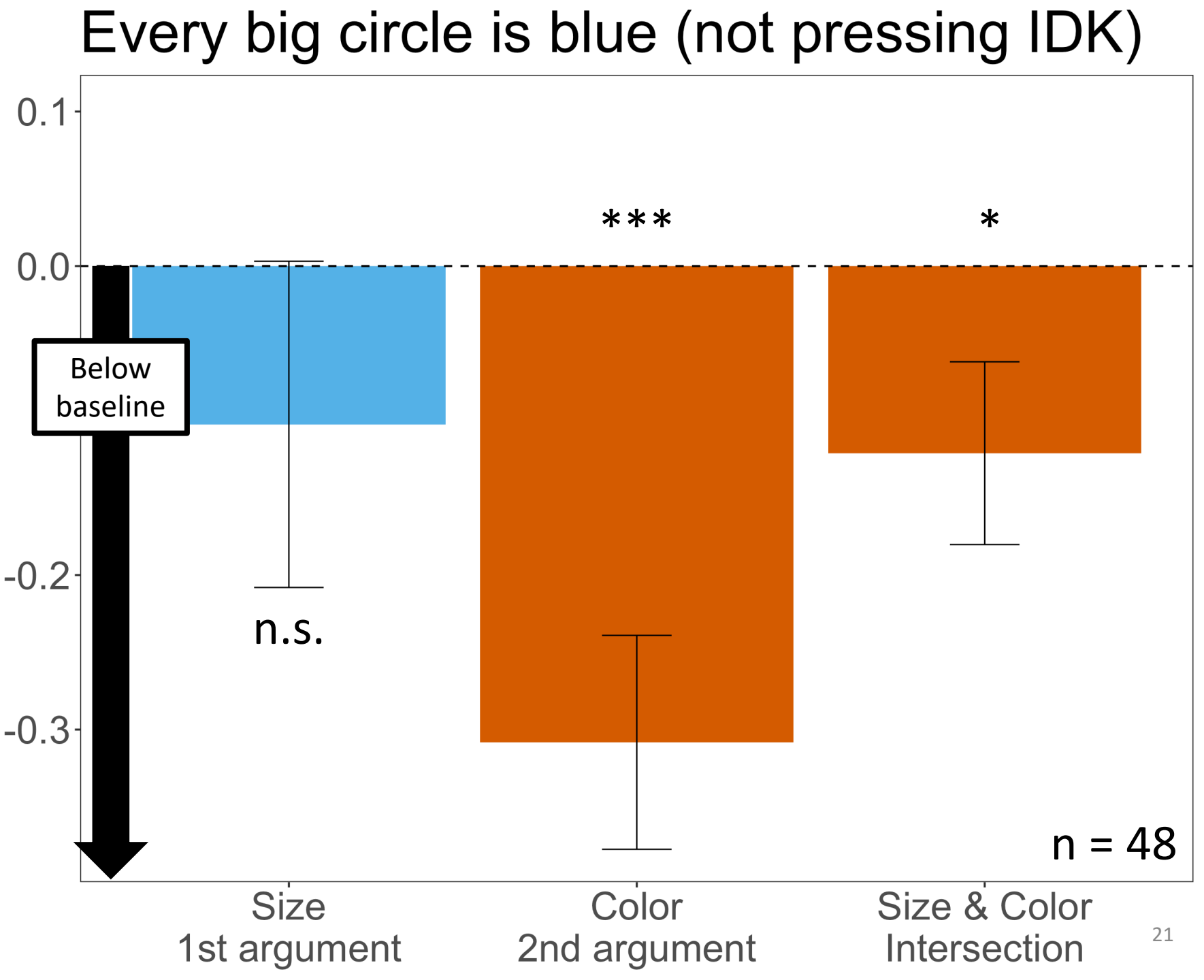


Are participants fully conscious of not knowing #?

No:
same result when they did respond



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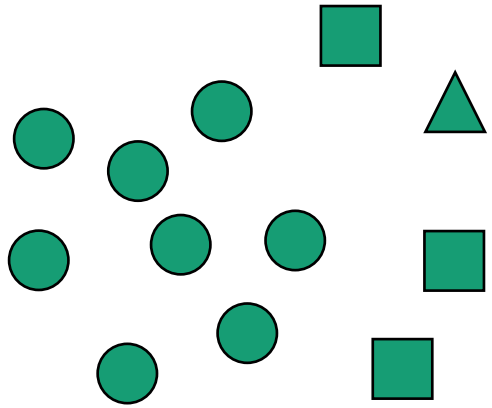
Natural language determiners are “conservative”

A determiner **DET** is conservative iff

(1) [[**DET** NP] PRED] =

(2) [[**DET** NP] [be NP that PRED]]



every *circle is green* (TRUE) =

every *circle is a circle that is green* (TRUE)

(e.g., Barwise & Cooper 1981; Higginbotham & May 1981; Keenan & Stavi 1986)

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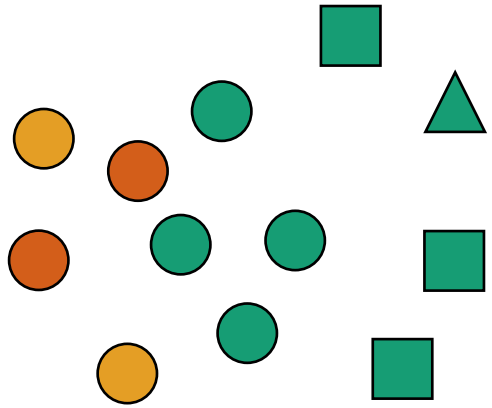

every *circle is green* (FALSE) =

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Natural language determiners are “conservative”

A determiner **DET** is conservative iff

(1) [[**DET** NP] PRED] =

(2) [[**DET** NP] [be NP that PRED]]

➥ Cross-linguistically, all determiners are conservative

➥ 5year-olds can learn novel conservative determiners **but not** novel non-conservative ones!

(e.g., Barwise & Cooper 1981; Higginbotham & May 1981; Keenan & Stavi 1986; Hunter & Lidz 2013; *cf*. Spenader & de Villiers 2019)

“Conservativity” is puzzling on the relational view

What rules out all the non-conservative relations?

|CIRCLES ∩ GREEN| > |CIRCLES - GREEN|

≈*most circles are green*

CIRCLES ⊆ GREEN

≈*every circle is green*

|CIRCLES| = |GREEN|

CIRCLES ⊇ GREEN

(For relationality-preserving proposals, see: Keenan & Stavi 1986; Romoli 2015; Chierchia 1995; Fox 2002; Sportiche 2005)

“Conservativity” is entailed on the restricted view

Relative to the circles, *is green* applies to

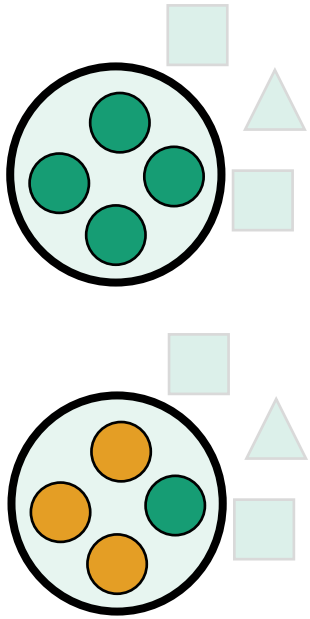
…all things

…most things

…at least 2 & at most 4 things

…??? things

(intended: |CIRCLES| = |GREEN|)



➥ Non-conservative meanings are not stateable if the first argument restricts the domain of quantification

(Pietroski 2005, 2018; Westerståhl 2019)

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First- vs. Second-order (*each* vs. *every*)

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Consequences for language acquisition (*each* vs. *every*)

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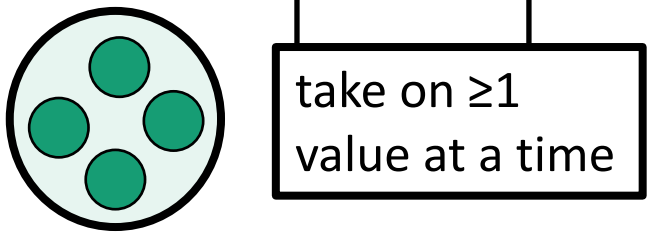
Different representations

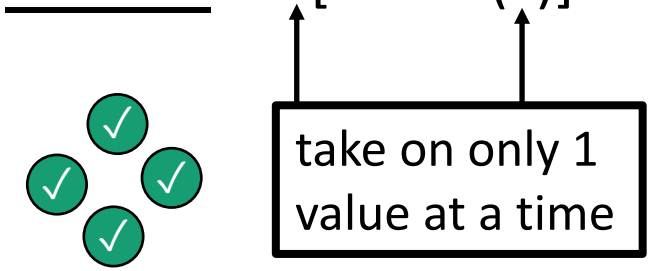
Second-order representations (*every*)

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



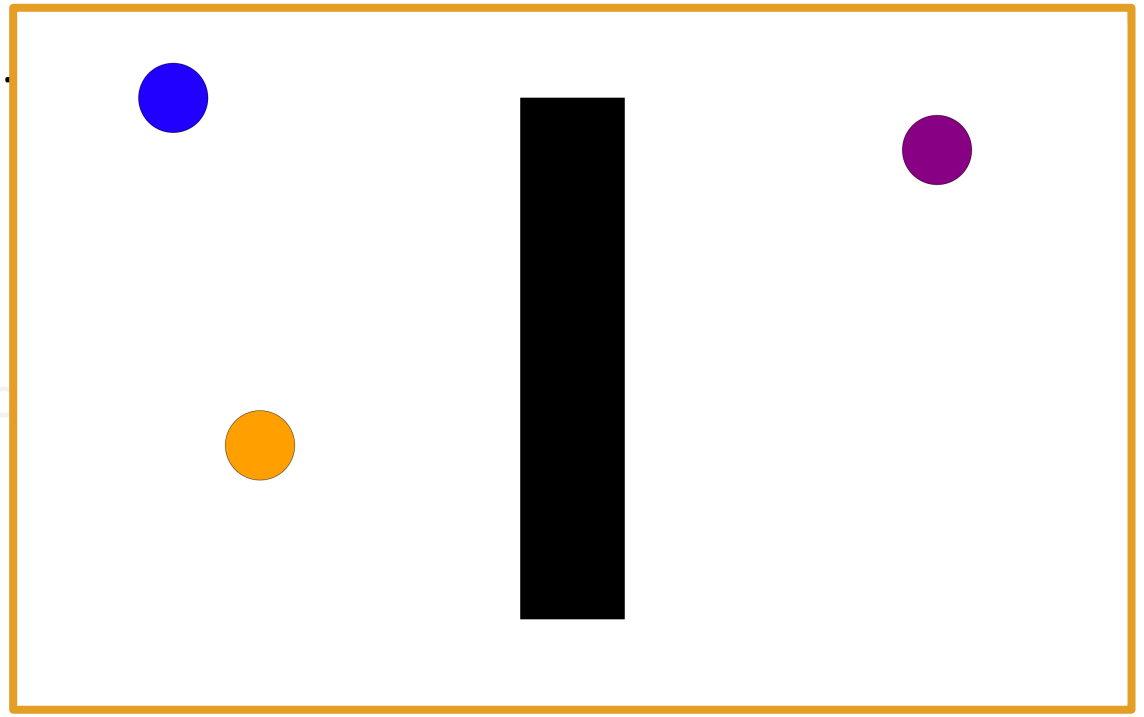
First-order representations (*each*)

CIRCLES: ∀x[Green(x)] ≈The individual circles$_x$ are s.t. each one$_x$ is green



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

Different underlying cogni



Second-order representations (*every*)

CIRCLES: ∀X[Green(X)] ≈The circles$_X$ are suc

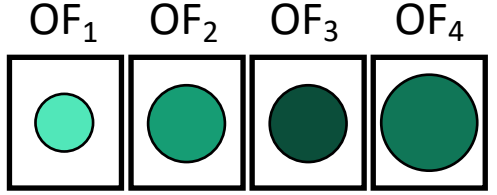
take on ≥1
value at a time

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

CIRCLES: ∀x[Green(x)] ≈The individual circles$_x$ are s.t. each one$_x$ is green

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

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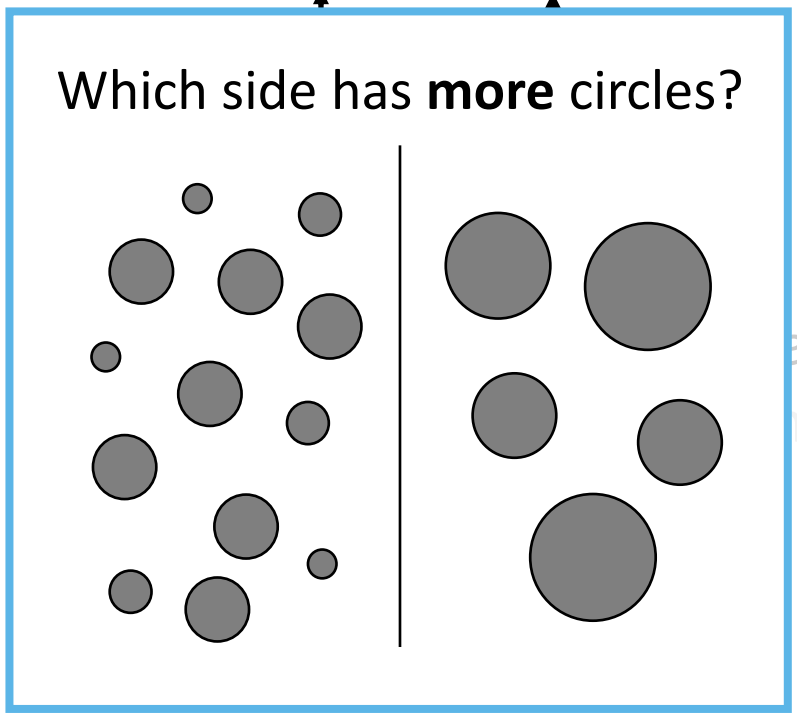

Objects abstracted away from **summary statistics** encoded

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

(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

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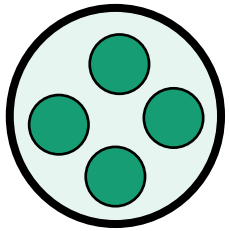

take on ≥1 value at a time

Objects abstracted away from **summary statistics** encoded

Ensemble$_1$

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Cardinality: 4
Avg. Size:

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

CIRCLES: ∀x[Green(x)] ≈The individual circles$_x$ are s.t. each one$_x$ is green

take on only 1 value at a time

Objects individuated **individual properties** encoded

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

Different representations & cognitive systems

This representational distinction isn't the whole story

e.g., Distributivity

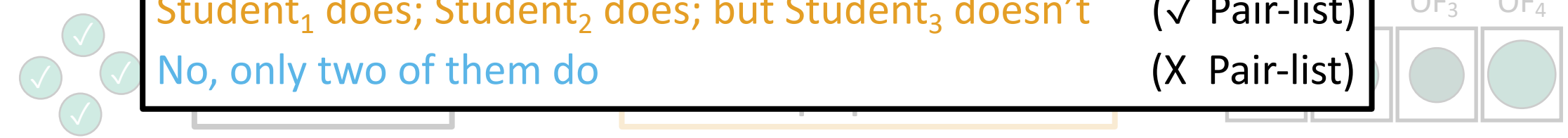
*each student {gathered/surrounded the teacher/is similar}

?every student {gathered/surrounded the teacher/is similar}

Determine whether {each / every} student has a copy of Aspects

Student$_1$ does; Student$_2$ does; but Student$_3$ doesn't (✓ Pair-list)

No, only two of them do (X Pair-list)



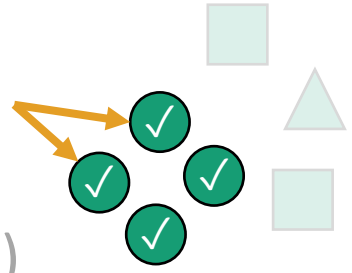
(e.g., Vendler 1962; Williams 1986; Dowty 1987; Gil 1995; Beghelli & Stowell 1997; Beghelli 1997; Tunstall 1998; Winter 2002; Szabolcsi 2010; Champollion 2017)

Different behavioral predictions

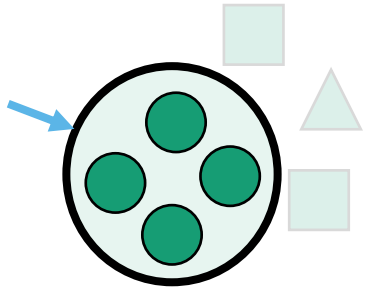
Linking hypothesis: people are biased toward verification strategies that directly compute the relations & operations expressed by the semantic representation under evaluation

First-order (*each*)	**Second-order (*every*)**
CIRCLES: ∀x[Green(x)]	CIRCLES: ∀X[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)



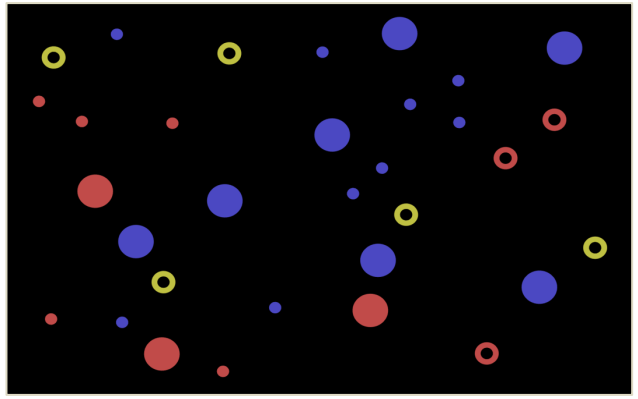
Encode summary statistics (e.g., #)



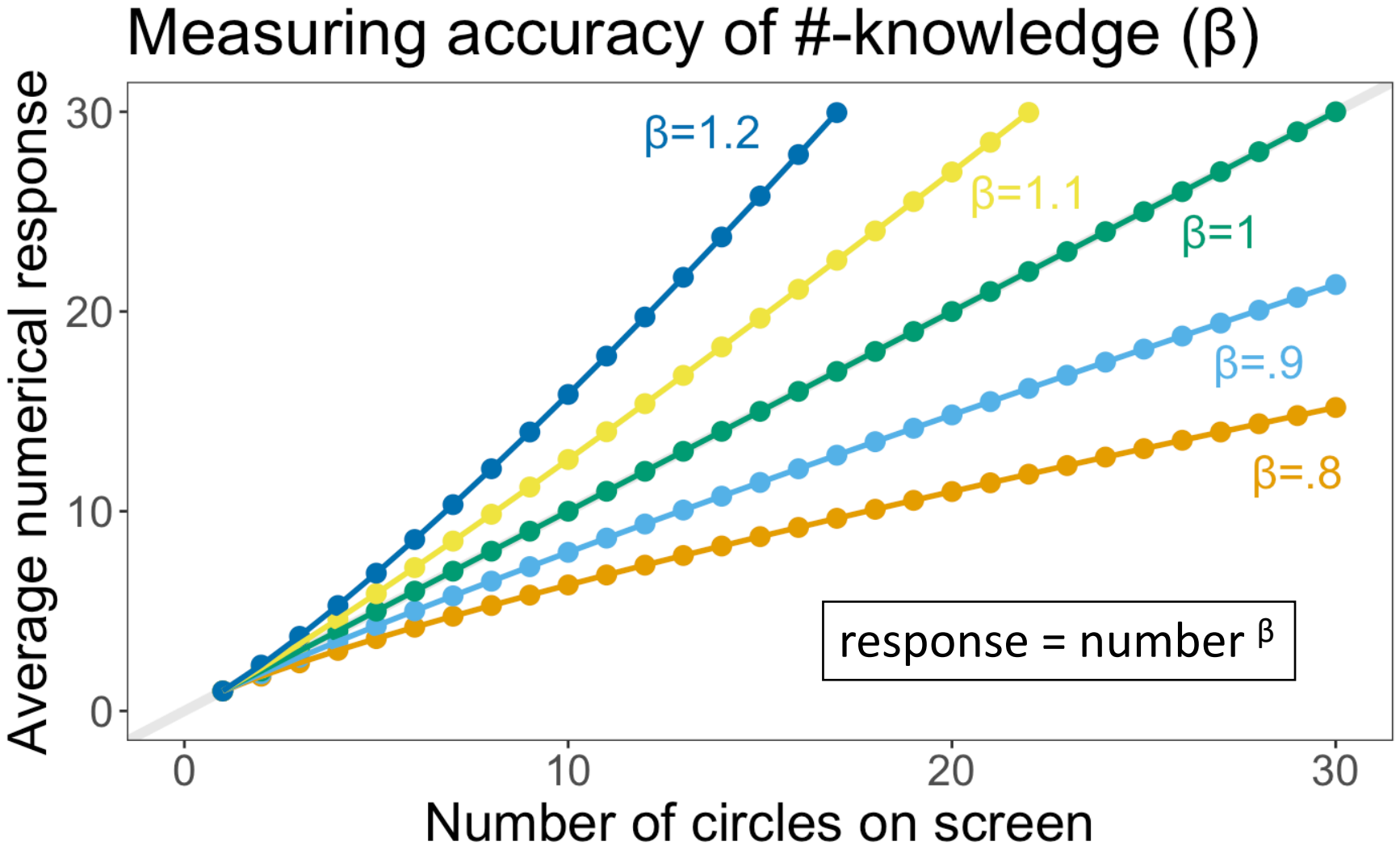
Abstract away from individual properties

{Each/Every} big circle is blue

TRUE FALSE

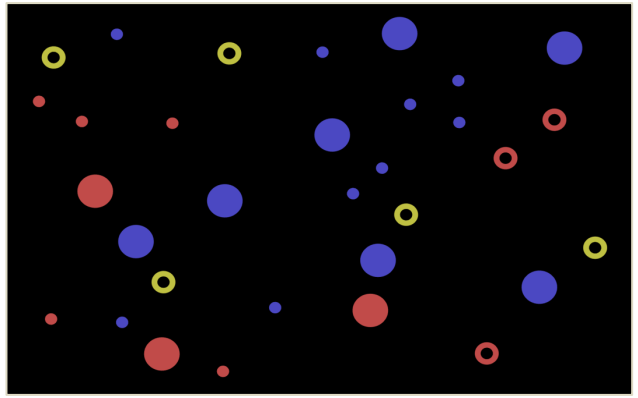


How many {big/medium/small} circles were there?



{Each/Every} big circle is blue

TRUE FALSE



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

#-knowledge accuracy - Bayesian estimates

Each < Every

Each = Every

Cardinality (group property)

target

distractor

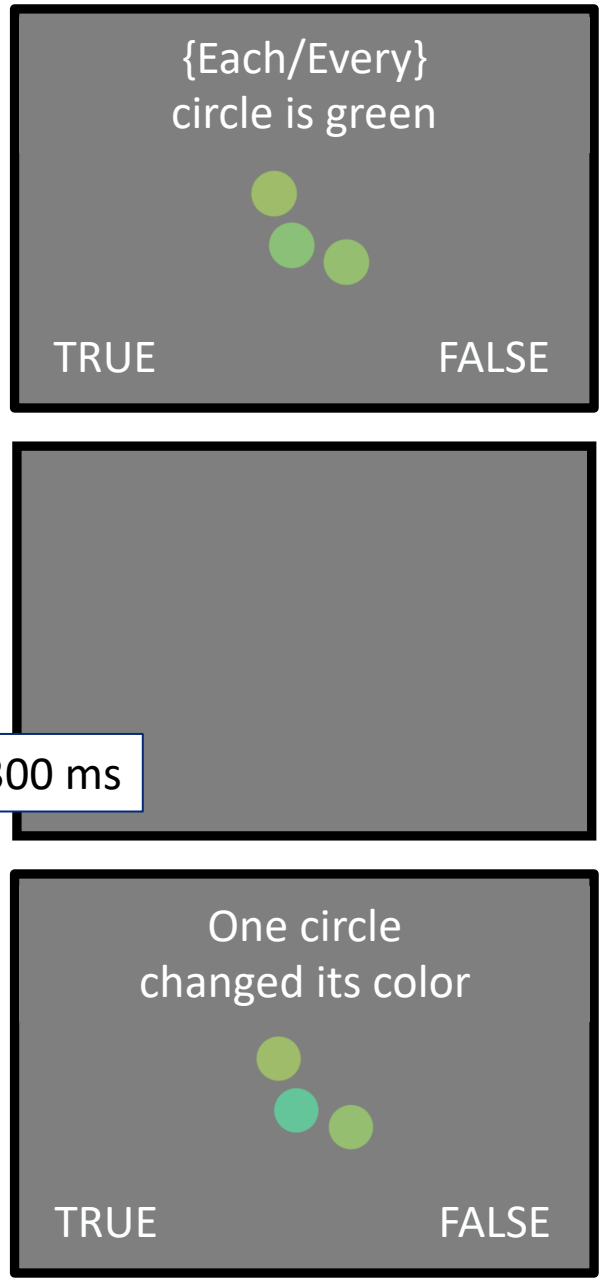
Probability density

15
10
5
0

0.0 0.2 0.4 0.6 0.8

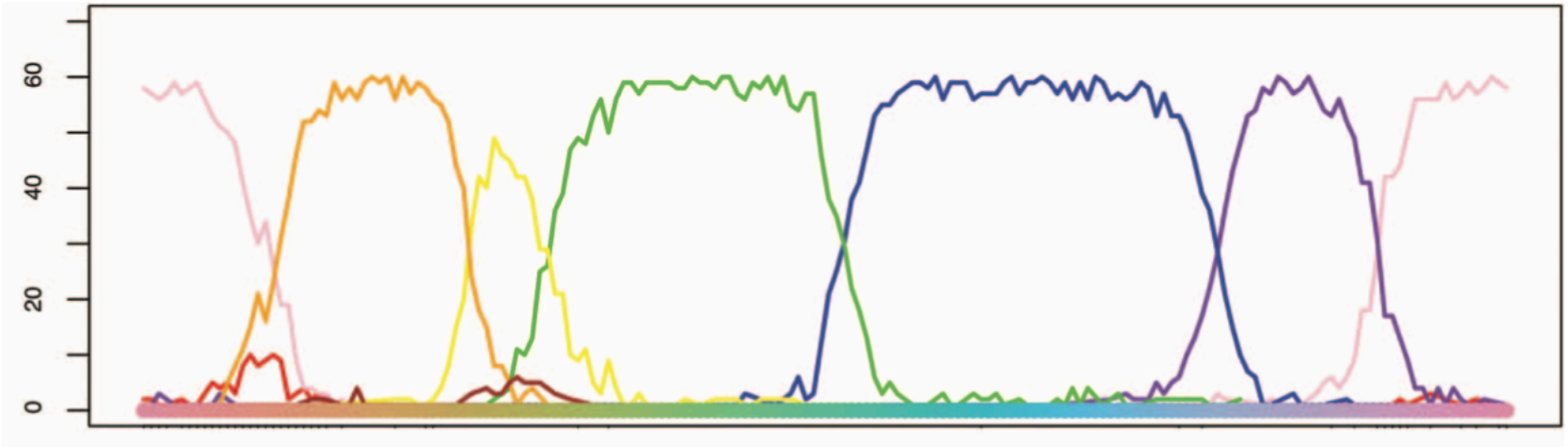
Accuracy parameter (β) estimate

n = 24

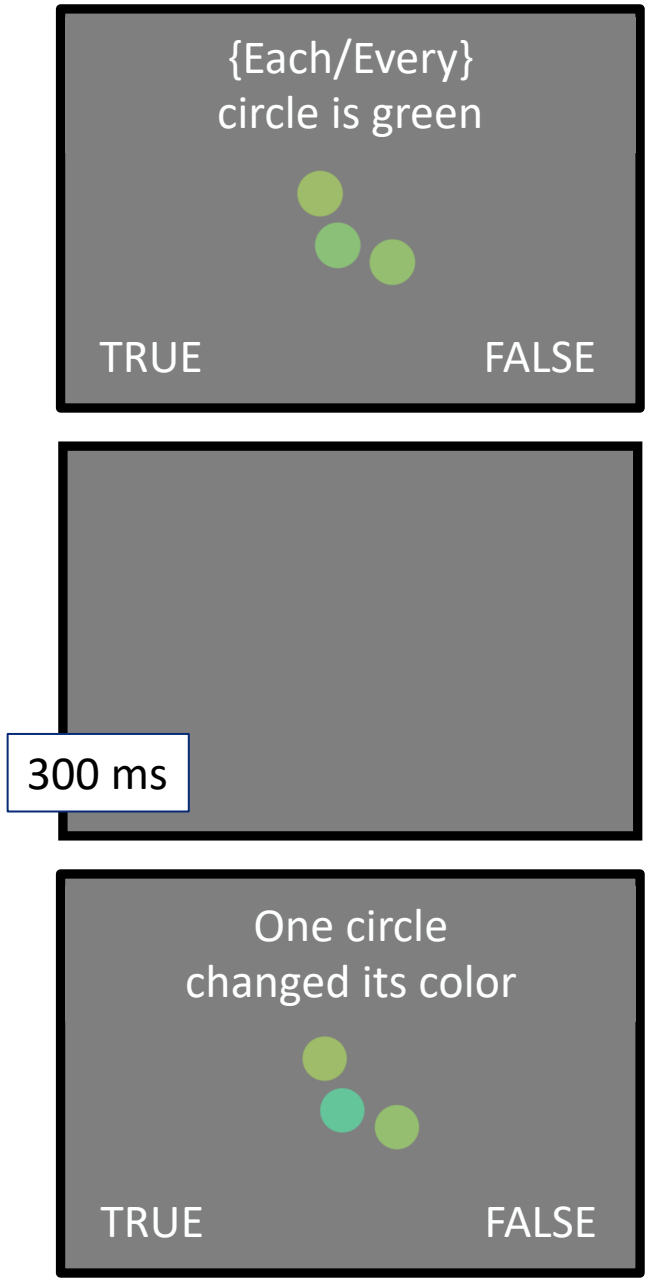


Color (individual property)

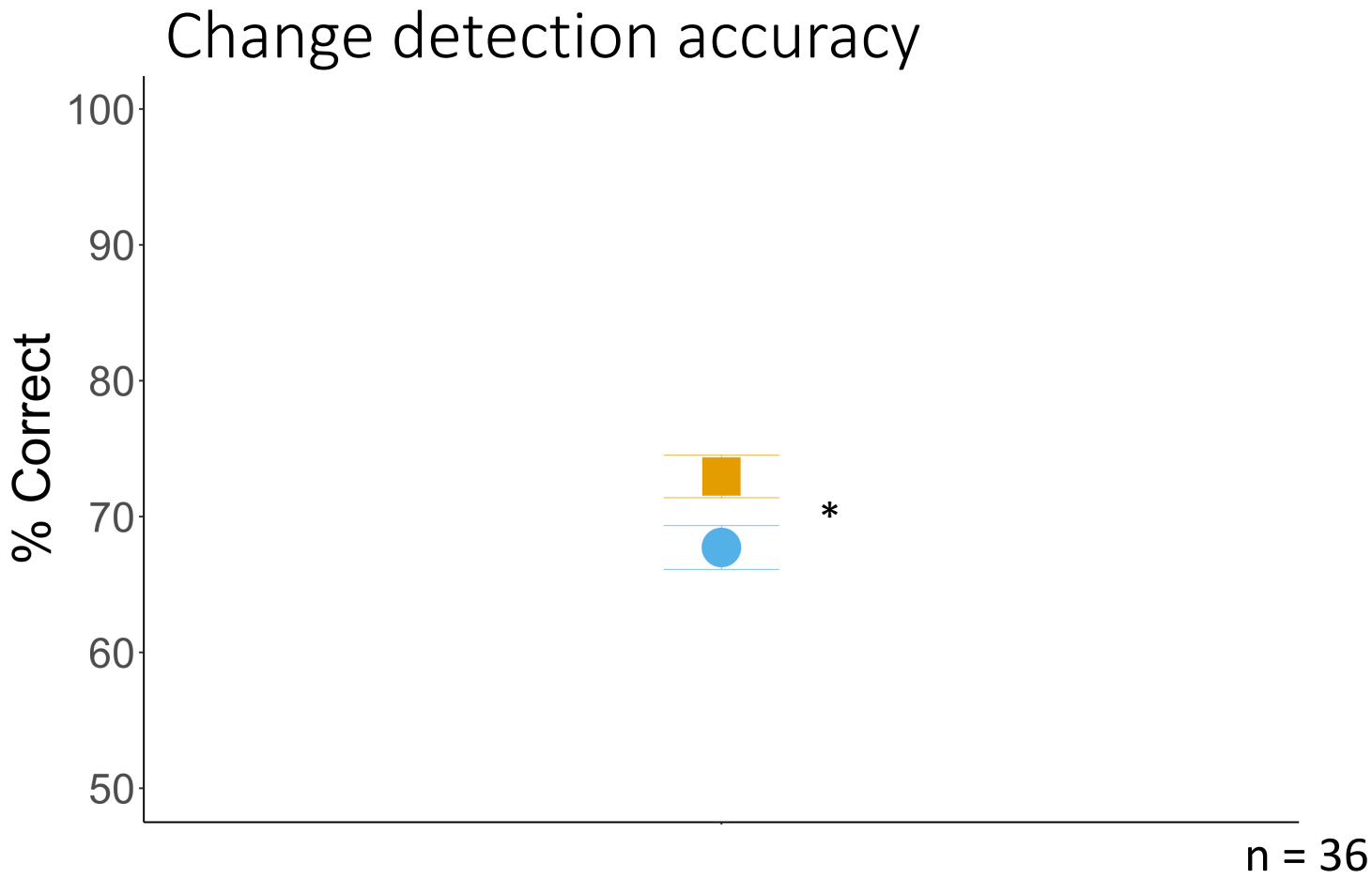
Color category naming task

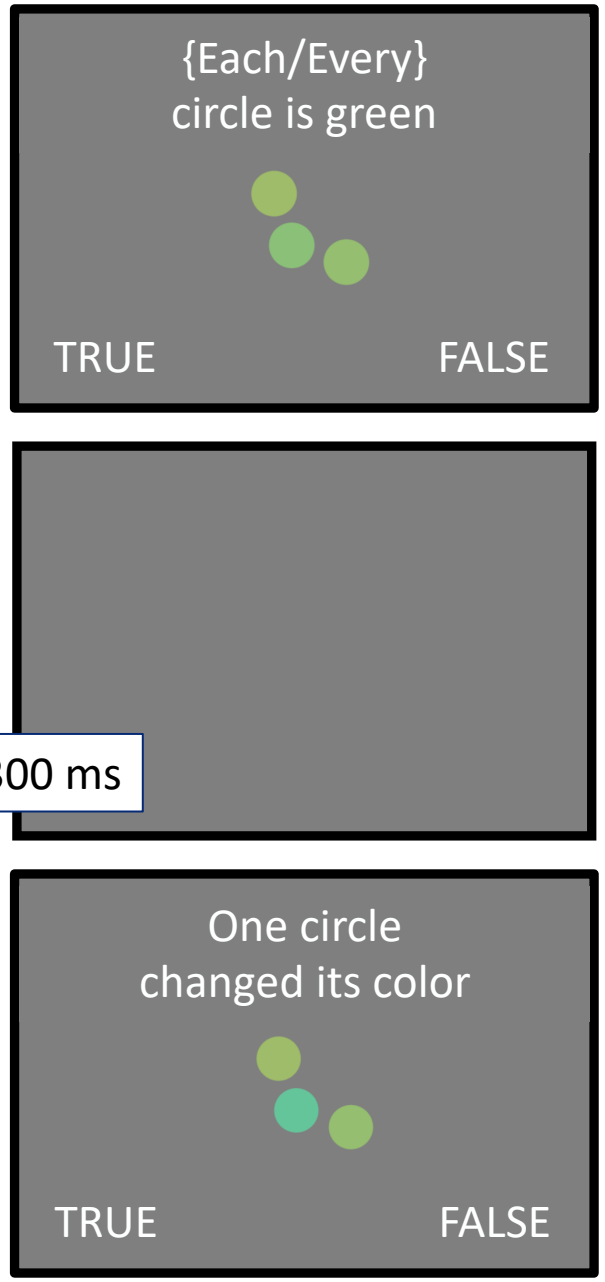


(Bae, Olkkonen, Allred & Flombaum 2015)



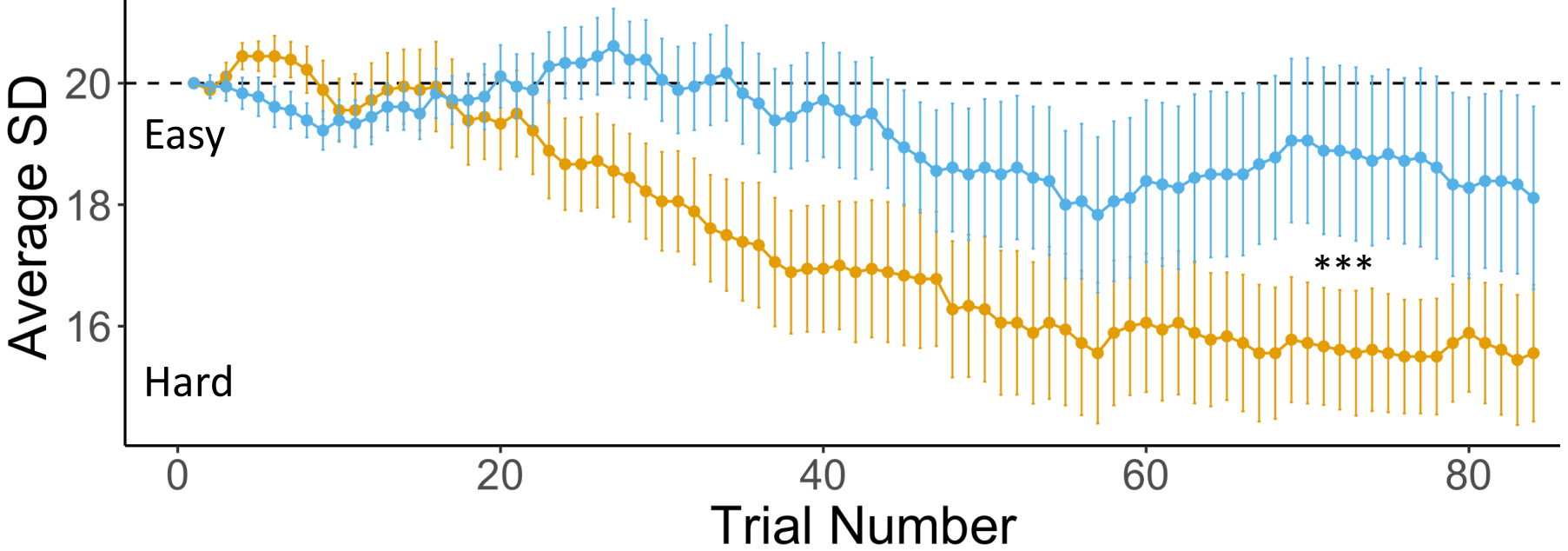
Color (individual property)





Color (individual property)

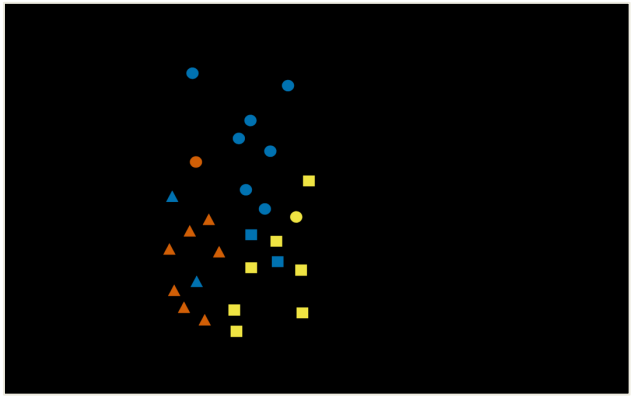
Color change detection: difficulty required for 70% accuracy following *each* or *every*



n = 36

Is {each/every} circle blue?

“Yes” “No”



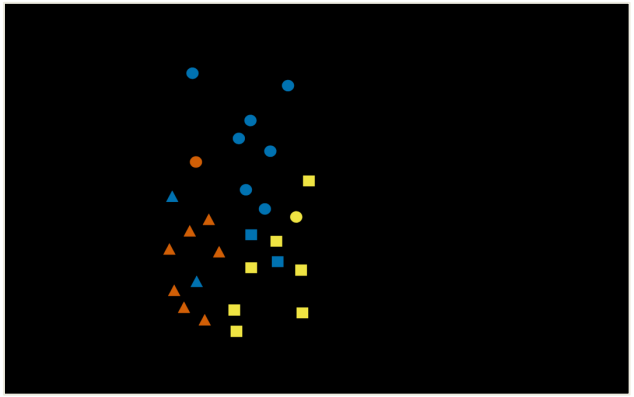
Where was the middle of the circles?

Center of Mass (group property)

How young can we observe the effect?

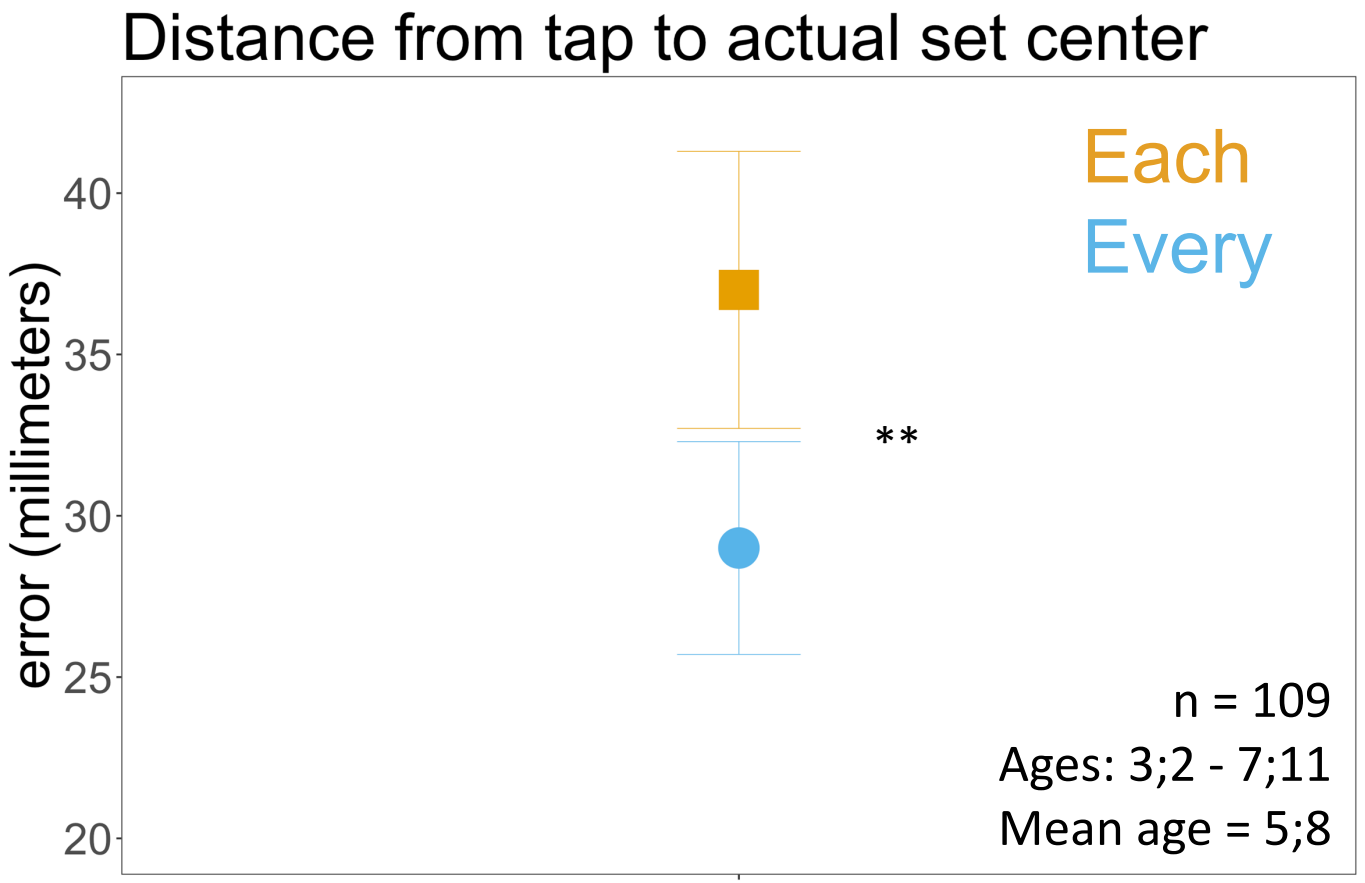
Is {each/every} circle blue?

“Yes” “No”



Where was the middle of the circles?

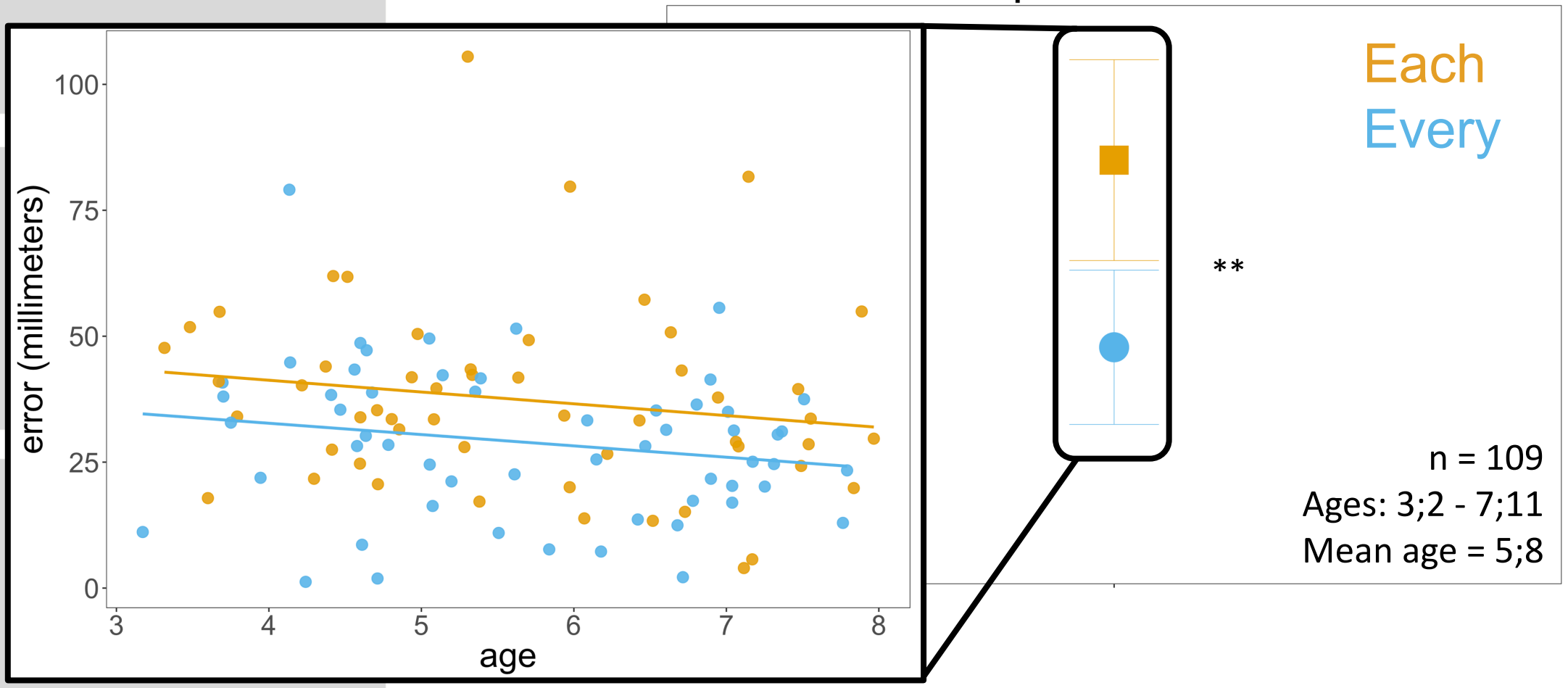
Center of Mass (group property)



Is {each/every} circle blue?

Center of Mass (group property)

Distance from tap to actual set center



How are universal quantifiers mentally represented?

Relational vs. Restricted (*every*)

✓ Number cognition as a probe into which arguments are represented

✓ Explanation of the "conservativity" universal

First- vs. Second-order (*each* vs. *every*)

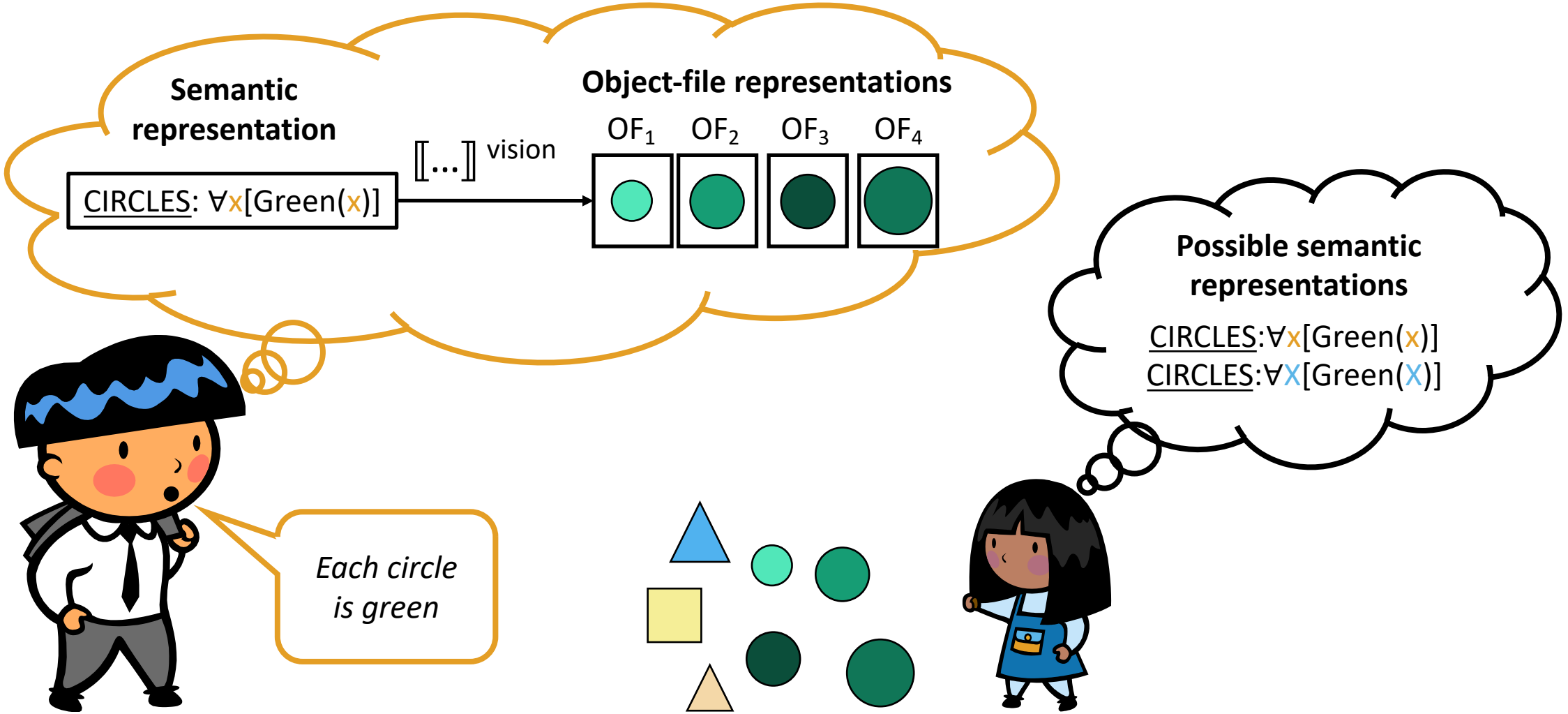
✓ Object-files vs. Ensembles as a probe into how arguments are encoded

Consequences for language acquisition (*each* vs. *every*)

➥ Precursors of quantification in infants

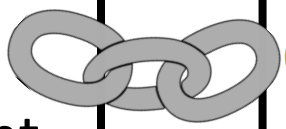
➥ Differences in child-directed speech

Acquiring *each* and *every*



Sketching a learning story for *each* & *every*

Semantic representations?
First-order universal concept
Second-order universal concept



Supporting cognitive systems
Object-file representations
Ensemble representations

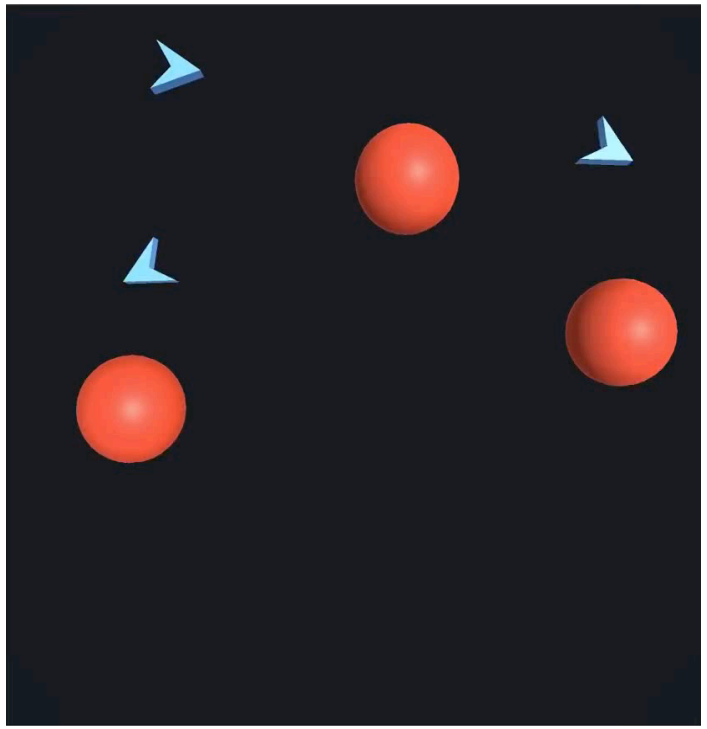
Concepts

(e.g., Xu & Carey 1996; Xu & Spelke 2000; Lipton & Spelke 2003; McCrink & Wynn 2004; Feigenson & Carey 2003, 2005; Cheries et al. 2005; Carey 2009)

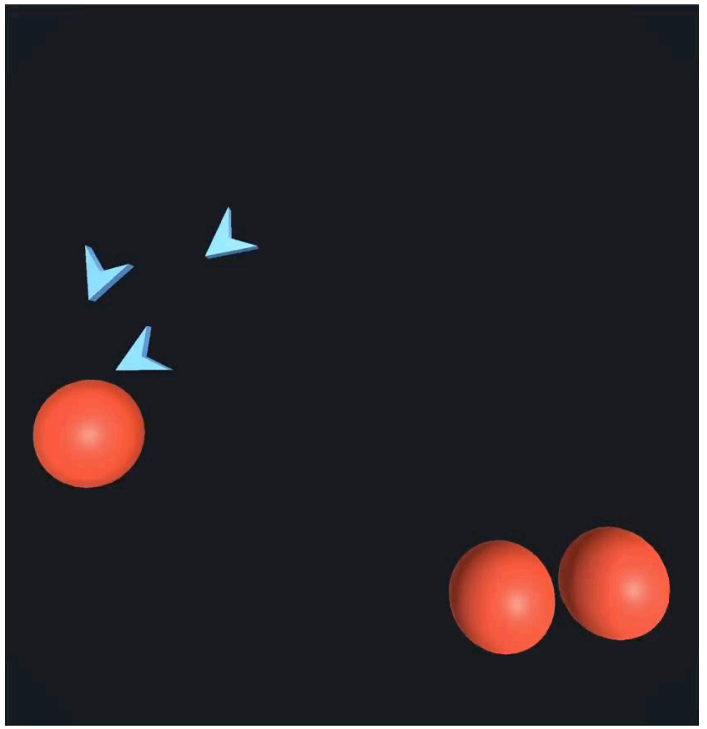
How early are the relevant concepts available?

➤ Exploring precursors of quantificational thought in 10-month-olds

Individual-chasing



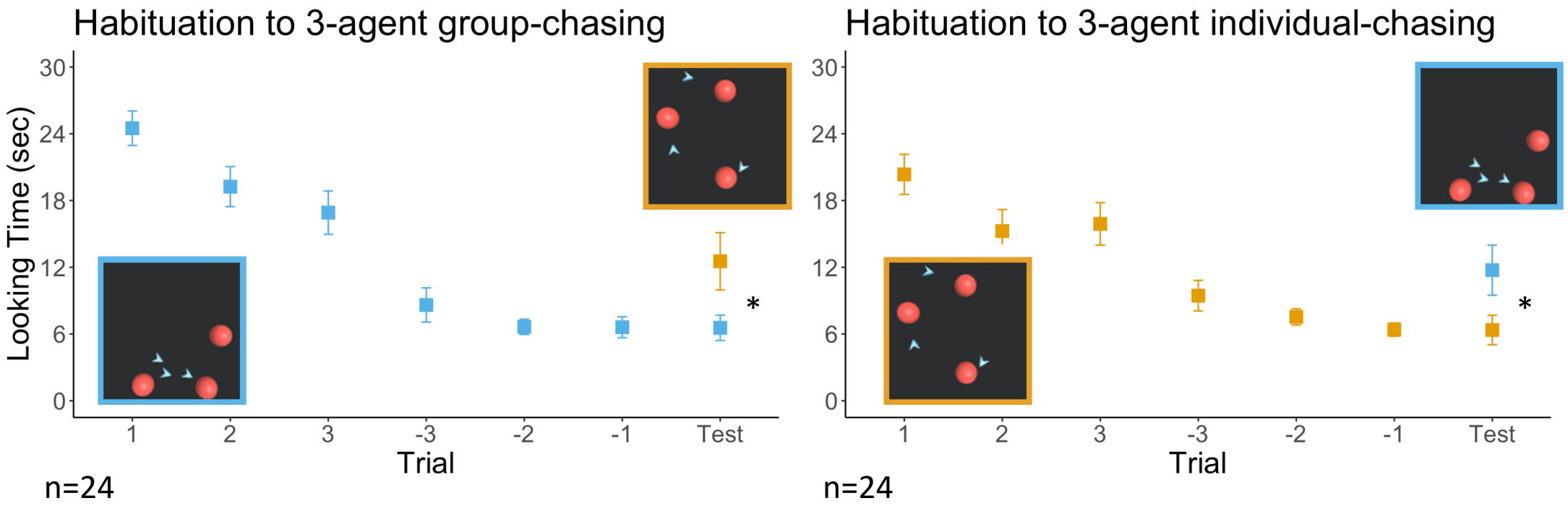
Group-chasing



(Cesana-Arlotti, Knowlton, Halberda & Lidz *in prep*)

How early are the relevant concepts available?

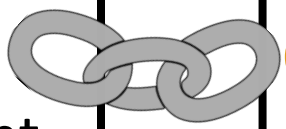
➤ 10-month-olds differentiate group- and individual-chasing events



(Cesana-Arlotti, Knowlton, Halberda & Lidz *in prep*)

Sketching a learning story for *each* & *every*

Semantic representations
First-order universal concept
Second-order universal concept



Supporting cognitive systems
Object-file representations
Ensemble representations

Concepts

?

Intake

Each and *every* in child-directed speech

➥ Could the pair-list asymmetry signal a difference? (*each*: ✓ PL; *every*: X PL)

Out of over 1.7 million utterances:

WH-question & *each*: 11

With possible PL-responses: 1

Dad: What do you think each animal is about to do?

Child (3;04): Clean up that mess

WH-question & *every*: 19

With possible PL-responses: 1

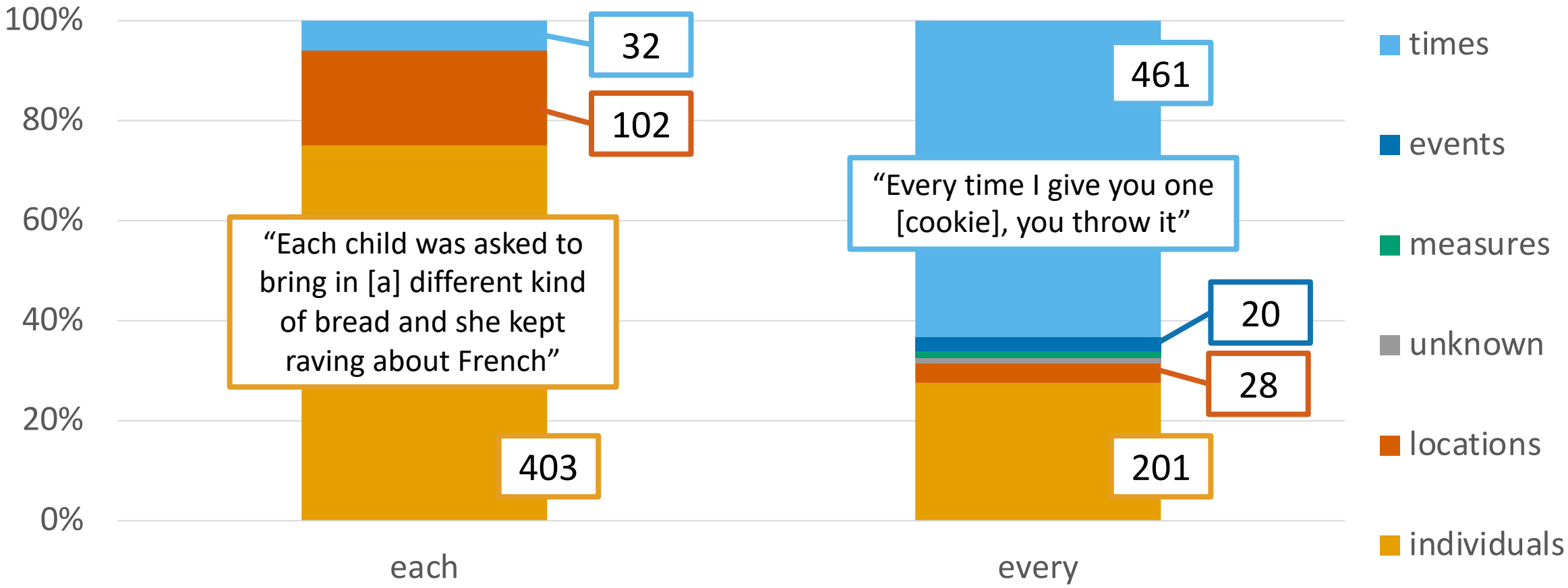
Mom: What did you play every day while you were there?

Child (4;11): …the water game

(Knowlton & Lidz *forthcoming*)

Each and *every* in child-directed speech

What's being quantified over?



(Knowlton & Lidz *forthcoming*)

Each and *every* in child-directed speech

Low-level differences, including:

- ➤ Quantifying over individuals vs. times
- ➤ Being in argument vs. adjunct position
- ➤ Relative clause modification: rarely vs. sometimes

"You have to ring up each thing"
"Could you put a flower on each plate?"
"Put sugar in each coffee"
"We'll put one finger on each thing we count"
"We each have three"

Generalize over local domain

"Every time I ask a question, you say you don't know"
"Every time I see ya, ya got something in your mouth"
"You turn into a wild man every time we get out"
"Your birthday's always at the same time every year"
"She watches every movie they make"

Project beyond local domain

(Knowlton & Lidz *forthcoming*)

Projecting beyond the local domain

After a lifetime of investigation, Suzie came to a striking discovery:

{#Each / Every} language has over 20 color words

Suzie just discovered 4 new languages and interestingly,

{Each / #Every} language has over 20 color words

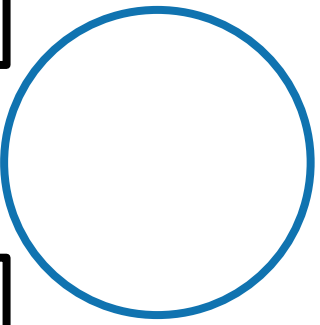
(Beghelli & Stowell 1997)

Sketching a learning story for *each* & *every*

Semantic representations
First-order universal concept
Second-order universal concept

Supporting cognitive systems
Object-file representations
Ensemble representations

Concepts



Intake

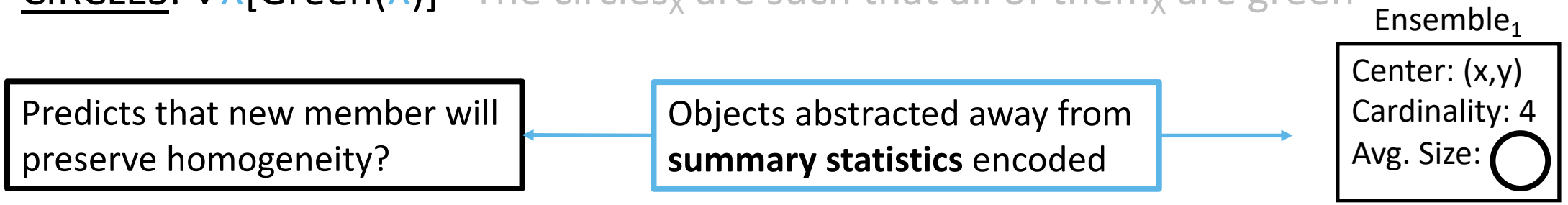
Surface level differences
e.g., Quantify over individuals
e.g., Quantify over times

Intended speaker meaning
Generalize over local domain
Project beyond local domain

Projecting beyond the local domain

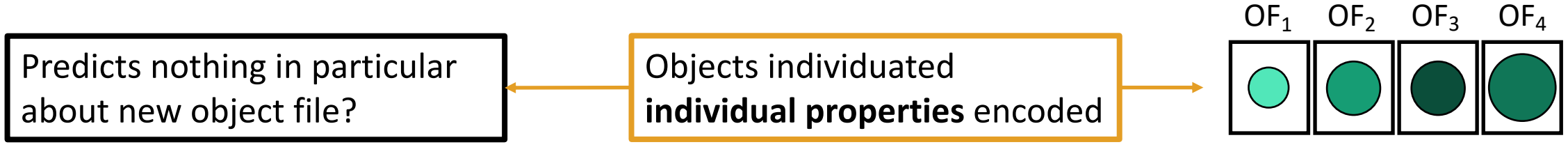
Second-order representations (*every*) rely on ensembles

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

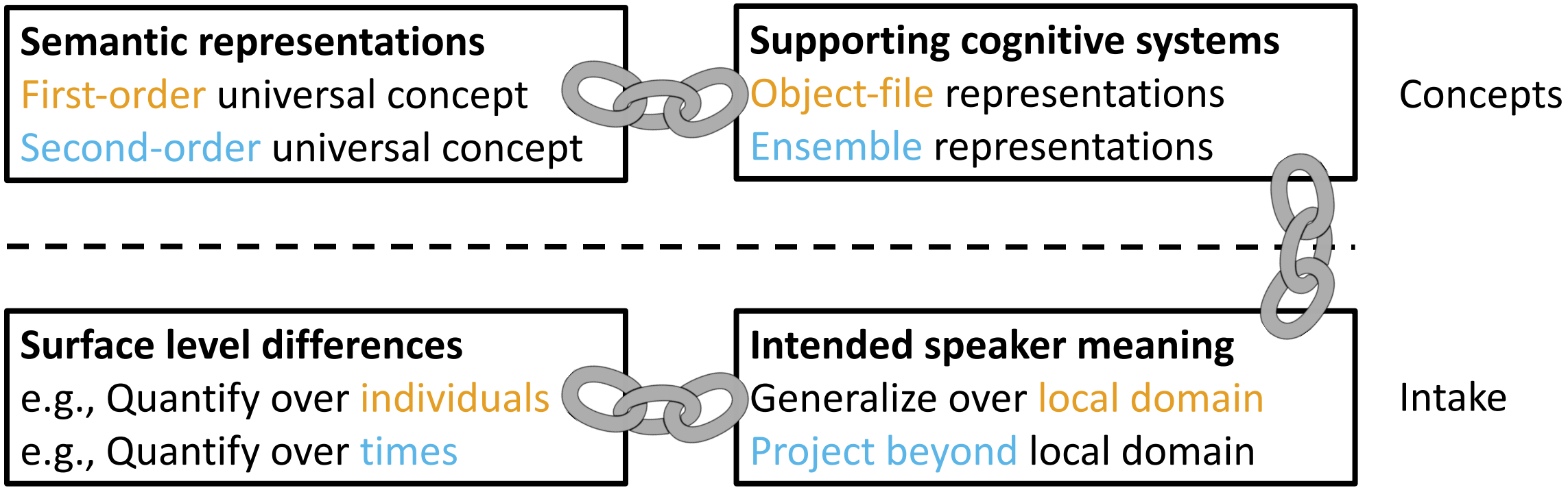


First-order representations (*each*) rely on object-files

CIRCLES: ∀x[Green(x)] ≈The individual circles$_x$ are s.t. each one$_x$ is green



Sketching a learning story for *each* & *every*



For each individual$_x$, if it$_x$ is a circle, it$_x$ is green

UNIVERSE: ∀x[Circle(x) → Green(x)]

Restricted quantification:
➥ Only 1st argument represented
➥ Explains "conservativity"

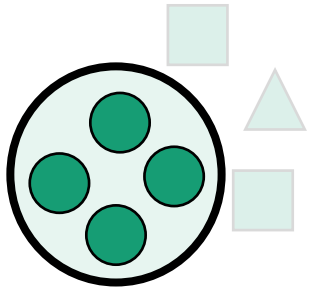
First vs. Second-order:
➥ Encode individuals vs. groups
➥ Consequences for acquisition

Unrestricted First-order

Unrestricted Second-order

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

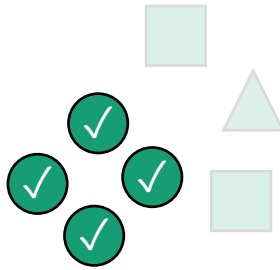
CIRCLES: ∀X[Green(X)]



Restricted Second-order

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

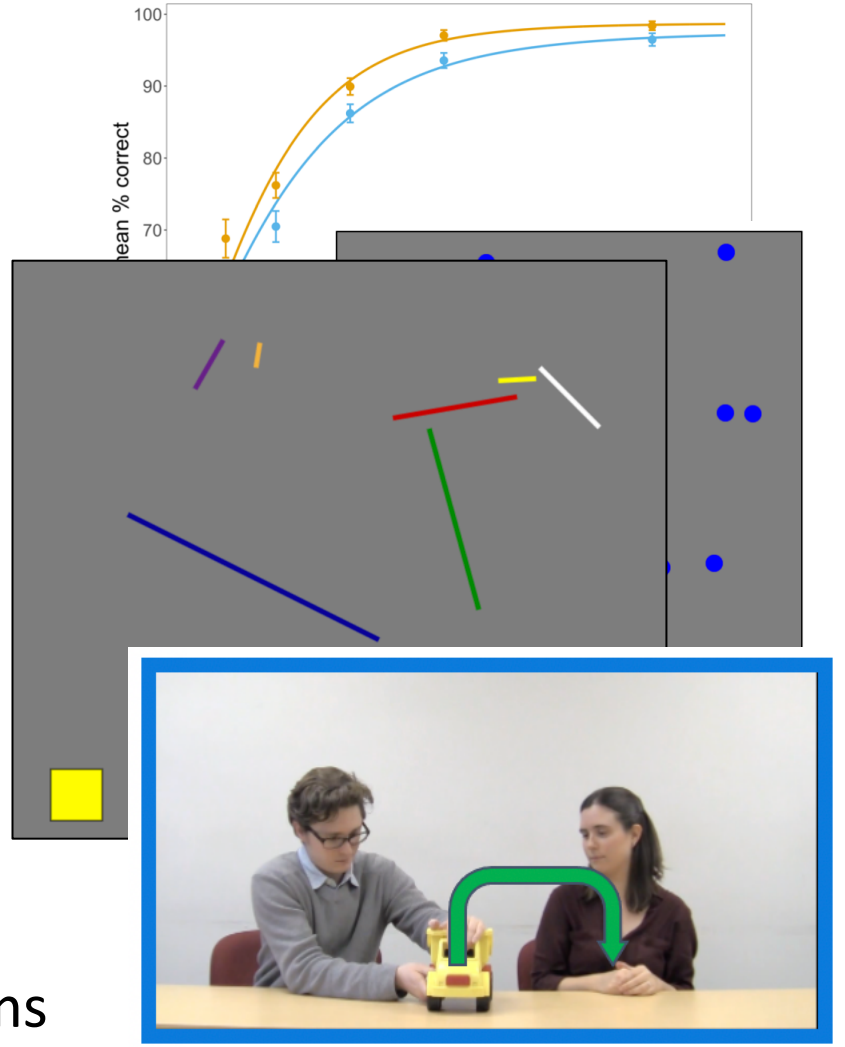
CIRCLES: ∀x[Green(x)]



Restricted First-order

What do semantic representations look like?

- ➤ *More* vs. *Most* in English and Cantonese
- ➤ Superlatives in language and cognition
- ➤ Event concepts and verb learning
- ➤ Anytime we have:
  - ➥ Specifications of competing representations
  - ➥ Understanding of the supporting cognitive systems



Thanks!

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

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