

How do children interpret number words before learning their exact meanings?

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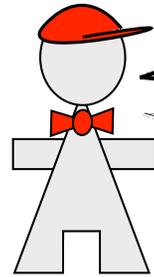


giving N



not giving N

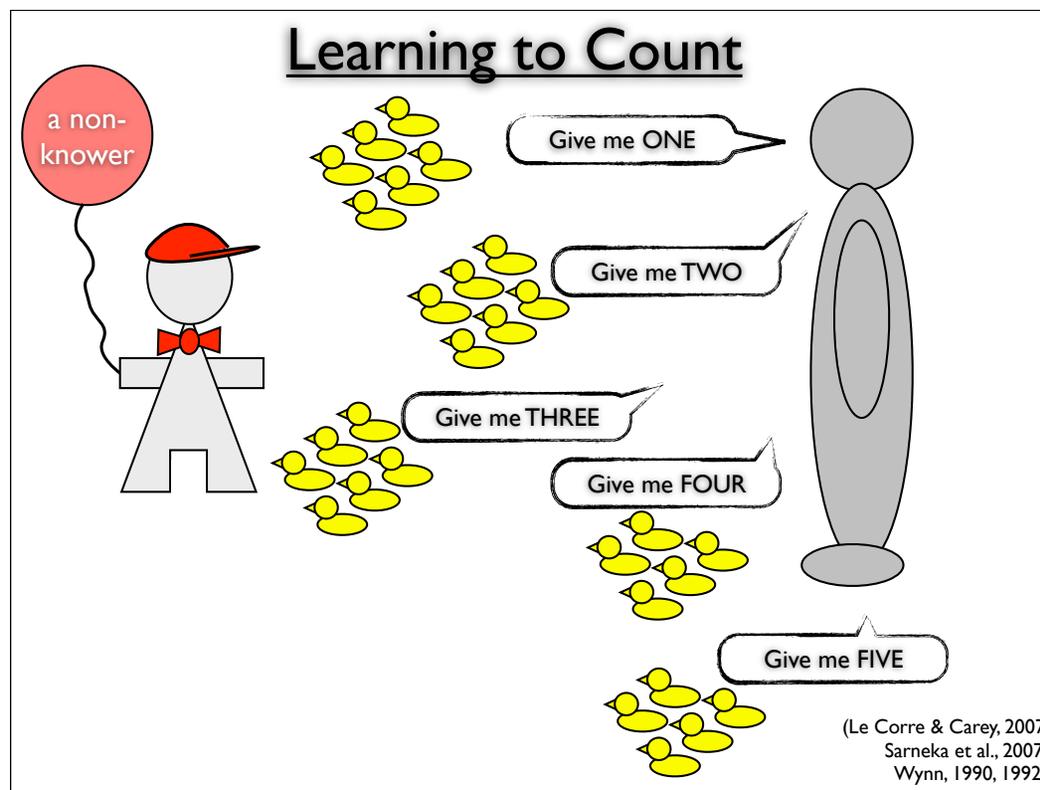
Learning to Count



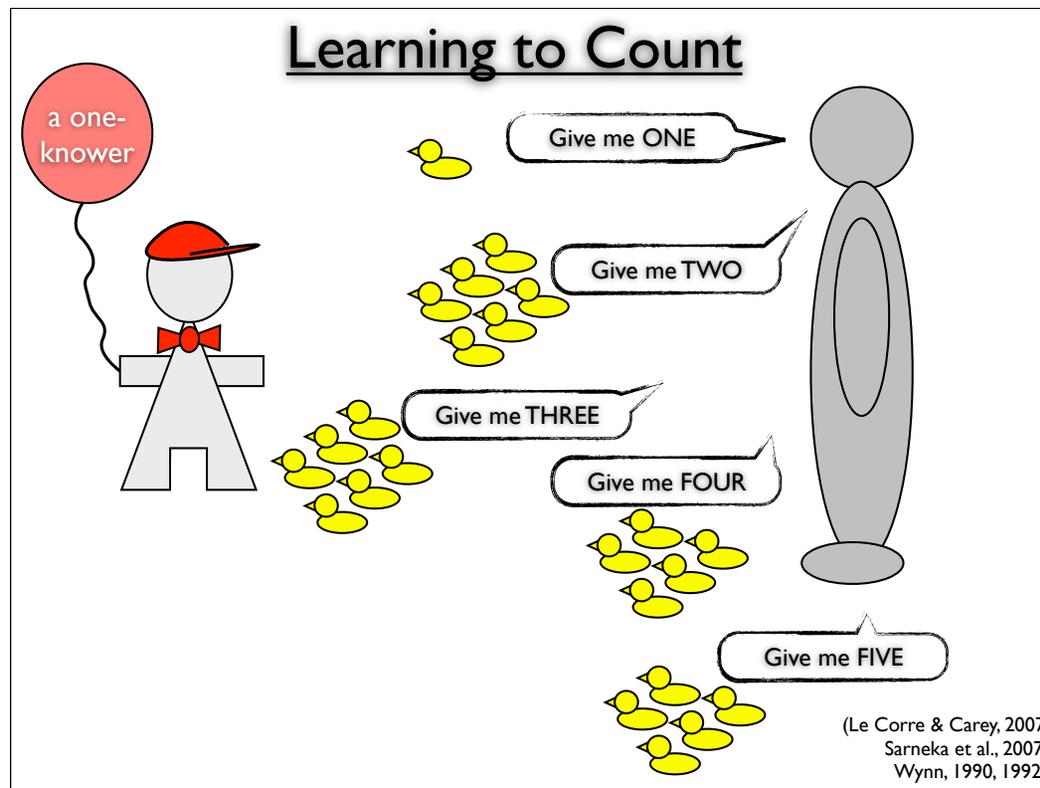
one, two, three, four, five, six...

one, two, four, five, six...

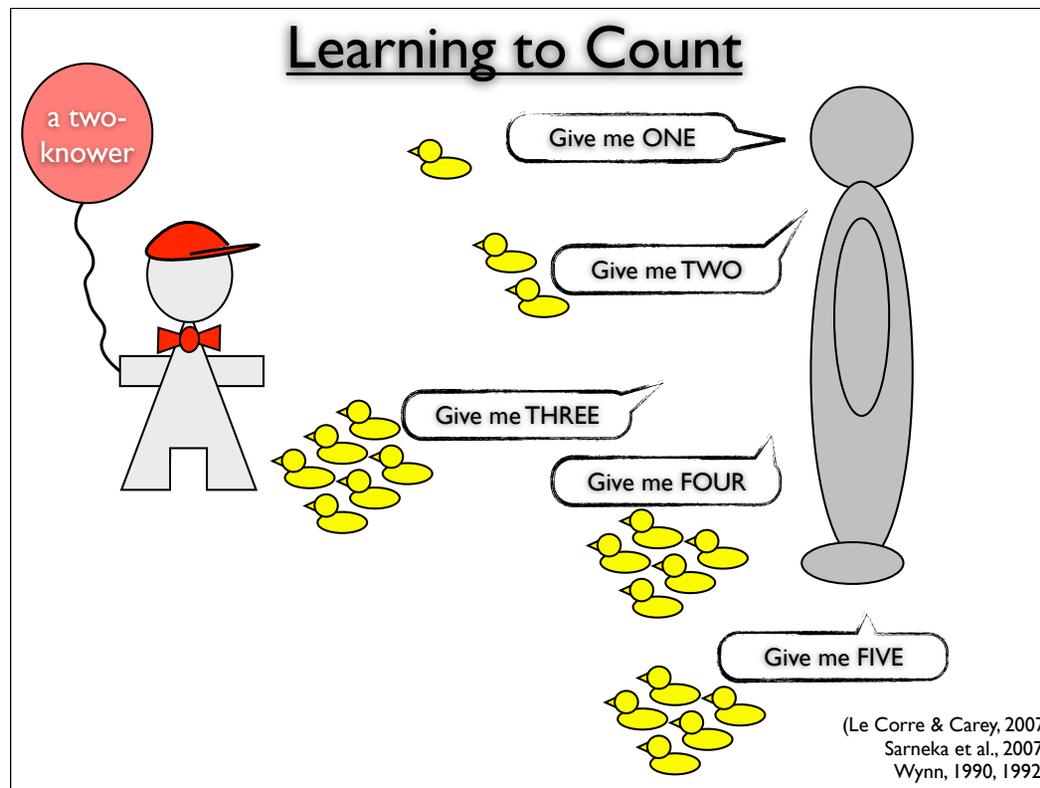
A curious thing happens when children learn to count. For over a year, and beginning when they are 2 years of age, they produce and use number words despite apparently not knowing what many of the words mean. These words often and especially appear in counting routines [space] -- usually correctly but sometimes with errors [space] -- but are also used in other contexts.



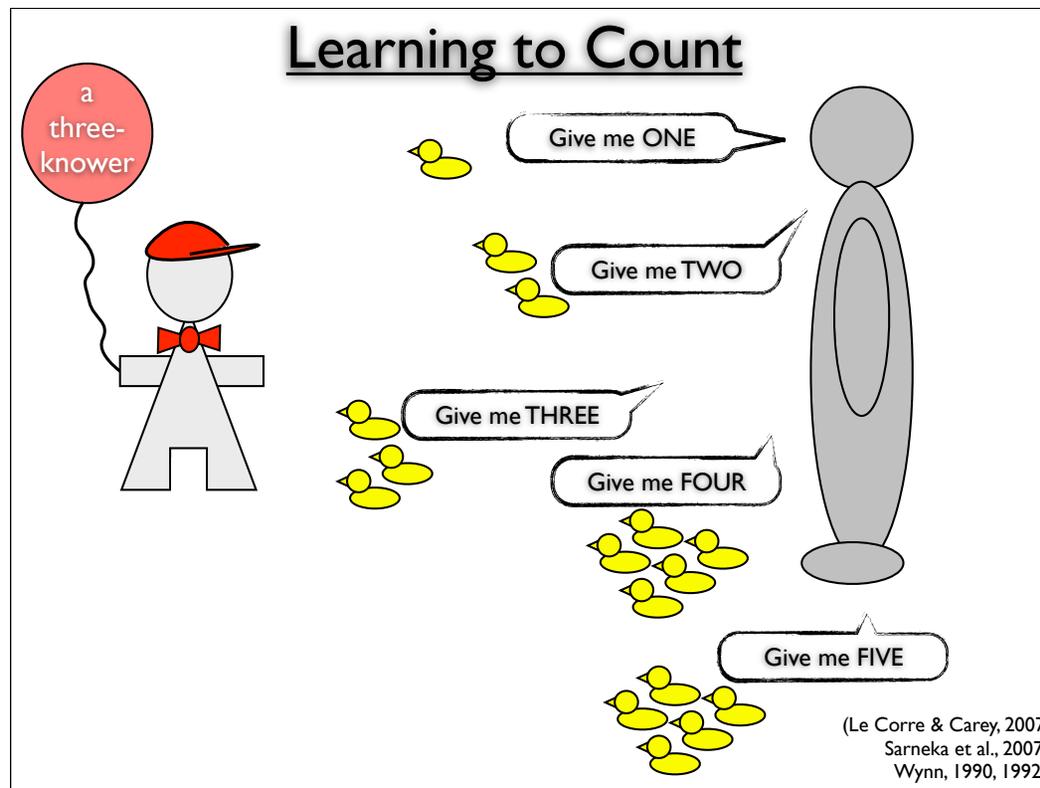
in the 1st stage the children go through, they don't appear to reliably map any number words onto any particular quantity. For reasons that will become clear momentarily, these children are called non-knowers. [Space] so if such a child has a pile of rubber duckies, and you ask her to [space] give you one rubber ducky, she will typically give you a handful [Space]. The number that she gives you is not reliably different from the number she gives you if you ask for two rubber duckies [space], 3 rubber duckies [space], 4 rubber duckies [space], 5 rubber duckies [space], or any other number. This isn't a problem particular to this give-a-number task, and shows up in many other tasks, such as if a child is asked how many rubber duckies are in a pile.



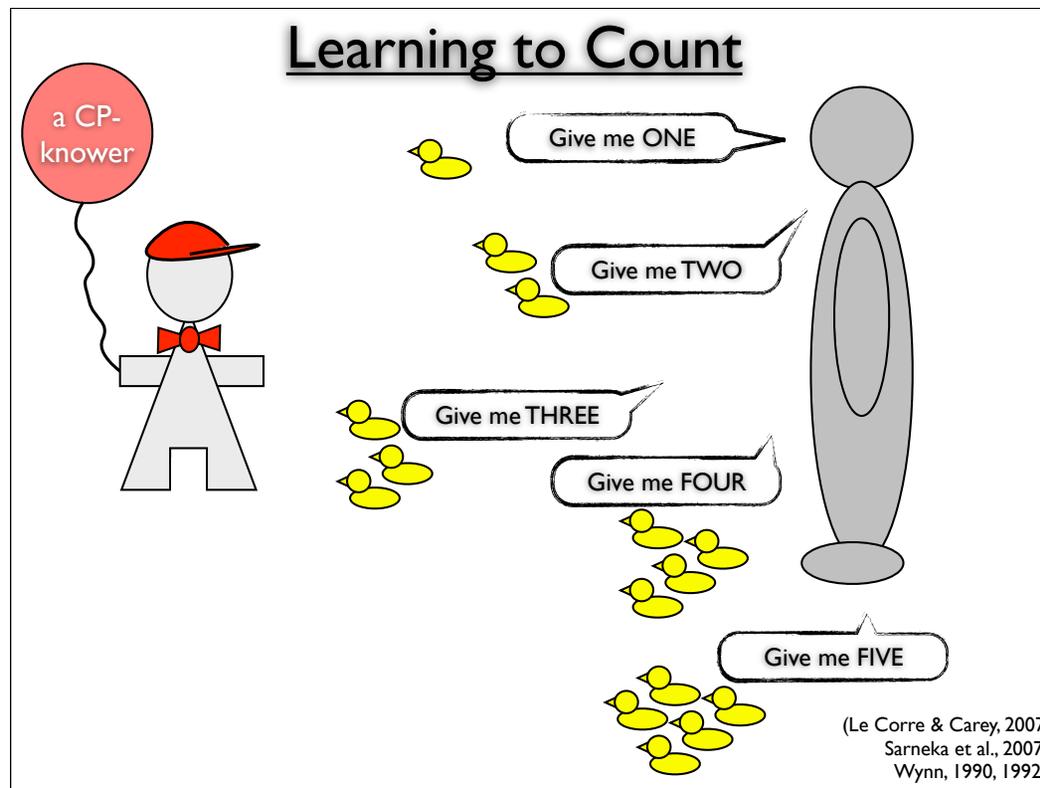
The next stage is the one-knower. She gives one rubber ducky if you ask for one rubber ducky, but does not reliably distinguish between the other numbers -- other than that she doesn't give one for any of them`.



After a few months, she will graduate to being a 2-knower, reliably mapping “1” onto one, and “2” on to two, but failing for the larger numbers.

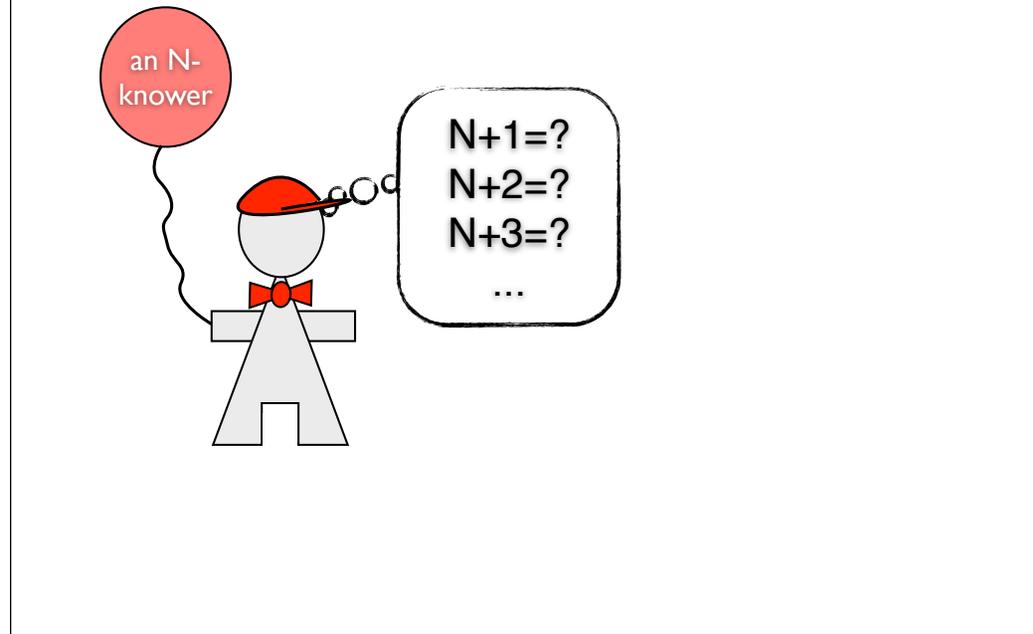


After a few more months, she will become a 3-knower.



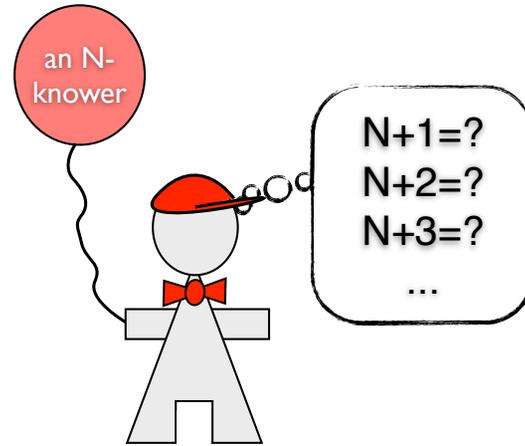
You sometimes encounter 4-knowers, but most often children who succeed at giving four also succeed at giving five, six, and any other number as high as they can count. and one interesting fact about these children, is that they are much more likely than children in the earlier stages to explicitly use counting to solve this and related tasks. When asked to give four rubber duckies, they will count out one, two, three, four rubber duckies. Whereas with children in the earlier stages, if you ask them for four duckies and prompt them to use counting, they don't do so successfully. They may count "one, two", stop, and seem satisfied with the outcome. Children who succeed at larger numbers and use counting reliably are typically named "cardinal principle knowers" or "CP-knowers".

What does an N-knower think numbers $>N$ mean?



There has been a great deal of work over the last 40 years investigating how children go from being non-knowers to CP-knowers. Much of this has focused on how children interpret the numerals that they have acquired. I will be focusing on a complementary question: [click] what do they think the numerals they *haven't* yet acquired mean? [pause] Before discussing that question, I want to address a question that, for this talk, is logically primary: that is, what can we learn from the answer to this question?

Why does it matter what an N-knower thinks numbers $>N$ mean?



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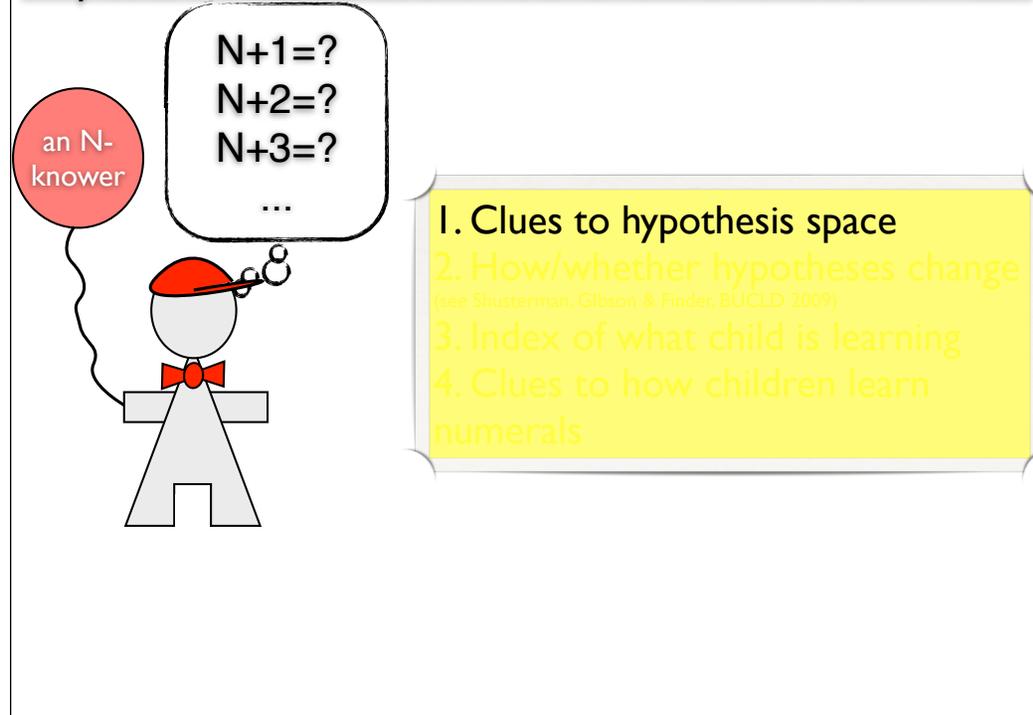
an N-knower

$N+1=?$
 $N+2=?$
 $N+3=?$
...

1. Clues to hypothesis space
2. How/whether hypotheses change
(see Shusterman, Gibson & Finder, BUCLD 2009)
3. Index of what child is learning
4. Clues to how children learn numerals

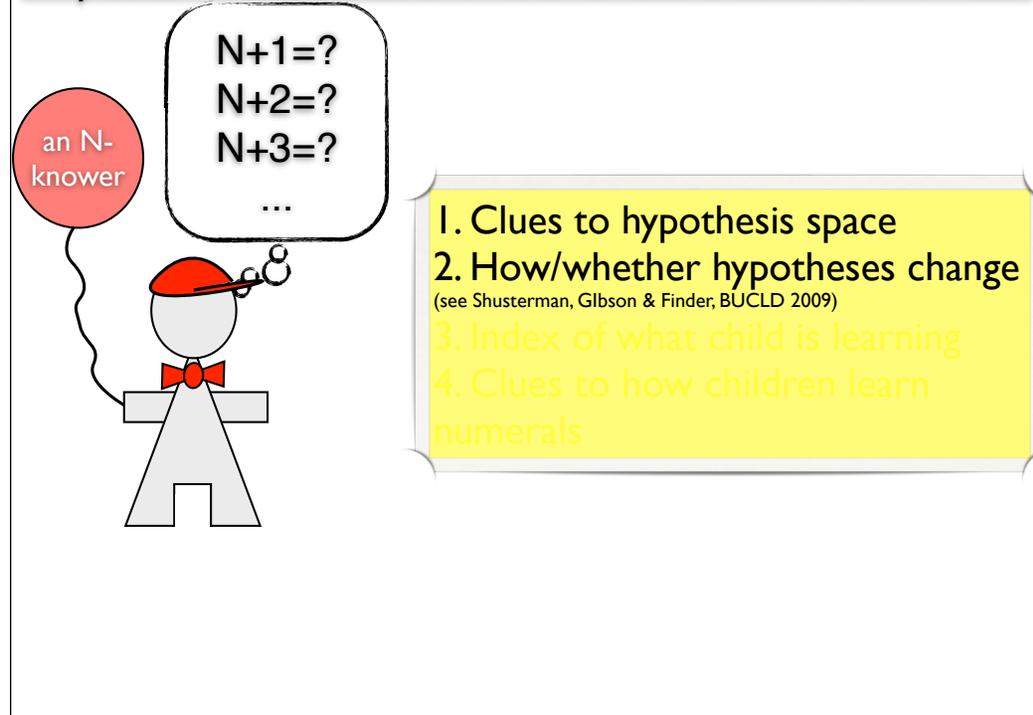
There are at least a few things.

Why does it matter what an N-knower thinks numbers $>N$ mean?



First, understanding what children think these words mean gives us insight into the hypothesis space they are entertaining. Do they have any priors, and if so, what?

Why does it matter what an N-knower thinks numbers $>N$ mean?



Second, it may be the case that children's hypotheses about these un-acquired numerals changes over time; understanding this will give us additional insight into the learning process. For instance, two years ago at this conference Shusterman and colleagues argued that one-knowers go through a brief period where they hypothesize that "two" means "a pair", before retreating to the pattern I described at the beginning of this talk. These and analogous changes are highly relevant to our theory of numeral acquisition.

Why does it matter what an N-knower thinks numbers $>N$ mean?

an N-knower

$N+1=?$
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4. Clues to how children learn numerals

A corollary of that last point is that this will help us establish what the child is learning -- or thinks she is learning -- about numerals in general.

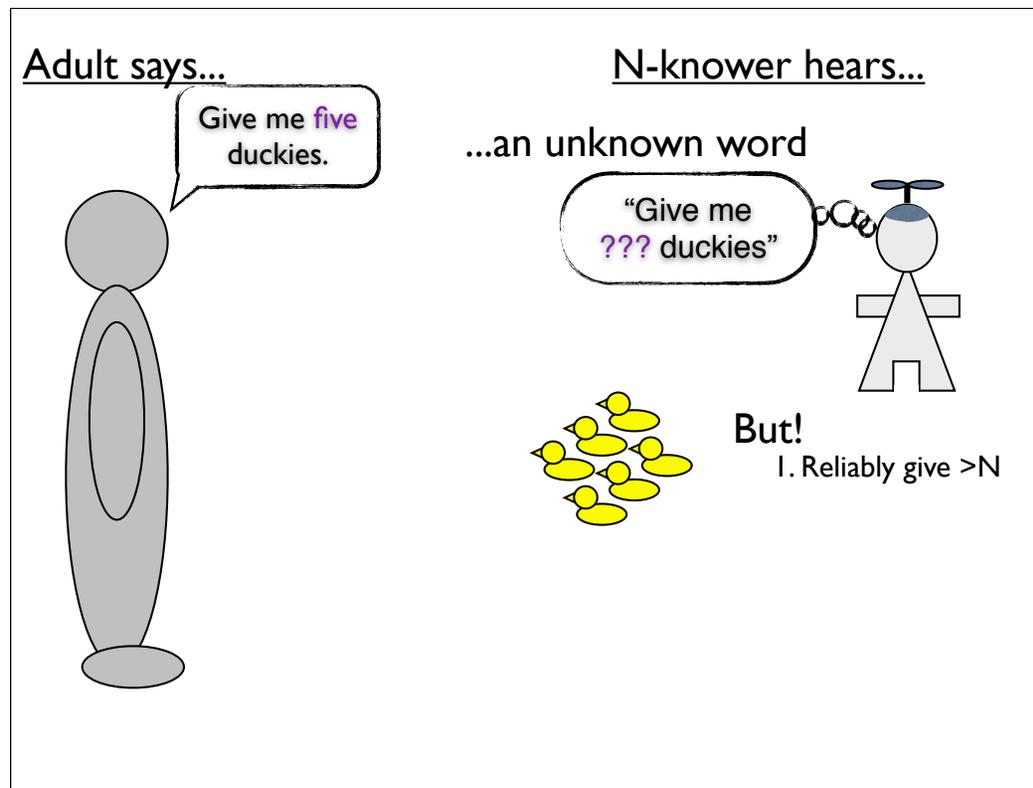
Why does it matter what an N-knower thinks numbers $>N$ mean?

an N-knower

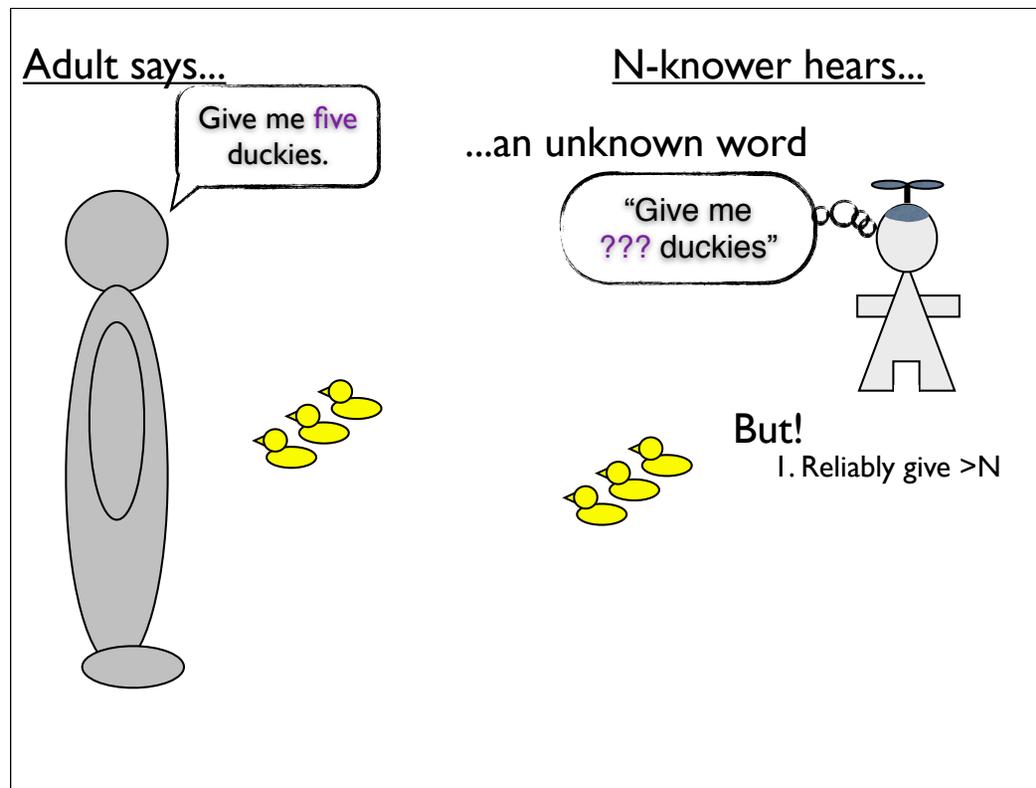
$N+1=?$
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...

1. Clues to hypothesis space
2. How/whether hypotheses change
(see Shusterman, Gibson & Funder, BUCLD 2009)
3. Index of what child is learning
⇒ Informing theory of how children achieve adult state

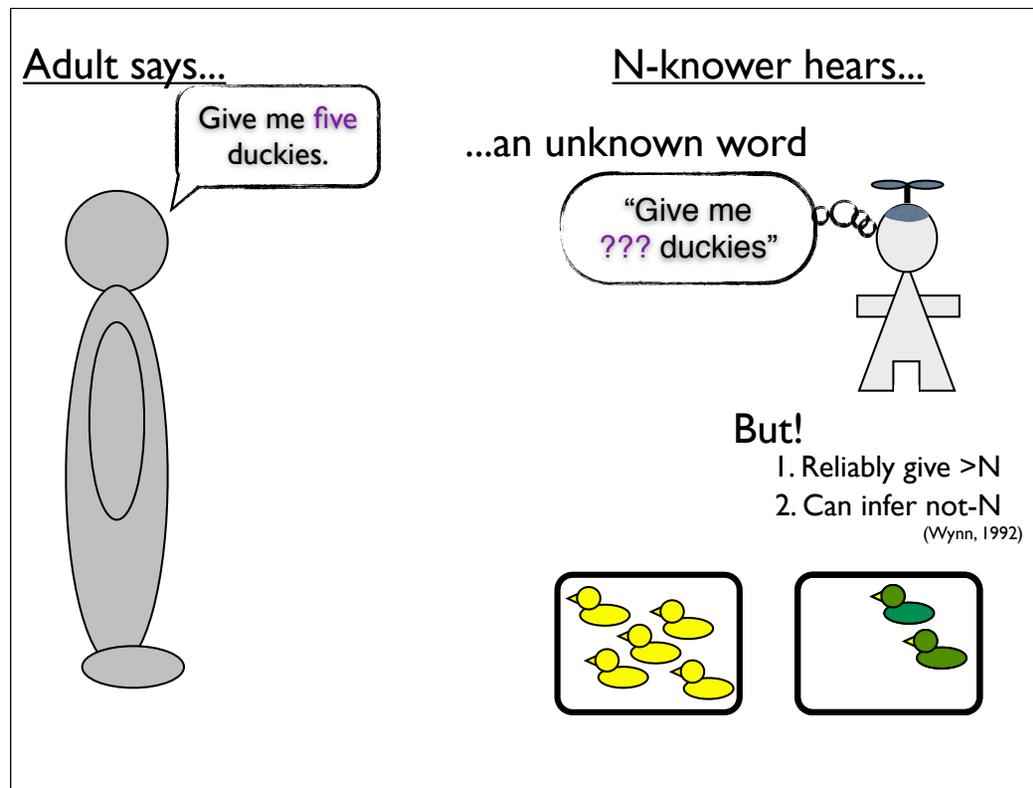
All of which should be relevant for furthering our understanding of how children eventually reach the adult state.[pause]
So what do N-knowers think numerals $>N$ mean?



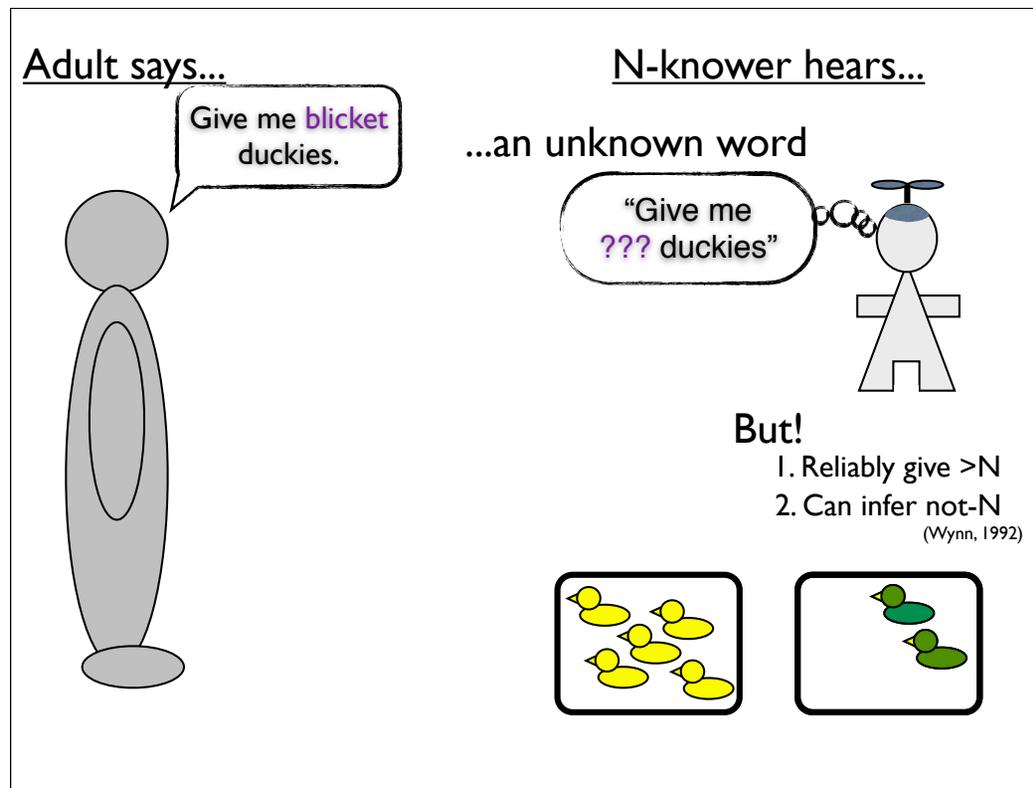
There are a few possibilities on the table. One of course is that these un-acquired numerals are largely gibberish. [click] So this space cadet has no hypotheses whatsoever about what “two” means. Maybe from the syntax he can tell it modifies the noun “duckies” in some way, but for all he knows it’s a color adjective.[pause] There are a few reasons to doubt that children have no constraints on what “five” means. For one thing, if this was the case, then when asked to give “five” duckies [click], they should behave randomly, giving two, three or any other number of duckies. However, as I already pointed out, their responses are not random. They give a number of duckies larger than any of the numbers they already understand. [click] So a two-knower will give more than two duckies.



A second piece of data comes from Wynn (1992).

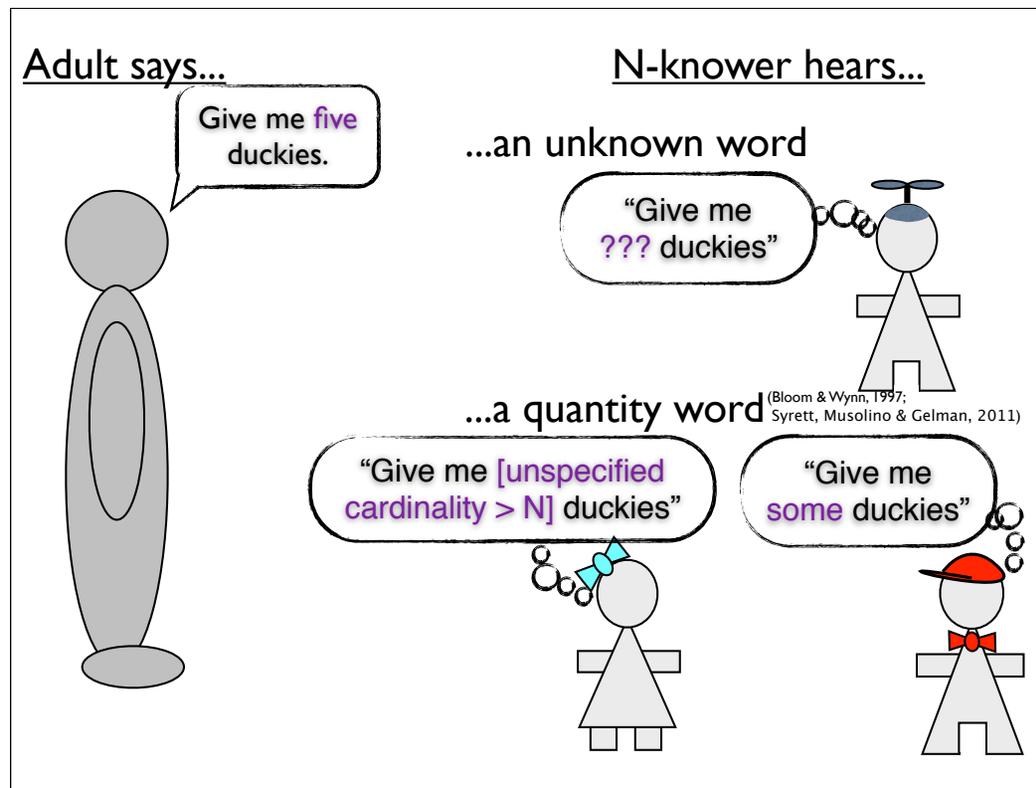


Children were shown 2 pictures that differed in quantity and in color. for instance, here we have a picture with 5 ducks in the picture with 2 ducks. The child might be asked “can you show me the 5 duckies?” Now, 1-knowers fail at this entirely, as we would expect. However, 2-knowers succeed, it even though on many different measures they clearly do not know what “5” means. Wynn Argued that 2-knowers succeeded by using something like the principle of contrast, assuming that (1) the correct answer depends on quantity, and (2) if the speaker had wanted the picture with 2 duckies, the speaker would’ve said so. Therefore, the correct answer is the other picture (the one that doesn’t have 2). [click][pause] could children just be using a souped-up version of the principle of contrast, having no idea what “3” means, other than that doesn’t mean the same thing as any word they know already?



Wynn included a control condition, in which the child was asked “can you show me the blicket duckies”. In this condition, both 1-knowers and 2-knowers performed a chance. So children do not appear to be treating un-acquired numerals as novel words with unknown and otherwise unconstrained meaning.

[PAUSE] So children appear to have *some* constraints on un-acquired numerals. In particular



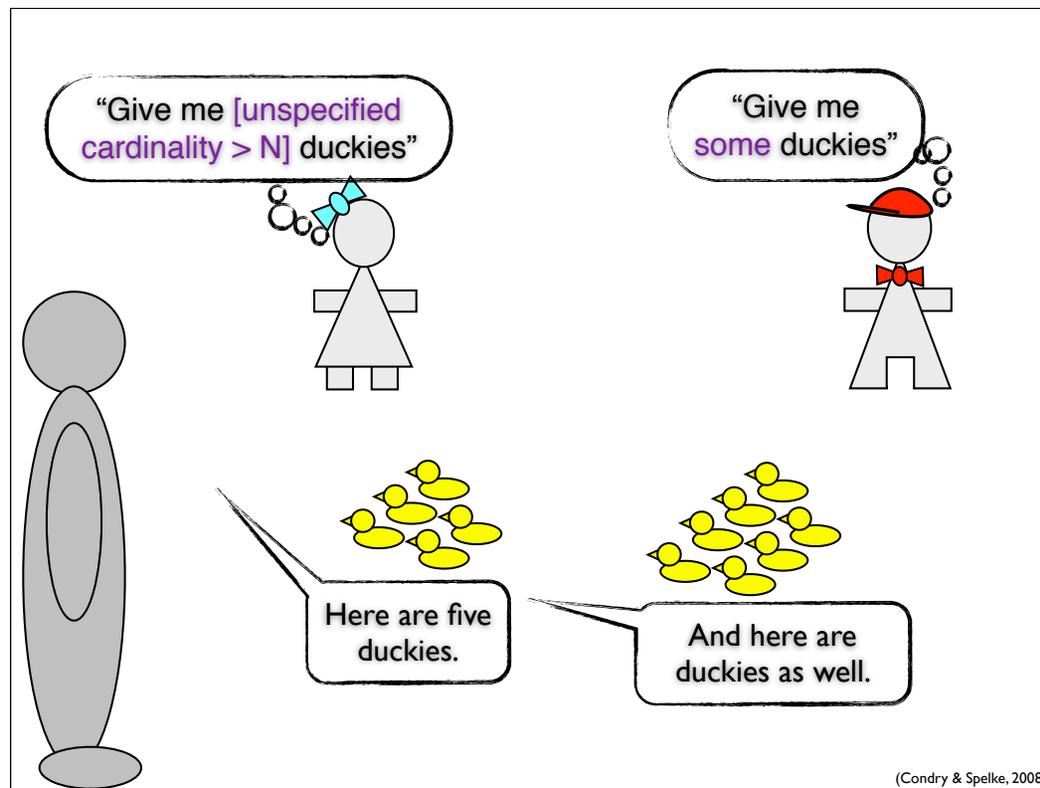
they seem to believe that un-acquired numerals are quantity words, but they have not yet worked out which numeral refers to *which* quantity. There are two versions of this hypothesis considered in the literature. The first, and better-known, [click] is that the child knows that un-acquired numerals refer to an exact quantity such as “five” or “seven”, but haven’t figured out which numeral refers to which quantity. The second is that the child believes [click] that un-acquired numerals are non-numeral quantifiers such as “some” or “many”. As a point of terminology, I will call these words “quantifiers”, I will call numerals “numerals”, and when I want to refer to both, I will say “quantity word”.

Quantity word contexts (Bloom & Wynn, 1997; Syrett, Musolino & Gelman, 2011)

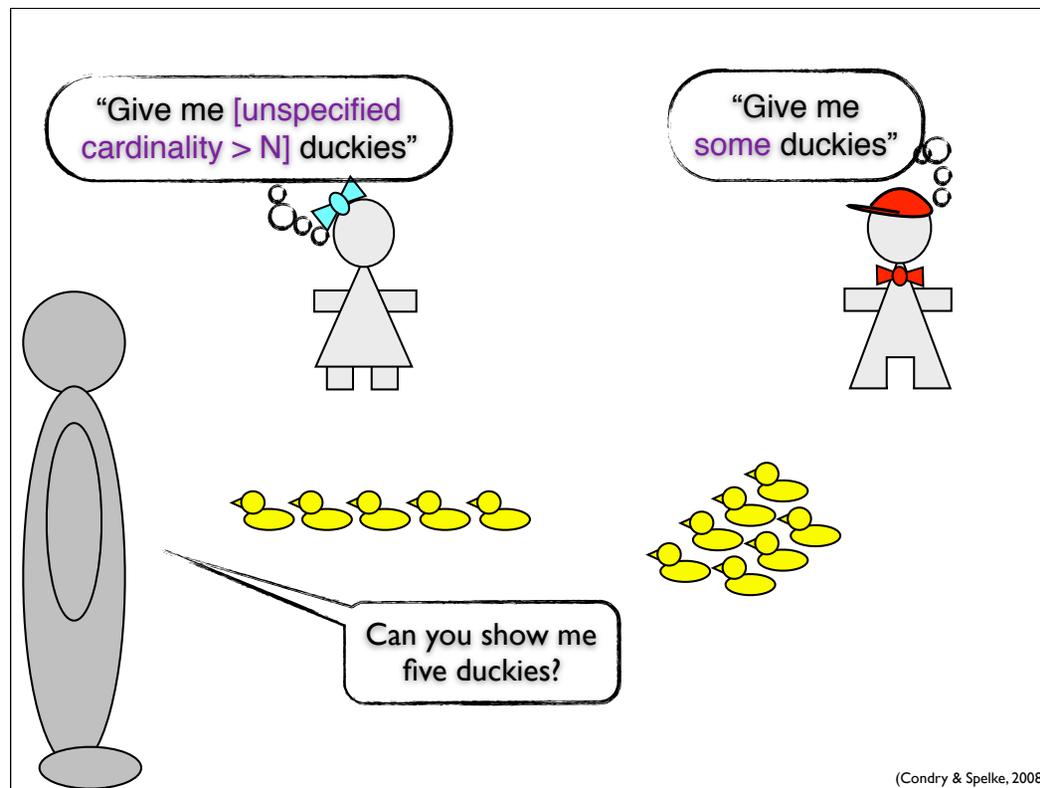
1. Two/many/some/*red/*good of the duckies
2. The duckies are ?two/?many/?some/red/good
3. The very *two/many/*some/red/good duckies
3. *Two/*many/some/red/good water

One reason children might suspect un-acquired numerals measure quantities is -- besides the fact that parents often explicitly teach counting -- numerals appear in the same syntactic contexts as quantifiers, which also measure quantities.

For instance [click] numerals and quantifiers are used in the partitive construction, [pause/click] typically do not in predicate position, [pause/click] cannot be modified by “very”, [pause/click] and cannot be used with mass nouns.

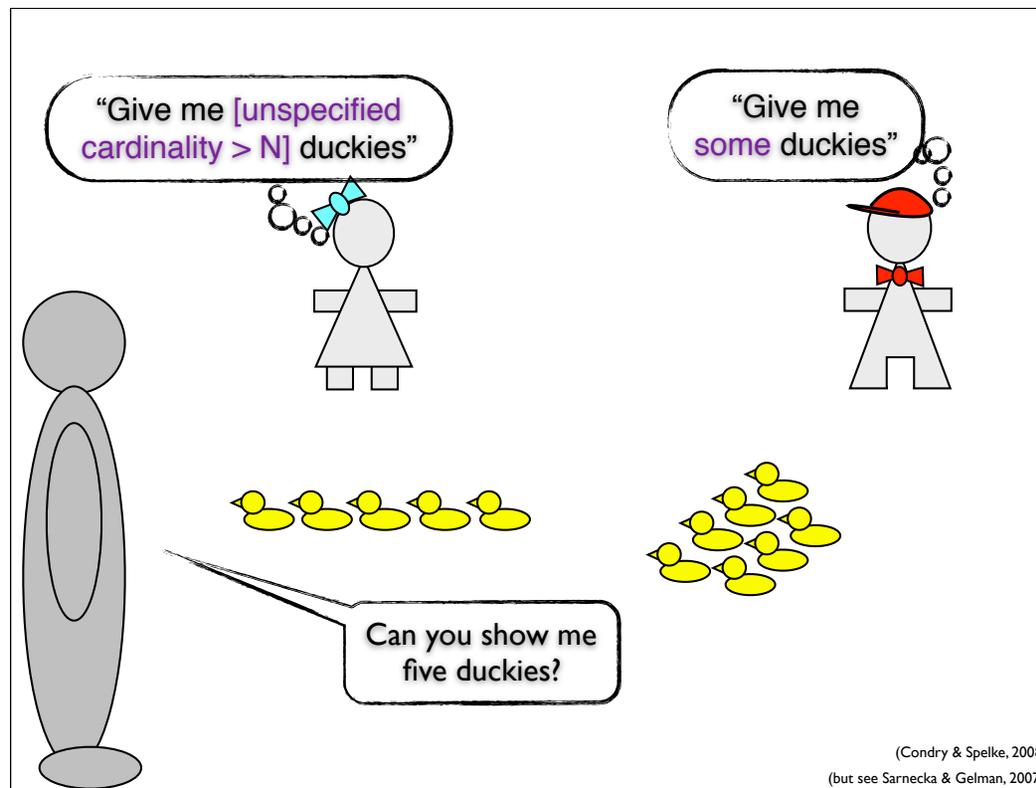


So what evidence is there that children believe un-acquired numerals specify an exact quantity, rather than having the semantics of a quantifier like “some” or “many”? [PAUSE] Condry & Spelke, 2008, ran the following study. In an example of a critical trial, they [click] presented children with five rubber duckies, [click] saying “Here are five duckies.” They also [click] presented a second pile of ducks, [click] saying “And here are duckies as well.” Critically, this second pile did not have 5 ducks. Then, they rearranged the pile of five ducks.

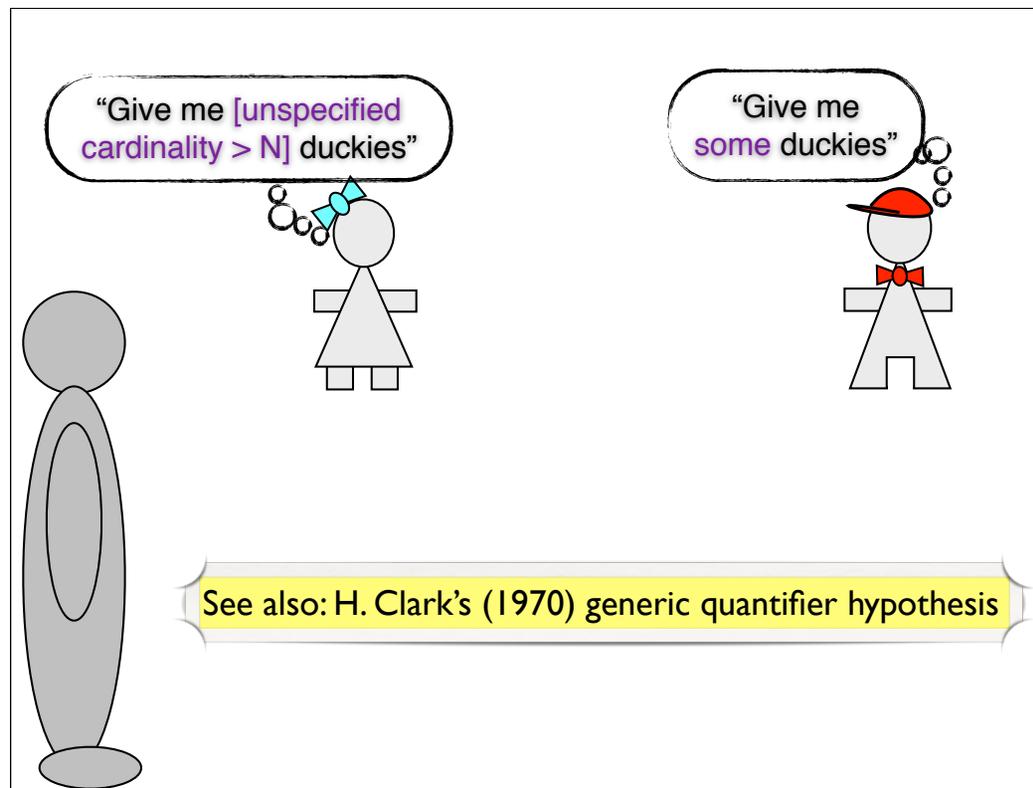


And asked [click] "Can you show me five duckies?" Surprisingly, children performed at chance ... just as they did in a separate condition in which the pile of duckies had one duck added or subtracted. This is not because they didn't understand the task, because these n-knowers succeeded if both piles had cardinalities that they knew -- that is, of N or less.

So this is evidence that children do not know that un-acquired numerals represent exact -- if unknown to the child -- quantities. Except that Sarnecka & Gelman did find such evidence using a task very similar to Condry & Spelke's.

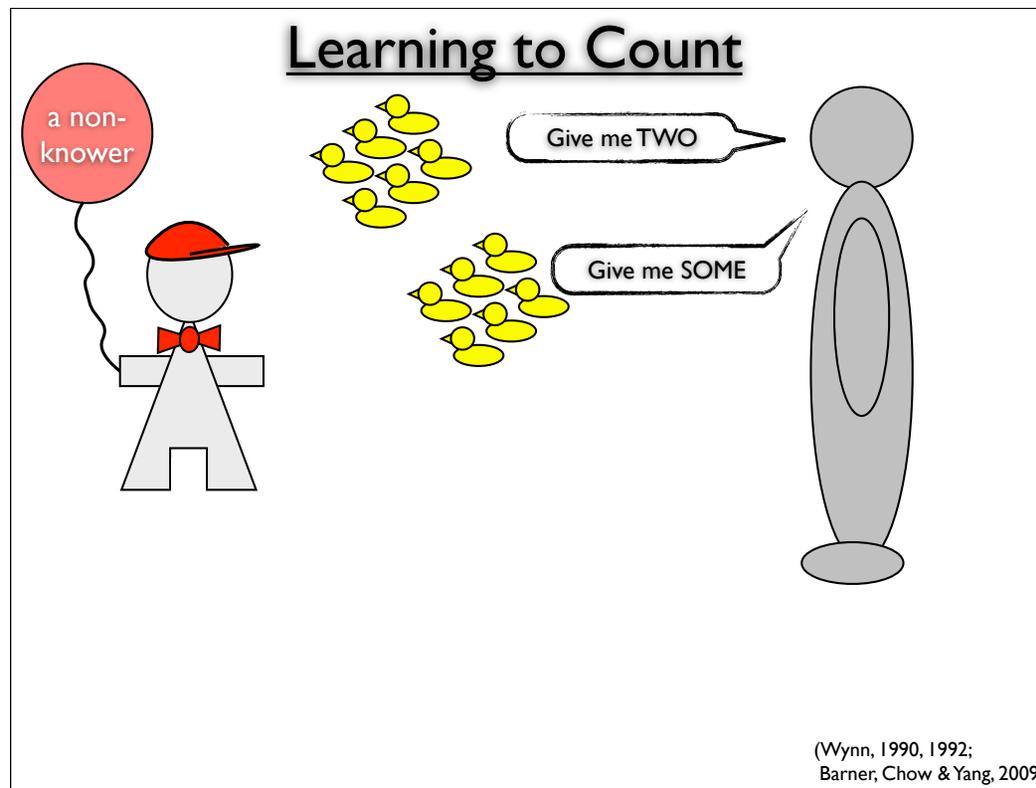


There is ongoing work trying to reconcile this data-clash, but in any case there are other reasons to be skeptical that children believe un-acquired numerals have exact quantities. One is that, on many theoretical approaches, such as the one Susan Carey detailed in her 2009 book, children’s conceptual systems are initially incapable of representing exact quantities larger than 4. Despite decades of research, researchers have been unable to demonstrate that children -- or animals -- have the concept of “seven” or “eight” prior to learning the relevant word. If children do not have these concepts, they cannot be entertaining them in the hypothesis space of possible meanings for un-acquired numerals.



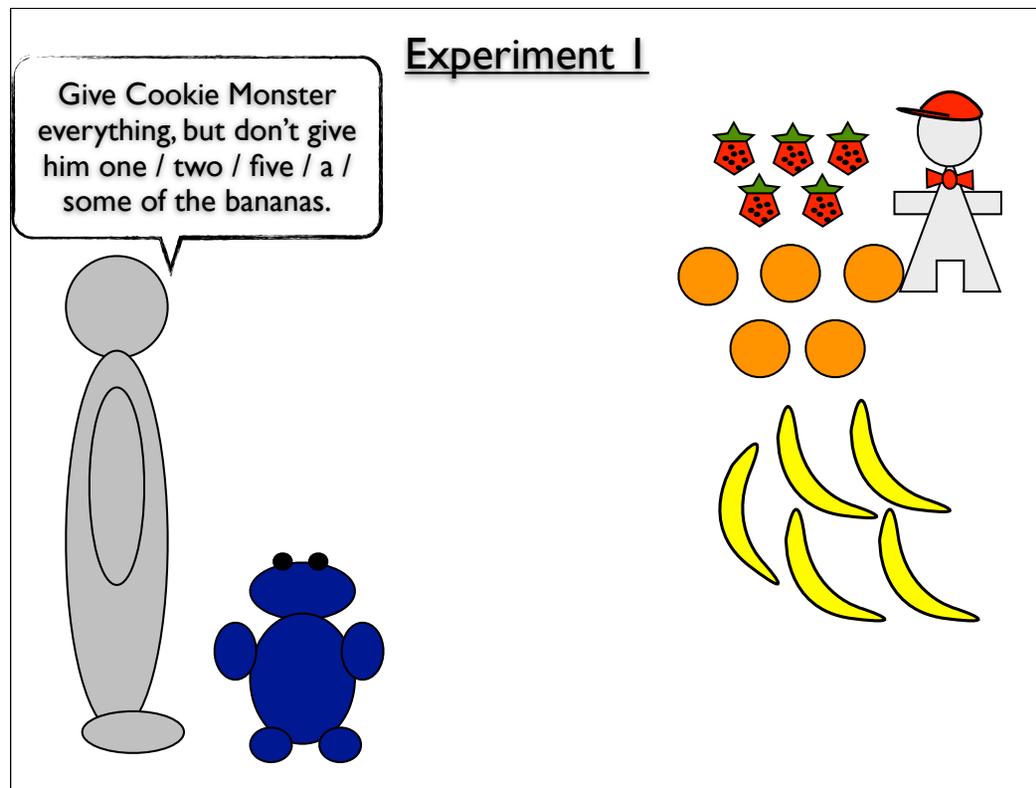
Additional theoretical motivations come from a hypothesis put forward by Clark (1970) about the acquisition of quantifiers. Drawing on studies showing that children just beginning to acquire quantifiers do not distinguish between “more” and “less” or “some” and “most”, Clark argued that children initially assigned the same semantics to all quantity terms: something similar to the semantics of “some”. Only as development proceeds to children begin to distinguish these quantifier terms and arrive at the adult semantics. While Clark did not explicitly address numerals, it is straightforward to extend this account in that direction.

[PAUSE] These arguments do not constitute evidence that children do indeed think unacquired numerals are quantifiers. So that is what we set out to test.



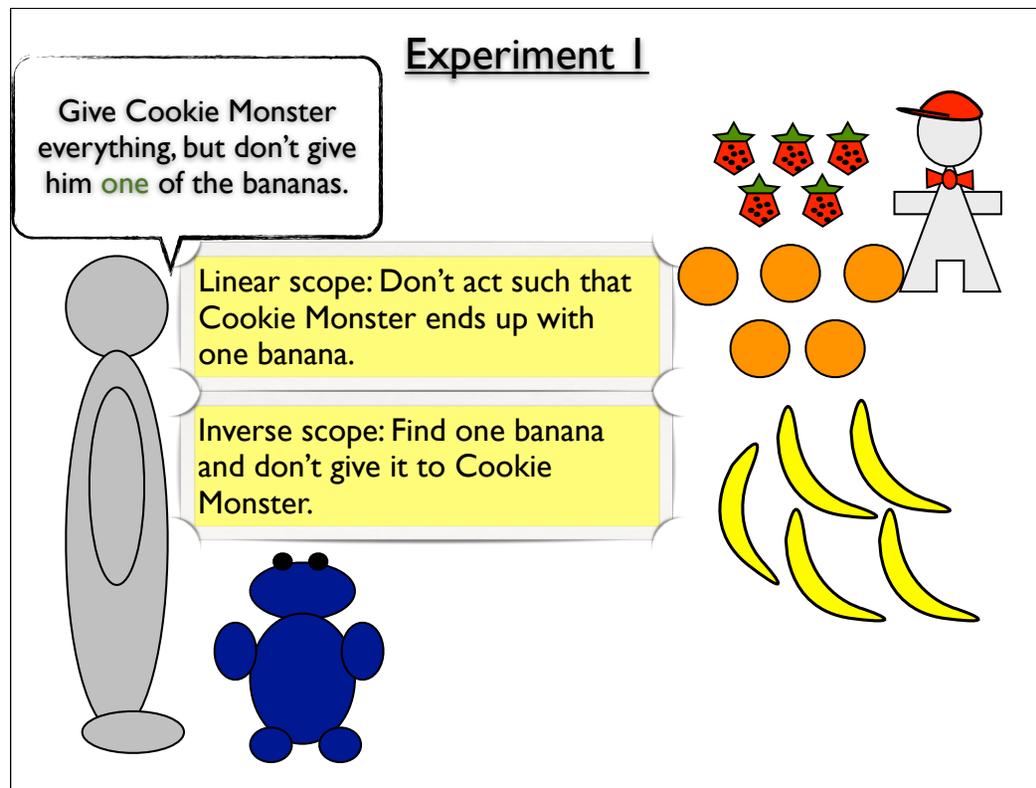
If you want to compare quantifiers to un-acquired numerals in the give-a-number task, you immediately run into a problem. Ask a non-knower to give you “two” [click]. If he believes “two” refers to some specific quantity, but he doesn’t know which, he should give you a handful [click] -- which is what he does. of course, that’s also what you expect [click] if you ask him to give some.

We made a very slight modification to the method which can better distinguish numerals from quantifiers, which was to ask the child *not* to give us two or *not* to give us some.



Here is the task: the participant [click] is introduced to a puppet [click] such as cookie monster and who happens to be hungry. Luckily, there is a lot of fruit available [click]: 5 strawberries, 5 oranges, and 5 bananas. [Pause] the experimenter [click] then instructs the participant to [click] “ give cookie monster everything, but don't give him one, 2, 5, a, or some bananas.” Every participant got 2 trials in each of the 5 conditions. The participants' knower-level was assessed separately using the standard give-a-number task.[pause]

So what do we expect to have happen? Let's consider the case of not giving one.

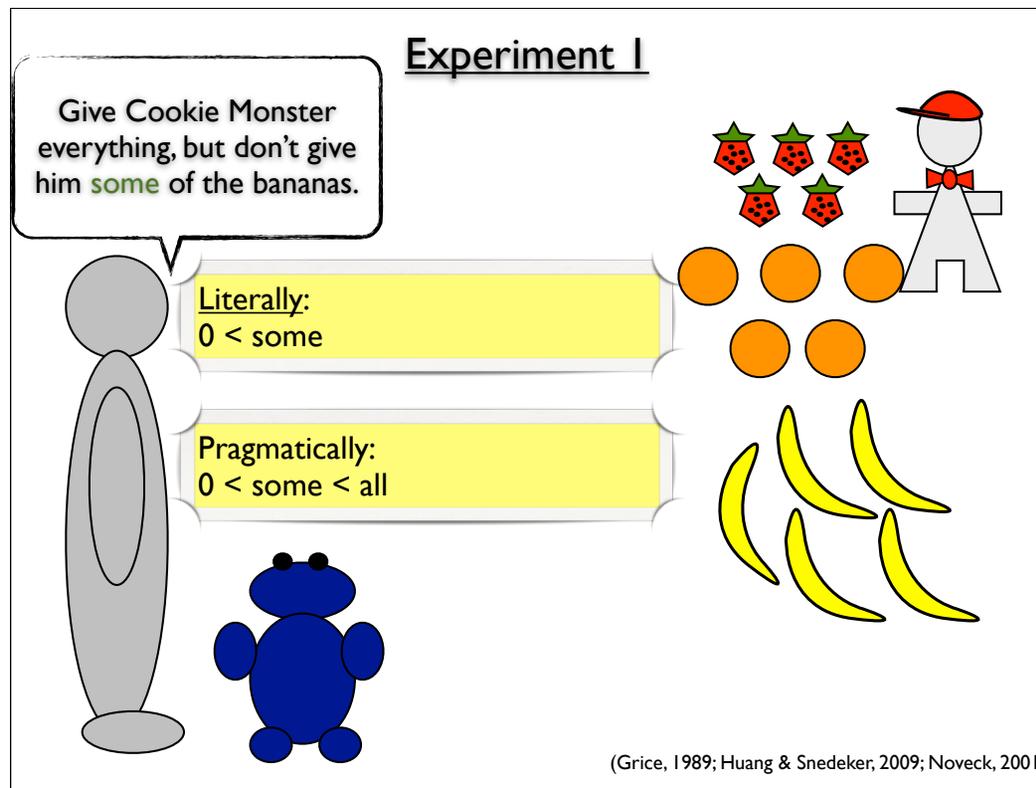


Most adults will recognize an ambiguity here. [click] On one reading -- the linear scope reading -- we should not act such that Cookie Monster ends up with one banana.

[click] But there is also the inverse scope reading: Find one banana and don't give it to Cookie Monster. That is, give him four bananas.

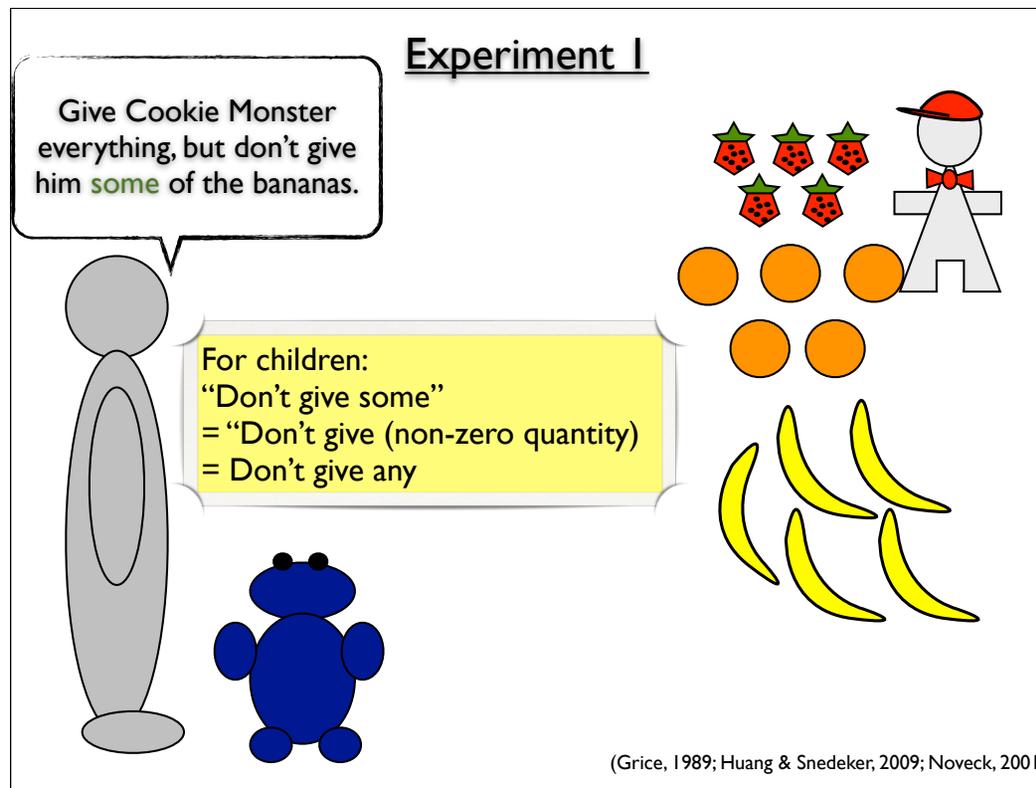
[PAUSE] As it turns out, there is a large literature -- much of it presented here at BUCLD -- showing that the ability to notice inverse scope readings is relatively late emerging in children. Children in our age range 2-3yo, typically only notice the linear scope reading. So if they know what one means, they should give him any number of bananas from zero to five *other* than one banana.

Now, let's consider "some".



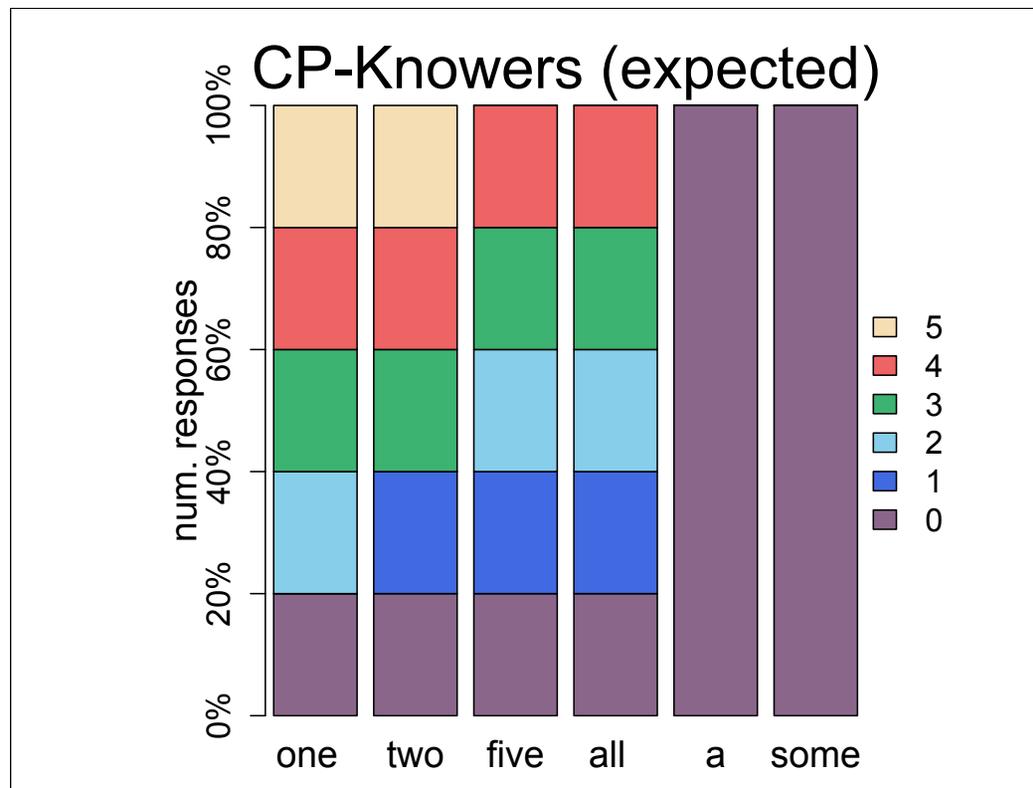
Adults will notice yet another ambiguity. There are two readings of “some”. [CLICK] Some literally means “more than zero”. However, [CLICK] most adults make the inference that “some bananas” means more than zero but fewer than all. [PAUSE]

Once again, though, preschoolers rarely notice this ambiguity and almost always go with the literal meaning. To them, some bananas just means a non-zero quantity of bananas.



What this means is that [children] we expect children to interpret “don't give some” as “don't give a non-zero quantity” -- that is, don't give any. We actually expect something similar for “don't give a banana”, since young children also treat the quantifier “a” as an existential -- it seems to just mean a non-zero quantity.

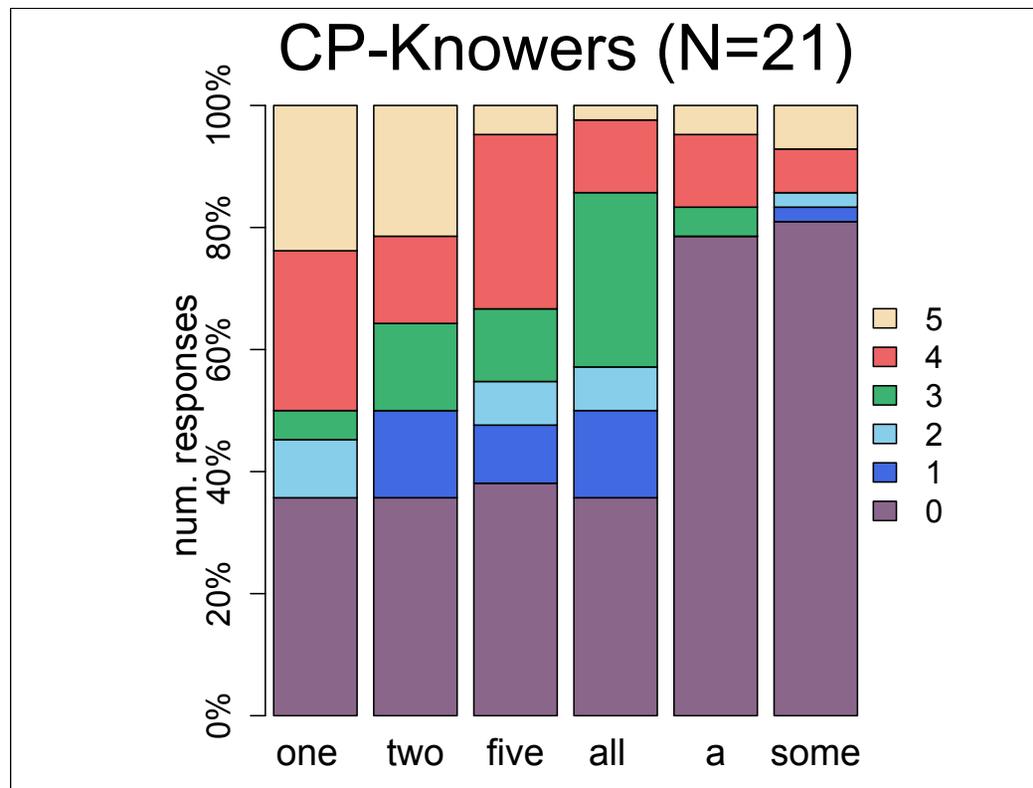
[PAUSE] So here's what we expect, then, for CP-knowers, who know what all the numerals mean



What I am showing is -- for each condition -- the proportion of children who give 0, 1, 2, 3, 4, or 5 bananas. So when asked to not give "one" -- that's the data in the column on the left -- they should avoid giving one banana, but otherwise give a smattering of different responses. So you see all the colors except dark blue, which signifies giving one. [PAUSE] Similarly, for "don't give two", they should avoid giving two bananas, but otherwise apportion their answers among the other possibilities, and so we see every color except light blue. Similarly for "don't give five". Of course, "don't give all" is equivalent in our task to "don't give five", since there are only five bananas. [PAUSE]

Where we expect something very different is "don't give a banana" and "don't give some of the bananas", where the children should give 0 bananas.

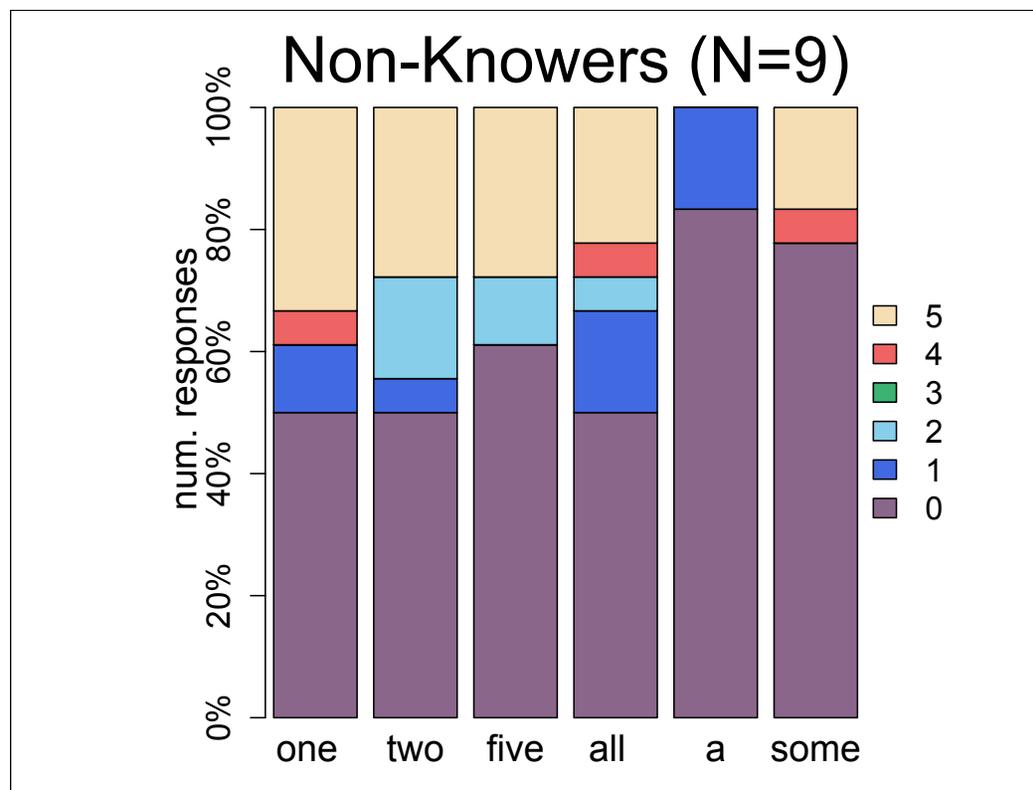
[PAUSE] Now, of course, these are idealized data, and children may have independent reasons to prefer certain responses over others, but nonetheless these idealized data are very similar to what we see for actual CP-knowers.



[PAUSE] [LONG PAUSE]

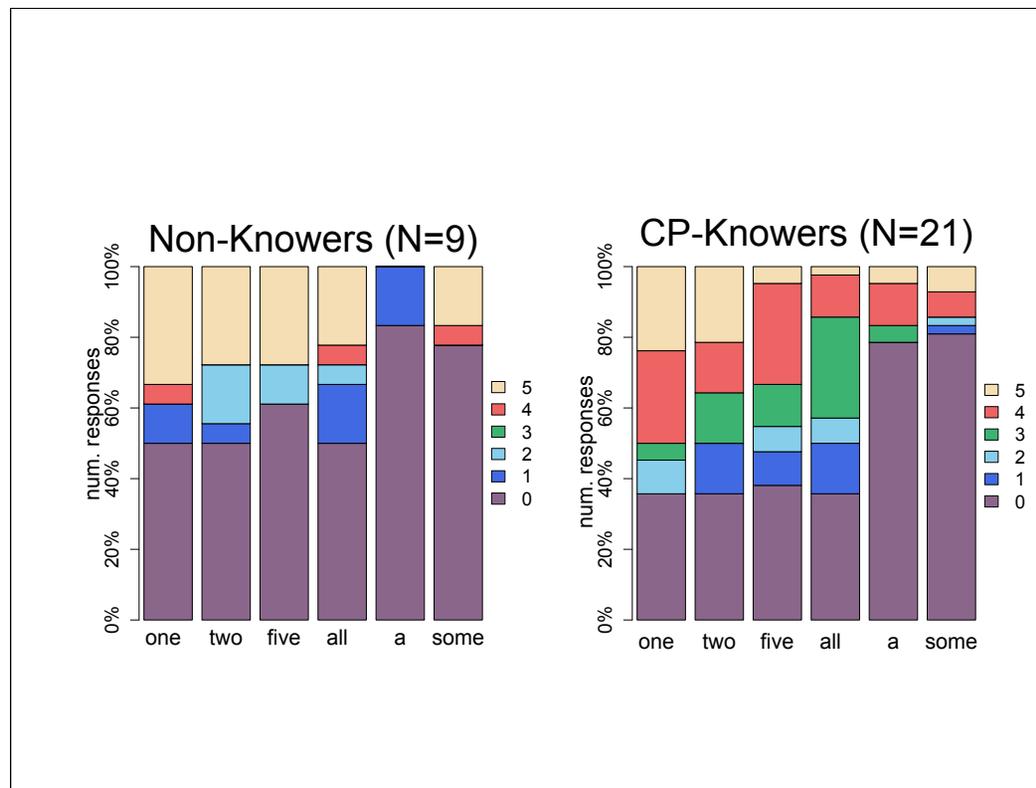
Some of you may be wondering how I'm going to get a p-value out of this. I will be pointing out some interesting descriptive patterns in the data. For instance, here we see children successfully not giving "1 banana" when told not to and not giving two bananas when told not to -- which is good, since it means they understood the task! For statistical analysis, though, I will be focusing on how often the children gave zero bananas, since a lot of the signal loads on that. So here, for instance, there is a significant interaction between condition and the proportion of children giving zero, with more of them giving zero for "a" and "some" than in the other conditions.

[PAUSE] So the key question is how do children do on numerals they have yet to acquire the adult meanings of. Do they treat them like "a" or "some" and give nothing, or do they do something closer to what they do with numerals they do know the meaning of?

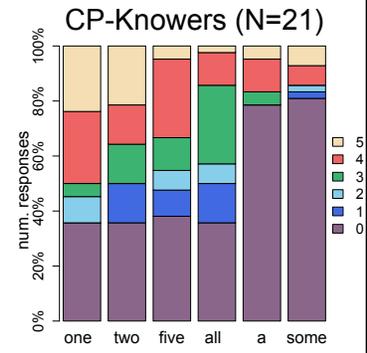
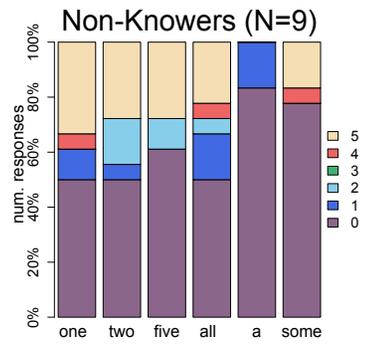


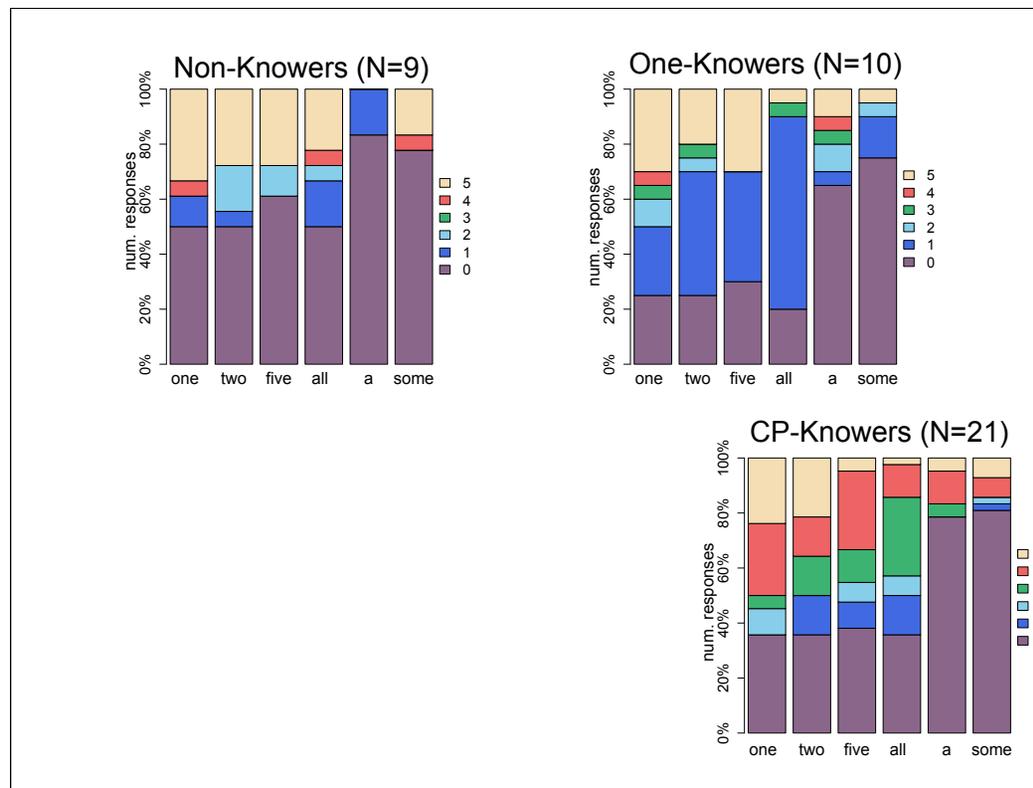
Here are non-knowers. [PAUSE] You can see that they aren't very good at avoiding giving one, two or five when asked not to. In fact, they aren't that great at not giving all, either. However, there does seem to be a hint of the pattern that we see in the CP-knowers, and in fact children gave zero more often for the quantifiers "a" and "some" than for the other items, and the difference between "a" and "some" was not significant. [using lmer. Effect for "five" was actually just marginal – $p = .07$, though this is a one-tailed test. I want to try bootstrapping, though.]

So we can see non-knowers and CP-knowers side-by-side.

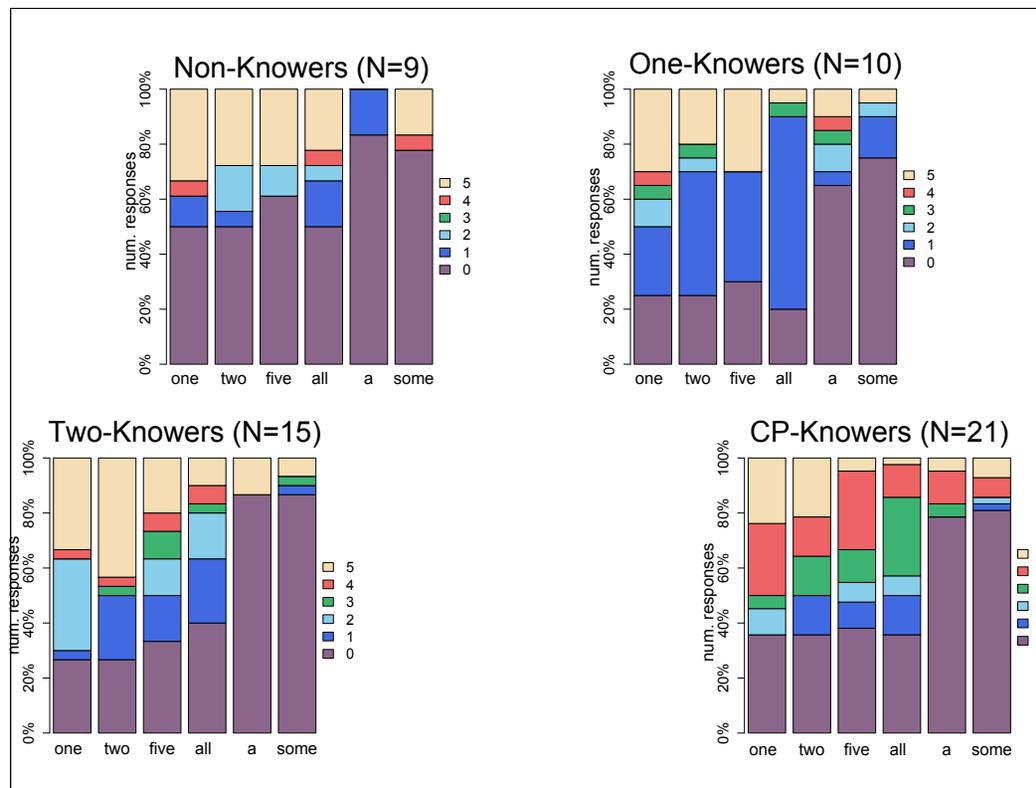


And now what about the other knower-levels?

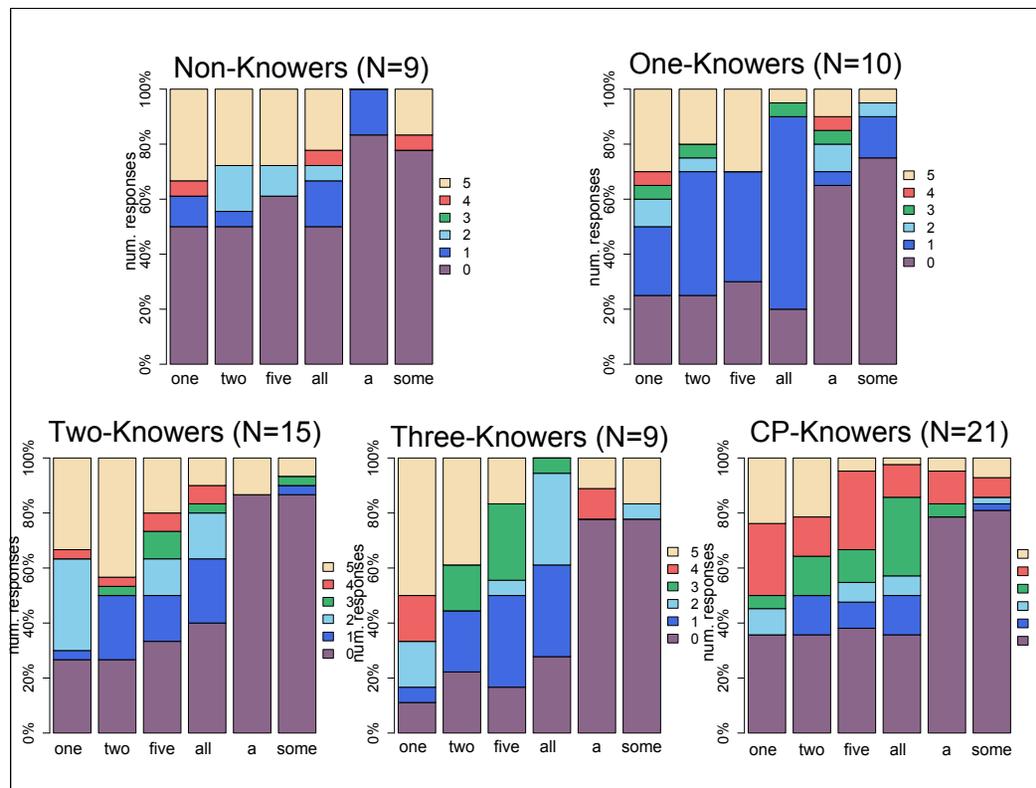




[PAUSE] One-knowers show a much bigger difference between the numerals and the quantifiers “a” and “some” -- this is highly significant -- with again there being little difference between the acquired and un-acquired numerals. [PAUSE] They aren’t super successful at avoiding giving “one” when told not to, though numerically they give one less often in that condition than when asked not to give two, five, or all.



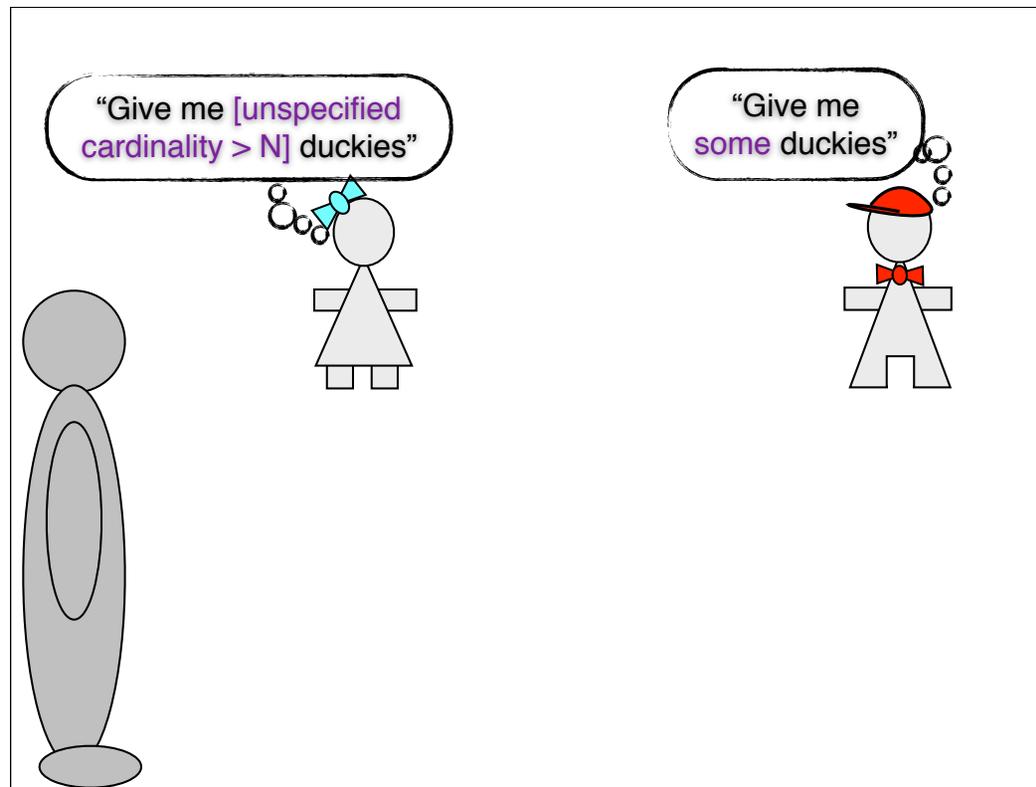
[PAUSE] Two-knowers show again roughly the same pattern. Moreover, they are successfully avoiding giving “one” or “two” when asked not to.



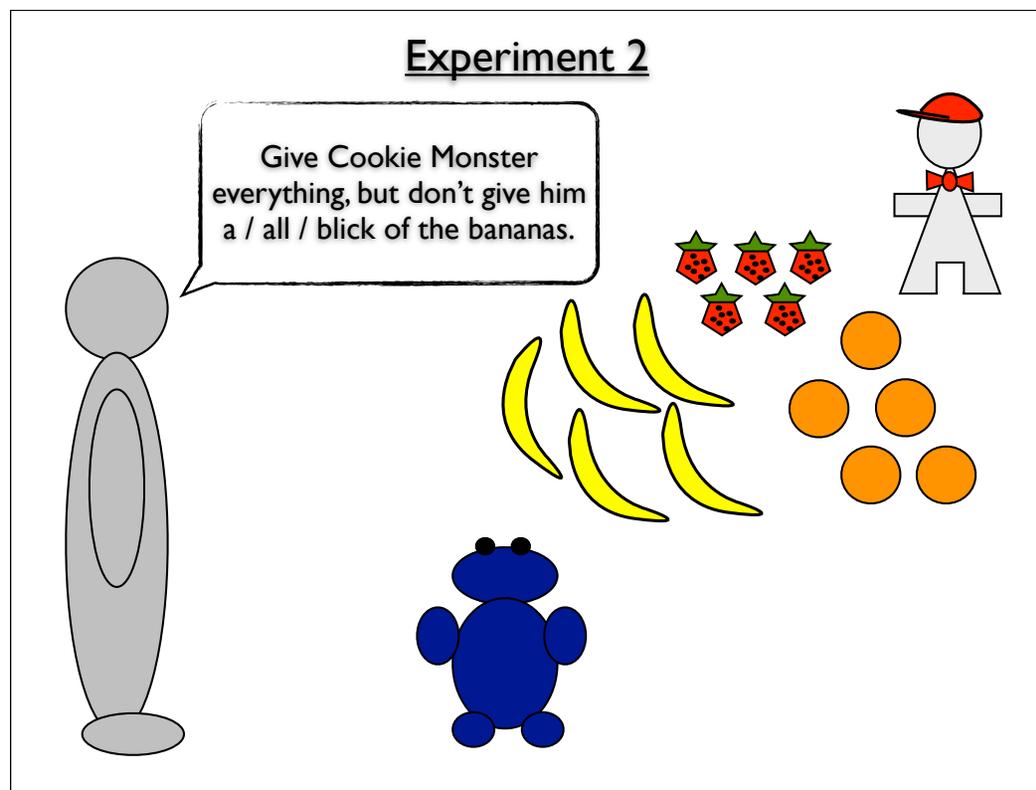
And then three-knowers look a lot like two-knowers.

[PAUSE]

So it looks like children in all our knower-levels treat the quantifiers “a” and “some” differently from how they treat the numerals -- whether acquired or un-acquired. [PAUSE] You might have wondered what is going on with “all”. Not giving all leaves open giving anywhere from 0 to 4, so superficially, it will pattern with the numerals in this task. However, Barner, Chow & Yang used nearly identical stimuli but asked children to *give* all the bananas. Of their 13 non-CP-knowers, nearly 100% successfully gave all the bananas. That is not what children do when asked to give some un-acquired number of objects.

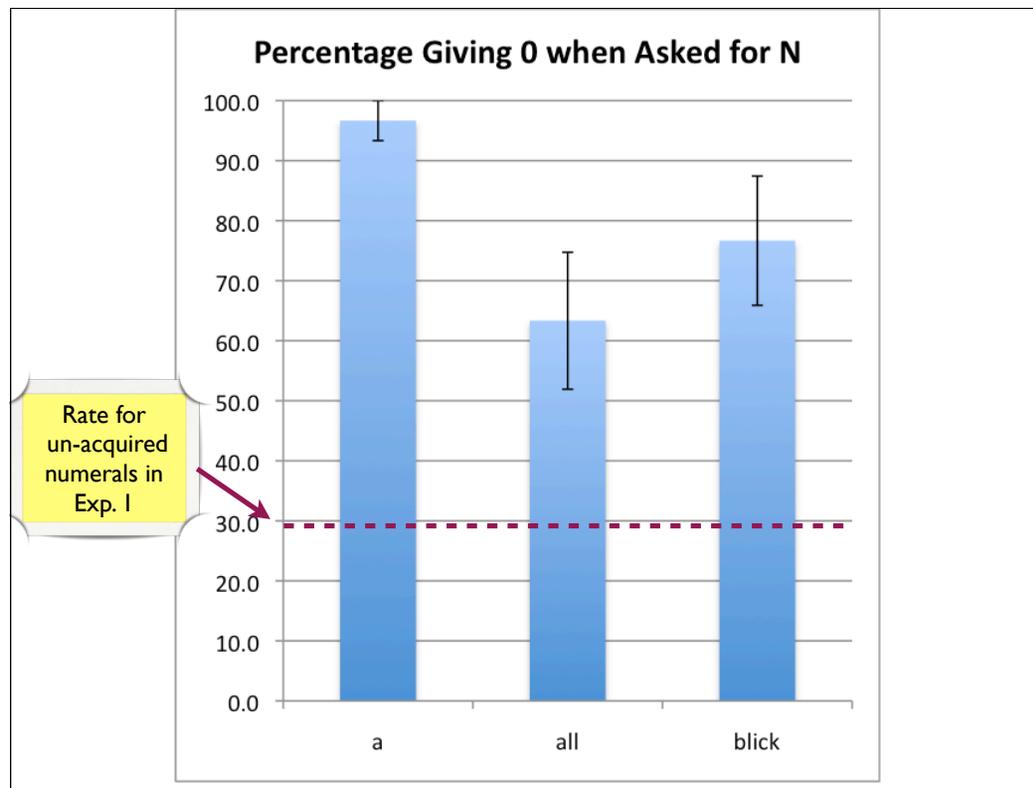


So back to our question: What do children think un-acquired numerals mean? It doesn't look like they think those words are like "some" or "a". But there are other kinds of quantifiers. We had focused on "some" and "a" because of Clark's 1970 hypothesis that children initially interpret new quantifiers as if they meant "some". But what if children have some *other* hypothesis about novel quantifiers?



So we did a follow-up experiment with 15 three-year-olds in which they were asked not to give a banana, all of the bananas, or blick of the bananas. Children of course don't know what "blick" means, but the fact that it appears in the partitive construction indicates that it refers to quantity in some way. So we can use this condition as a stand-in for how children might interpret un-acquired numerals if they know nothing about un-acquired numerals except for that they are quantity terms.

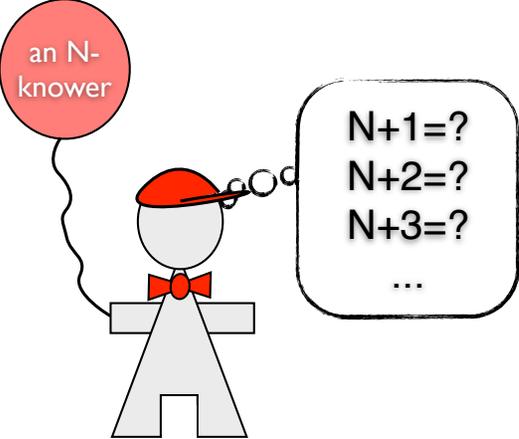
[pause] Just to make data presentation simpler, I will show only the proportion of children giving zero bananas.



And again we see very high rates of giving no bananas at all in all three conditions -- treating "blick of the bananas" differently from, say, "five of the bananas" in the last experiment.

[pause] So putting the two experiments together, So it does not look like children are treating un-acquired numerals as the quantifiers "a", "some" or "all", or even as a novel quantifier.

What does an N-knower think numerals >N means?



Numerals >N do:
✗ Encode quantity

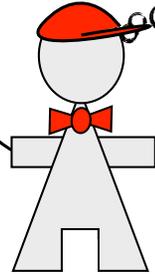
Numerals >N do not:
✓ Mean “all”
✓ Mean “some”
✓ Mean “a”
✓ Mean “blick of the”

Numerals >N could mean:
? [unspecified exact #]
? “several”

So to summarize: I reviewed data showing that [CLICK] un-acquired numerals encode quantity. [click] They do not [click] mean “all”, “some”, “a” or “blick” of the bananas. [PAUSE] [CLICK] So what do they mean? The jury’s still out. They could mean, as is often suggested, “unspecified exact quantity”. That is, children know what numerals are; they just don’t know which is which. [CLICK] But we haven’t ruled out every type of quantity word. So the word “several” works differently from “a” or “some” in representing a fuzzy range. Whether children believe un-acquired numerals have a semantics like “several” must still be tested.

What does an N-knower think numerals >N means?

an N-knower



N+1=?
N+2=?
N+3=?

...

Numerals >N do:

✗ Encode quantity

Numerals >N do *not*:

✓ Mean “all”

✓ Mean “some”

✓ Mean “a”

✓ Mean “blick of the”

Numerals >N could mean:

? [unspecified exact #]

? “several”

? contrasting quantity word”

Another possibility is that children know that numerals represent quantity, and they know that the numerals contrast with one another, but they do not yet know how. Bloom & Wynn 1997 noted that one way that children might notice that un-acquired numerals are not quantifiers is that they are often used contrastively. It is normal to correct somebody’s count (“that’s not three ducks -- that’s four!”) but circumstances in which quantifiers are corrected are probably more rare (“that’s not some of the ducks -- that’s many of the ducks!”), particularly since many of the quantifiers entail others (if you have many of the ducks, you by definition have some of the ducks). In fact, both the Condry & Spelke and Sarnecka and Gelman results I mentioned earlier could be characterized as “children suspect if you change a set in any way, the relevant numeral changes”.

[pause] Future work is needed to tease these possibilities apart.

With that, I’d like to

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