

# Pragmatic Inference, Not Semantic Competence, Guides 3-Year-Olds' Interpretation of Unknown Number Words

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Before children learn the specific meanings of numerals like *six*, do they know that they represent precise quantities? Previous studies have reported conflicting evidence and have found that children expect numerals to label precise quantities in some tasks but not in others (Condry & Spelke, 2008; Sarnecka & Gelman, 2004). In this article, we present evidence that some of children's apparent successes are best explained not by domain-specific semantic understanding of number but instead by language-general pragmatic abilities. In Experiment 1, we replicated the findings of the previous studies in a within-subject design. When 3-year-olds saw a set labeled with a number (e.g., *five*) and an item was added, they preferred a new label (*six*) over the old one, as though they believed that number words have precise meanings. However, when 1 of 2 sets was labeled (e.g., as *five*) and children were asked to find the same quantity (*five*) or a new quantity (*six*), they performed identically whether the original set was changed in quantity or merely rearranged. Thus, when 2 numerals were offered as alternative labels for 1 set, children behaved as though they had precise meanings, whereas when they were asked to determine which of 2 sets a single numeral referred to, they did not. In Experiment 2, children were tested using similar methods but with novel nouns and objects that were transformed, instead of sets. Children showed the identical pattern of results despite lacking meanings for these words, suggesting that their judgments for numerals may not have relied on semantic knowledge that numerals have precise meanings. We propose that children's behavior can be explained by the use of domain-general pragmatic inference and does not require positing domain-specific numerical knowledge.

*Keywords:* word learning, number, pragmatics, cognitive development, number words

Learning the meanings of numerals (e.g., *one*, *two*, *three*, etc.) is a complex developmental task, which likely involves the integration of multiple cognitive, linguistic, and sociopragmatic capacities (Barner & Bachrach, 2010; Barner, Chow, & Yang, 2009; Carey, 2009; Le Corre & Carey, 2007; Lee & Sarnecka, 2010; Piantadosi, Tenenbaum, & Goodman, 2012). However, for the most part, past research has focused on identifying the semantic and conceptual factors that influence early number word learning, with less attention paid to other factors (e.g., see Carey, 2009, for a review). This is potentially problematic, since some behaviors that appear to reflect semantic knowledge can also be explained by

appeal to pragmatic competence: children may respond to tasks in ways that are consistent with domain-specific understanding of number, while in fact relying on pragmatic abilities that are domain-general in nature. In this article, we explore one such case—children's use of numerals to denote precise numerosities—and provide evidence that pragmatics, rather than semantic understanding of number, may best explain children's earliest behaviors.

In past studies, researchers have proposed two broad accounts of how children might discover that *all* number words, not just *one*, *two*, and *three*, can be used to refer to precise numerosities. By one class of accounts, children acquire this knowledge only once they have learned the relationship between counting and cardinality and not before (Condry & Spelke, 2008; Lipton & Spelke, 2006). A second class of accounts, however, proposes that children understand that number words are precise much earlier—that after learning one or two numeral meanings, they infer that all numerals denote precise numerosities (Bloom & Wynn, 1997; Sarnecka & Gelman, 2004; Wynn, 1990, 1992; for discussion, see Barner, 2012; Syrett, Musolino, & Gelman, 2012).

As a large body of past research has shown, children begin the acquisition of number words by learning to recite a partial count list at around the age of 2 years, after which they gradually learn precise meanings for the numerals *one*, *two*, and *three*, one word at a time, over a period of many months (these children are often called one-knowers, two-knowers, and three-knowers as each numeral meaning is acquired). These children likely know that all numbers denote properties of sets, much like quasi-cardinal quan-

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tifiers such as *several* and *many*, but they are not yet able to relate higher numerals to the quantities that they represent. Sometime after learning the meaning of *three* (or *four*, in some cases), children appear to realize that counting can be used to determine the numerical label of any set, at which time they are categorized as cardinal principle (CP) knowers (for different accounts of these early stages, see Briars & Siegler, 1984; Fuson, 1988; Gelman & Gallistel, 1978; Le Corre, Van de Walle, Brannon, & Carey, 2006; Wagner & Walters, 1982; Wynn, 1990, 1992). These CP-knowers are able to label the precise numerosity of any set within their counting range and appear to know that numbers outside their counting range also denote precise quantities (Lipton & Spelke, 2006; although see also Davidson, Eng, & Barner, 2012).

Most researchers agree that CP-knowers understand that number words refer to precise values. Also, it is generally agreed that children know that numerals, like other quantifiers (e.g., *several*, *many*, *every*, etc.), denote properties of sets and that number words contrast in meaning, as shown by Wynn and others (Barner, 2012; Bloom & Wynn, 1997; Condry & Spelke, 2008; Syrett et al., 2012; Wynn, 1992). However, the question of when children understand what makes number words different from other quantifiers—that number words are precise—remains unsettled. Recent studies have found conflicting evidence about whether children understand that a change in quantity always requires a change in numerical label before they become CP-knowers.

In one study, for example, Sarnecka and Gelman (2004) presented evidence that children treat numerals like *five* as precise before they become CP-knowers. These children, often called “subset knowers,” know meanings up to *one*, *two*, *three*, or *four* but have not yet learned how counting represents number and thus cannot use counting to generate quantities like five or six. In their study, children watched as an experimenter placed between two and six objects into a box and said, for example, “Here are five erasers.” After a memory check, the experimenter manipulated the set either by shaking the box or by adding or removing a single object from it. The child was then asked—e.g., “Now how many erasers—is it five or six?” When the box was merely shaken, children used the original label to refer to the set (*five*). However, when the set had undergone a change in quantity, children preferred the new, correct, label (*six*). Overall children’s performance was very good, and there was no difference between their responses to known numbers (e.g., *one*, *two*, *three*) and unknown numbers (e.g., *five*), suggesting that children treat all numerals as precise before they have learned the cardinal principle.

Against this conclusion, however, a second task presented by Sarnecka and Gelman (2004) failed to find evidence for precise number knowledge in subset knowers, as did an experiment conducted by Condry and Spelke (2008) that used a very similar method. In the Condry and Spelke study, children were presented with two sets that were either identical (on “transformation” trials) or differed in numerosity by 1 (on “rearrangement” trials). One of the sets was labeled with a numeral—for example, “This tray has five sheep” (pointing at one set)—and the other was labeled without a numeral—for example, “And there are sheep here as well” (pointing at the second set). The experimenter then manipulated the contents of the tray labeled as *five*, either by adding an additional toy or by rearranging the toys (e.g., by putting them in

a row). Children were then asked, “Can you point to the tray with five sheep?” Surprisingly, children chose the originally labeled set as frequently as they chose the unlabeled alternative, regardless of whether an item was added or the set was merely rearranged. Follow-up experiments confirmed this finding and extended it using larger transformations (e.g., doubling or halving of target sets). Also, Condry and Spelke showed that children had no difficulty with the task when smaller quantities within children’s range of known number words (*one*, *two*, *three*), were used. Thus, unlike the one-set experiment of Sarnecka and Gelman, this two-set method failed to find early knowledge that all number words denote precise meanings. Instead, the results suggest that children only pass this task once they have become CP-knowers. The results of the two-set experiment conducted by Sarnecka and Gelman support this conclusion: while CP-knowers generated results consistent with the one-set task, one-, two-, and three-knowers performed at chance.

What accounts for the differences between the results of these studies? One possibility is that children know from early on that numbers denote precise quantities and that they fail selectively on tasks involving two sets because they involve greater task demands (Sarnecka & Gelman, 2004). However, similar two-alternative forced-choice tasks are routinely used to test 3-year-old children and generate meaningful data in contexts that require mapping language to different quantities (e.g., Barner & Snedeker, 2006; Brannon & Van de Walle, 2001; Condry & Spelke, 2008; Wynn, 1992). Also, such an account has difficulty explaining why this task would be so much easier with numerals that denote small quantities (e.g., *two*, *three*) relative to numerals that denote only slightly larger quantities (e.g., *five*, *six*), despite the fact that the higher numerals are familiar to children and used in their counting routines. Children in past studies were nearly perfect with small numbers but were completely random for slightly larger numbers, and only on the two-set task. This is especially puzzling in cases like those reported by Condry and Spelke, where sets underwent dramatic changes like doubling and halving, with no effect on performance. Finally, the hypothesis cannot explain why children’s performance on the two-set task improves so suddenly once they learn how counting represents number, as demonstrated by Sarnecka and Gelman (2004).

Another possibility, which we explore here, is that language-general pragmatic principles, rather than number-specific knowledge, best explain children’s early interpretation of unknown numerals in these experiments. By this view, children may not know that all numerals denote precise quantities before they become CP-knowers, but only that they somehow represent sets, like other quantifiers. When children treat numerals as exact, this may reflect their use of pragmatic inferences that apply not only to numerals but also to other linguistic forms, like nouns and verbs (Clark, 1991; Diesendruck, 2001; Gathercole, 1989; Grice, 1989). Because past studies did not conduct experiments with nonnumerical controls, it is impossible to know whether children’s responses were driven by knowledge that numbers have precise meanings or by more general pragmatic principles. Thus, in the present study, we conducted such experiments, by testing children’s interpretation of novel nouns.

To understand the role that pragmatics might play in previous studies, consider the situation in which the child is shown a single set that is first labeled (e.g., as *five*) and then manipulated. According to most accounts, this child knows that a change in

quantity, unlike a rearrangement of the set's contents, is relevant to number words, since numerals represent the properties of sets (as do nonexact quantifiers like *some* and *all*). On this basis, the child can assume that changes in quantity are *necessary* to warrant changes in quantity word. However, without knowledge that all numerals denote precise quantities, the child could not know whether a particular change in quantity is *sufficient* to warrant a change in label and thus whether the label *five* or *six* should apply to the transformed set. Our suggestion is that pragmatic cues alone might allow children to generate an adult-like response. In the one-set experiment, the child sees one set labeled, then sees a quantity change, and then is offered a new numeral as a potential label—for example, “Is this *five* or *six*?” If children, like adults, expect their interlocutors to be relevant when communicating (Grice, 1989), then they might infer that the new label was offered for a reason—for example, “If six were not the correct label, why would the adult mention it as an alternative?” In contrast, when no change is made to the quantity of the set (i.e., the items are rearranged), children should not be swayed by this type of pragmatic cue, since they should know that a change in quantity is necessary for a change in quantity expression.

In the two-set conditions, this type of pragmatic inference is not licensed, since the child is not asked to choose between two alternative labels but rather to decide which of two sets might satisfy a single label's meaning. If the child does not know the precise meaning of *five*, he or she should have no firm basis for deciding whether it applies only to the labeled set or to both the labeled set and the alternative. Similarly, if a new label is introduced but not directly contrasted with the original word, children should have no basis for deciding which sets it can be applied to.

In the present study, we explored whether it is necessary to posit number-specific knowledge of exactness to explain children's treatment of unknown numbers or if their behavior can be explained by domain-general pragmatic inference. To do this, we compared children's performance on number tasks like those used in past studies to their judgments for novel nouns in an otherwise identical set of tasks. We reasoned that if pragmatic inference can explain previous findings, then children should exhibit an identical pattern of behavior when referents are novel objects as when they are sets. Children's intuitions about when new labels apply may not be specific to numerals and may not require an assumption that their meanings are precise. In this case, it would be premature to conclude that they know that all numerals have precise meanings. More strongly, if a simple pragmatic account can explain children's interpretation of both numerals and nouns, whereas the number-specific account fails to explain even the extant number data, then much stronger evidence may be needed before concluding that subset knowers know that unknown numerals denote precise numerosities.

In Experiment 1, we sought to replicate both the Sarnecka and Gelman (2004) and Condry and Spelke (2008) experiments using a within-subject paradigm, allowing us to rule out the possibility that differences in experimenters or participants were responsible for the discrepancy in these findings. In Experiment 2, we tested children using methods identical to Experiment 1, but using novel objects rather than sets of things. We asked whether children's use

of noun labels would differ across the one-referent and two-referent conditions, as in the case of number.

## Experiment 1

### Method

**Participants.** A total of 28 children participated in Experiment 1 ( $M$  age = 3 years 2 months; age range = 2 years 4 months–3 years 11 months). All participants were native speakers of English. Children were recruited from day care facilities and museums in the San Diego area, or by phone from a database maintained at University of California, San Diego. Children were selected to participate in this study on the basis of their number knowledge as determined by a pretest.

**Give-a-number pretest.** All children were given a pretest to determine whether they understood how counting represents number. Only children who did not yet understand counting (i.e., were not CP-knowers) were included in the study. To assess this, we used Wynn's (1990) give-a-number task. The experimenter placed 10 plastic fish and a plate in front of the child, and asked, “Can you put  $N$  fish in the red circle?” The experimenter began the task by asking the child to put four fish in the circle. If the child succeeded, the experimenter then asked for five fish; if the child failed on four, he or she was asked to put one fish in the circle. On subsequent trials, we used a titration method such that when a child successfully gave  $N$  fish, he or she was then asked to put  $N + 1$ , and when a child failed, he or she was tested on  $N - 1$ . We continued this process until the child's “knower level” could be identified. Using the criteria described by Wynn (1990), children were classified as *non-knowers* if they failed on all numerals, as *subset-knowers* (one-, two-, three- or four-knowers) if they successfully gave  $N$  fish when asked for  $N$  but failed at  $N + 1$ , and as *CP-knowers* if they succeeded on four through eight. As noted earlier, only children who were classified as subset knowers were included in the study. We identified 9 one-knowers, 12 two-knowers, 5 three-knowers, and 2 four-knowers.

**Design.** After the pretest, each child completed two tasks: (a) a one-set, two-label forced-choice task (one-set task) and (b) a two-set-set, one-label forced-choice task (two-set task). Half of the children received the one-set task first, and half received the two-set task first.

### Procedure.

**One-set task.** The one-set task was based on Sarnecka and Gelman's (2004) transform-sets task. Materials included a box with a removable lid and a collection of small toys (cars, lemons, dinosaurs, apples, frogs, and blocks). The child first completed four warm-up trials in which the experimenter held up a toy and labeled it (e.g., “This is a car”) and then put it inside the box and replaced the lid. The child was asked, “What's in the box?” The experimenter then performed one of two actions in front of the child: either the toy was removed from the box and replaced by a different item, or the box was rotated or shaken. The child was then asked, “Now what's in the box?” All children succeeded on all warm-up trials.

For the experimental trials, the child was instructed to “try to remember how many things are in the box.” The experimenter placed either a small number (two or three) or a large number (five or six) of toys into the box, labeled the set with the appropriate

number as she placed them in the box (e.g., “Here are two cars”), and covered the box with the lid. As in the warm-up trials, a memory check was performed on each trial (e.g., “How many cars?”). The experimenter then performed one of two manipulations on the set: the numerosity of the set was either changed (by adding or subtracting one toy) or was kept constant (by rotating or shaking the closed box). On addition and subtraction trials, a toy was added to sets of two or five, or subtracted from sets of three or six. After the manipulation, the child was asked about the quantity of toys in the box. On small number trials, children were asked, “Now, are there two or three [toys] in the box?” and on large number trials, “Now, are there five or six [toys] in the box?” The numbers were always presented in ascending order in the test question, such that the correct answer was presented first on half of the trials. Each child received two trials of each type (addition, subtraction, shaking, and rotation), for a total of eight trials. Half of the trials included small numbers, and half large numbers. Like Sarnecka and Gelman, we excluded all trials on which a child failed the memory check.

**Two-set task.** The two-set task was based on Condry and Spelke’s (2008) Experiment 5. Two brightly colored paper plates were placed side by side in front of the child. A set of five, six, seven, or eight small toys (cars, lemons, dinosaurs, apples, frogs, or blocks) was placed on each plate, as the experimenter drew attention to the objects (e.g., “Look, I have lots of cars here!”). On addition trials, each plate initially had the same number of objects; on rearrangement trials, the number of objects placed on the plates differed by one. The experimenter first pointed to the target plate (the plate to be manipulated) and identified the set with a number word (e.g., “This plate has six cars; there are six cars on this plate”). Attention was also drawn to the other (distractor) plate, without making mention of the number of toys on it (“Look, there are cars here too”). The experimenter then performed one of two manipulations on the objects on the target plate: either another toy was added to the set (“Look, I’m putting another car on this plate”), or the set of toys was rearranged on the plate (“Look, I’m putting these cars in a row”). After performing the manipulation, the child was asked to identify the plate requested by the experimenter. The test question either asked about the original number word label or a new number word label (“Can you point to the plate with five cars?”). Critically, only one numeral was presented at test, and it was offered as a potential label for one of two sets. Trials were counterbalanced for the location of the target plate (left or right), the number word used in the test question (original or novel), and, on rearrangement trials, the plate containing more toys (target or distractor). No more than two trials in a row were the same with respect to each of these variables.

Children received four types of trials: add–same (add to target plate, test on original number word); add–different (add to target plate, test on new number word); rearrange–same; and rearrange–different. Each child received two trials for each trial type presented in quasi-random order, for a total of eight test trials.

## Results

Results replicated the findings of both Sarnecka and Gelman (2004) and Condry and Spelke (2008) with a within-subject design. For the one-set task, children chose the original numeral on trials where the number of items stayed the same both on small

number trials (74%) and large number trials (70%). When the number of items changed, children responded with the same numeral on only 23% and 34% of small and large number trials, respectively. A binomial mixed effects model with trial type (add vs. rearrange), set size (small vs. large), and task order (one-set first or two-set first) as fixed within-subject factors and participant as a random factor revealed a strong effect of trial type ( $\beta = 2.73$ ,  $z = 4.99$ ,  $p < .001$ ), replicating Sarnecka and Gelman’s (2004) finding that children are more likely to choose a new numeral when a quantity is changed, whether the numeral has a known meaning or not. There was no effect of set size ( $\beta = 0.21$ ,  $z = 0.40$ ,  $p = .69$ ). Also, no effect of task order was found ( $\beta = 0.47$ ,  $z = 0.80$ ,  $p = .42$ ), indicating that children’s performance on the one-set task was not influenced by their prior participation in the two-set task (see Figure 1).

For the two-set task, on addition trials, children chose the original set on 54% of trials when asked to find the referent of the original numeral and on 52% when a new numeral was used. On rearrangement trials, the original set was chosen on 65% of original number word trials and on 69% of new number word trials. Here, a binomial mixed effects model with trial type (add vs. rearrange), label (same label vs. different label), and task order (two-set task first vs. second) as fixed factors and participant as a random factor revealed no significant effect of label ( $\beta = 0.07$ ,  $z = 0.20$ ,  $p = .85$ ) or trial type ( $\beta = 0.46$ ,  $z = 1.18$ ,  $p = .24$ ) and no interaction ( $\beta = 0.24$ ,  $z = 0.43$ ,  $p = .67$ ), replicating the findings of Condry and Spelke’s (2008) two-set task. Once again, no effect of task order was found ( $\beta = 0.07$ ,  $z = 0.25$ ,  $p = .80$ ; see Figure 2).

## Experiment 2

The first experiment showed the same pattern of data as the Sarnecka and Gelman (2004) and Condry and Spelke (2008) studies but with a within-subject design. In Experiment 2, we asked whether this pattern of results is specific to number or whether a similar pattern might also emerge for nonnumerical stimuli in an otherwise equivalent word learning experiment. If children’s judgments in Experiment 1 were due to pragmatic inference rather than number-specific knowledge that numerals denote precise quantities, then similar judgments should be found for novel words that denote kinds of objects. To explore this hypothesis, we created novel objects whose shapes could be

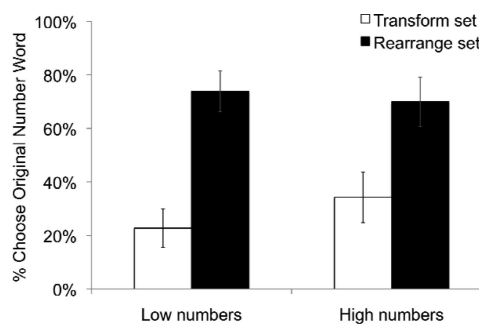


Figure 1. Percentage of trials on which children chose the original number word in the one-set task. Error bars represent standard error on participant means.

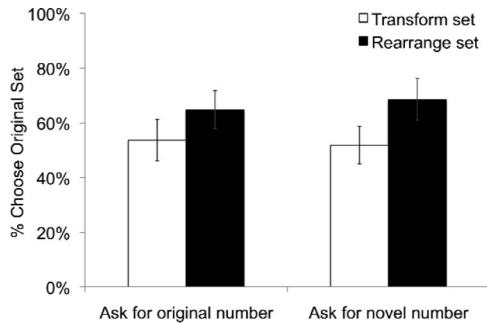


Figure 2. Percentage of trials on which children chose the target plate on the two-set task. Error bars represent standard error on participant means.

changed by the addition of a single piece. This manipulation provided a close match to the number manipulations in Experiment 1, which involved the addition of objects to an array. Also, it caused the novel objects to undergo a change in shape, a type of transformation that is known to be meaningful to children when learning nouns (e.g., Landau, Smith, & Jones, 1988).

## Method

**Participants.** Sixty-two children who were not tested in Experiment 1 participated in Experiment 2 ( $M = 3$  years 3 months; age range = 2 years 6 months–3 years 11 months). Children were recruited by the same means as in Experiment 1 and were also native speakers of English. As in Experiment 1, all children completed the give-a-number pretest to allow us to determine their knower level. Only children who were subset-knowers were included in the study. We identified 14 one-knowers, 23 two-knowers, 15 three-knowers, and 10 four-knowers.

**Procedure and stimuli.** The procedures in Experiment 2 were similar to those in Experiment 1, except that children were shown novel objects rather than sets of things. Also, each participant was given one of two tasks to assure that behavior on one task did not influence behavior on the other: (a) a one-referent, two-label, forced-choice task (*one-object task*) or (b) a two-referent, one-label, forced-choice task (*two-object task*). Half of the participants in each group were given “transform” trials, and half were given “rearrange” trials. Thirteen children participated in the two-object rearrange condition, while 17 participated in the

two-object, transform condition. Sixteen children participated in each of the one-object task conditions.

The key difference between this experiment and Experiment 1 was the stimulus set. Children were presented with unfamiliar objects instead of sets. We designed six novel objects, constructed from colored cardboard, small wooden blocks, and yarn. The objects were designed to have geometrically simple and distinguishable shapes. Also, each object was transformable: an additional piece (e.g., a block) could be added onto each toy to create a similar-looking object with a distinctly different shape. For example, one object had yarn wound around three blocks to create a triangle, but a piece could be added such that the yarn formed a square (Figure 3; see the Figure A1 in the Appendix for complete stimulus set and transformed alternatives). The six novel toys were each assigned two novel labels (one for labeling the original object, and one additional word for test trials). We used the following label pairs: *dax/speff*, *wuglfem*, *fendle/tulver*, *zerken/tibbit*, *toma/blicket*, and *rappletupa*.

**One-object task.** The one-object task consisted of six test trials. The experimenter showed children one novel object while labeling it (“Look what I have! This is a dax!”). In the transform condition, the experimenter then manipulated the object by adding a piece to it. In the rearrange condition, the experimenter lightly shook the object, without making any changes to its composition. All children were then asked the test question, “Now is this a dax or a speff?” These conditions were analogous to the large number trials in Sarnecka and Gelman’s (2004) transform-sets task. One difference between this task and the number tasks in Experiment 1 is that here the changed referent remained visible. This was necessary so that children could observe the object’s change in shape. Note that in Experiment 1 concealing the changed sets was necessary only to be certain that children could not use the visible sets to recount or estimate the new numerosity (rather than using the observed change by one item to guide an inference). Here, no such problem arose since the changed objects are entirely novel, and thus no prior associations with the labels could guide their judgments.

**Two-object task.** On the two-object task, the experimenter presented children with one novel object and labeled it (“Look what I have! This is a dax!”). A second identical object was also presented but without being labeled (“And look at this!”). Participants in the transform condition then watched as the experimenter transformed the labeled object. Children in the rearrange condition

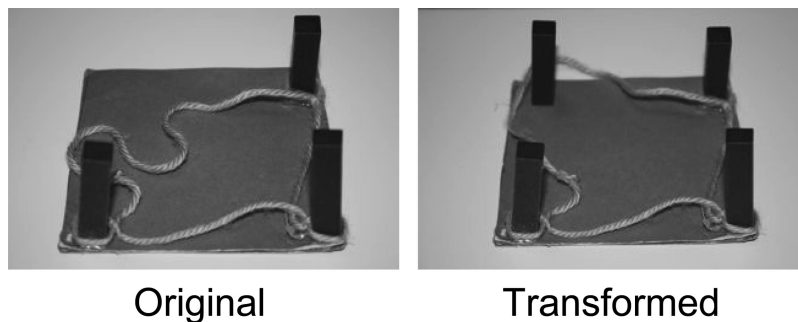


Figure 3. Example stimulus and transformed alternative from Experiment 2. See Appendix for photographs of all stimuli from this experiment.

saw the experimenter shake the labeled object. Children were then asked the test question, “Now can you point to the dax?” For both tasks, objects were presented in one of two quasi-random orders. The label for the target object was counterbalanced across participants.

## Results

As shown in Figure 4, the results for both the one-object and the two-object tasks were similar to the findings of Experiment 1. For the one-object task, children judged that the original label still applied after an object was shaken on 73% of trials, whereas children provided the original label when the object was transformed on only 44% of trials. A binomial mixed-effects model with condition (shake vs. transform) as a fixed between-subjects factor and subject as a random factor showed that this difference was significant ( $\beta = 1.64$ ,  $z = 2.86$ ,  $p = .004$ ). This result is analogous to our finding for the one-set task in Experiment 1, where children were more willing to assign the same label to a set in which the quantity remained constant than to a set in which the numerosity changed. Thus, whenever a single referent—whether an object or a set—was transformed by the addition of an item, children preferred a new label to the label used before the transformation.

For the two-object task, a binomial mixed-effects model showed no difference between the two manipulations ( $\beta = 0.03$ ,  $z = 0.03$ ,  $p = .98$ ). Whether the target object was changed or shaken, children chose the original target object when presented with the original label on exactly 74% of trials. These results are similar to those found in the two-set task in Experiment 1. When children saw two referents and only one was labeled, they were equally likely to assign a label to its original referent whether the referent changed or remained the same. To directly compare the results of Experiments 1 and 2, we constructed mixed-effects linear models comparing analogous trials.<sup>1</sup> For the one-referent tasks (i.e., one novel object or one set), we found no main effect of Experiment ( $\beta = 0.19$ ,  $z = 0.29$ ,  $p = .77$ ) and no interaction between experiment and trial type ( $\beta = 0.59$ ,  $z = 0.72$ ,  $p = .47$ ), confirming that children performed similarly across the one-object and one-set tasks. The same analysis performed for the two-referent tasks found no effect of experiment ( $\beta = 0.65$ ,  $z = 1.05$ ,  $p = .29$ ) and no interaction between task (object vs. set) and trial type (add

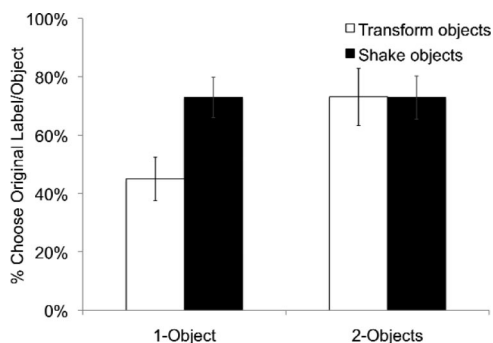


Figure 4. Percentage of trials on which children assigned the original label to the original referent on the one-object and two-object tasks. Error bars represent standard error.

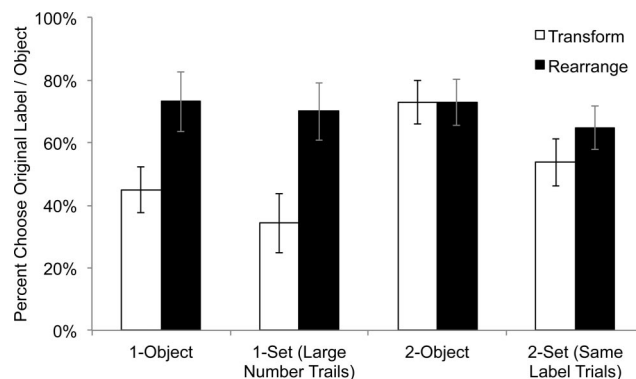


Figure 5. Comparison results from Experiment 2 and analogous trials from Experiment 1. Error bars represent standard error.

vs. rearrange;  $\beta = 0.66$ ,  $z = 0.81$ ,  $p = .42$ ), again showing no significant difference between children’s performance on number and novel noun trials (see Figure 5 for the comparison of the two tasks).

The reader might note that in both the two-set and two-object tasks, participants appeared to show a bias toward the original object in both the transform and rearrange conditions. This was true for the two-set task, but especially true for the two-object task, perhaps because of some property of the objects we used or the extent to which they were changed. This bias is not in conflict with our predictions: the critical result is that participants show no evidence of distinguishing between transformation and rearrangement manipulations, regardless of whether they are conducted on sets or on objects.

In sum, the same pattern of results was found in the object tasks and the set tasks. Whenever there was a single label and two possible referents, children preferred the originally labeled object whether the referent was rearranged or items were added to it. When there were two labels and a single referent, adding objects or parts to the referent led children to prefer a new label, while simply rearranging the referent led children to prefer the original label (see Figure 5).

## Discussion

In two experiments, we found that children make similar inferences regarding the reference of novel nouns and unknown numerals. In Experiment 1, we replicated findings previously reported by Sarnecka and Gelman (2004) and Condry and Spelke (2008) using a within-subject design. Like Sarnecka and Gelman, we found that when children heard a set labeled with an unknown number word (e.g., *five*), they preferred a novel number word (e.g., *six*) after a quantity change when the two labels were directly contrasted. When the set was rearranged instead of being transformed, children preferred the original label. However, we also found that children responded differently when they were presented with two sets and were asked to choose the referent of a single label (as in Condry & Spelke, 2008; Sarnecka & Gelman,

<sup>1</sup> For the one-set task, only large-number trials were used. For the two-set task, only same label trials were used.

2004). Children's responses were the same whether the target set had been transformed (e.g., by adding an item) or merely rearranged, suggesting that they did not make use of the fact that number words are exact in interpreting the label. In Experiment 2, we tested children with novel nouns and unfamiliar objects and found the same patterns of behavior. Participants in the one-object task responded like those in the one-set task in Experiment 1: when presented with a single novel object that was labeled and then transformed, children preferred a new label when it was directly contrasted with the original label. Participants in the two-object task showed the same pattern as those in the two-set task: when two identical objects were presented and only one was labeled, children made the same judgments regardless of whether the labeled object was transformed or merely shaken.

Our account of these data, described in detail later in this section, is that pragmatic inference, rather than domain-specific semantic knowledge of exactness, explains children's interpretation of unknown words in these tasks. However, another account of these data is that children use two distinct sets of assumptions to reason about nouns and numerals and that these separate assumptions generate similar results only by coincidence. For example, children may use domain-specific principles to guide noun learning, on the one hand, and similarly specific principles to guide number word interpretation, on the other. This idea, while perhaps explaining the one-referent tasks, cannot easily explain all of the data taken together, since children systematically fail to exhibit precise number knowledge on two-set tasks. As noted in the introduction, previous accounts have speculated that the two-set number tasks are more difficult than one-set tasks and thus that processing limits might cause differences in judgments. Besides failing to account for why children perform so differently on the two-set task for small and large numbers, this proposal does not explain why this difference disappears suddenly when children become CP-knowers. Although some explanation within the domain-specific perspective is perhaps possible, we believe that (a) positing domain-specific knowledge that number words have exact meanings requires stronger evidence and (b) a more parsimonious pragmatic account can explain the entire data set, without ad hoc assumptions about task difficulty. In our view, the existing evidence does not yet support positing domain-specific number knowledge.

Our suggestion is that before becoming CP-knowers, children do not know that number words are precise. Instead, to succeed at the one-set task, children make use of the same pragmatic abilities that they use when reasoning about novel nouns. As noted in the introduction, most accounts assume that by the time children are subset knowers, they understand that numerals denote the properties of sets, like the nonexact quantifiers *some* and *all*. On the basis of this knowledge alone, a child could assume that a change in quantity is *necessary* to warrant a change in label. However, this knowledge alone could not tell the child whether a particular change in quantity is *sufficient* to warrant a change in label (since adding one or two items to a set of "some fish" still results in "some fish"). Thus, if children lack semantic knowledge that numerals are exact, then they should have no basis for deciding whether a single label refers to one set or to another, as they are asked to do in the two-set experiments. However, in the one-set cases, children can exploit the pragmatics of contrast (Clark, 1990). After hearing one label used to refer to a set and seeing the

set transformed, children are then presented with a second numeral that is directly contrasted with the original one, an invitation to consider it as the label for the new set. If, like adults, children make the Gricean assumption that their interlocutor is cooperative, then they may assume that this novel label is relevant to the change in quantity<sup>2</sup> and select it on this basis (Grice, 1989)—for example, "If *six* isn't relevant to the change, why would the adult have mentioned it?"

In the two-set condition, the child does not hear two labels contrasted directly. This is important because, as shown by Condry and Spelke (2008), children are only able to contrast number words when they are explicitly counterposed. In their Experiment 1, children were shown two sets and were told, "This plate has five sheep, and there are sheep here as well. Now point to the plate with 10 sheep." Under these conditions, children were consistently able to use contrast (or mutual exclusivity) to pick out the unlabeled plate. However, in Condry and Spelke's Experiment 5 and in our two-set and two-object experiments, children heard, "This plate has five sheep, and there are sheep here as well" and saw a rearrangement before being asked to find the referent of a new label. In these cases, children failed to consistently choose the unlabeled referent (showing, if anything, a preference for the originally labeled referent), suggesting that this small difference was sufficient to disrupt children's use of contrast. If children had used contrast, then they should have succeeded in the two-set task, as they did in Condry and Spelke's Experiment 1. Consistent with this explanation, in a follow-up study reported in the supplemental materials of Condry and Spelke (2008), children failed at the one-set task when only one label was offered at test, rather than two. Specifically, they failed when a transformation occurred for unknown numbers, but not when tested with known numbers or when no transformation took place. These results strongly support the idea that pragmatic factors like contrast, rather than knowledge of precise numerosity, govern children's judgments for unknown numbers. In our account, because they cannot rely on contrast in the two-set task, children fail until they acquire the precise meanings of number words.

The idea that children make use of pragmatic information to guide their interpretation of unknown or novel words is consistent with previous studies of word learning, which show that young children deploy pragmatic strategies from early in acquisition. By at least age 18 months, children rely on speaker intent to mediate word learning, rather than direct associations between speech and perceptual stimuli (Akhtar, Carpenter, & Tomasello, 1996; Baldwin, 2000; Bloom, 2000; Diesendruck, 2005; Diesendruck & Markson, 2001; Tomasello, 1992; Tomasello & Barton, 1994). Also, children assume that new words contrast in meaning with known ones in a number of contexts, an assumption that is sometimes characterized as a form of Gricean pragmatic inference. For example, when children are shown both a familiar object (such as a car) and a novel object and are asked to interpret a novel label—for example, "Find the dax,"—they show a strong tendency to pick the novel object and do so as early as 18 months old (Carey & Bartlett, 1978; Golinkoff, Mervis, & Hirsch-Pasek, 1994; Mark-

<sup>2</sup> As mentioned previously, note that such a change in quantity is necessary, and thus the pragmatic inference will not apply if no change occurs.

man, 1990; Woodward & Markman, 1998). Similarly, as discussed in the introduction, children who know the meaning of *one* but not larger numbers systematically select a set of 5 over a set of 1 as the referent for the word *five*, despite not yet knowing its meaning (Wynn, 1992; see also Condry & Spelke, 2008). To explain these behaviors, Clark (1987, 1990) appeals to the pragmatic principles of contrast and conventionality. Children assume that the experimenter will use a conventional label to refer to an object. When they use a novel label, it must differ in meaning from all other labels and therefore is assumed to be the conventional label for the target object. Stated in Gricean terms (e.g., Clark, 1990; Gathercole, 1989), children assume that if an adult intends to refer to a familiar object that has a known label, then the adult should use that label, rather than some novel alternative (see also Diesendruck, 2005; Diesendruck & Markson, 2001).<sup>3</sup>

It is important to note that although past reports have argued that children use pragmatic inferences to identify the referents of novel words, this is not equivalent to acquiring their full lexical meanings, which in some cases, like color or number, may require months of additional learning (see Carey & Bartlett, 1978; Carey, 2010; Wagner, Dobkins, & Barner, 2012). For example, in her study of how children use contrast to infer the reference of number words, Wynn (1992) concluded that children used their knowledge of *one* to inform an inference about the likely referent of *five*. However, she did not conclude that by identifying the correct referent of *five*, children had therefore converged upon its exact numerical meaning. As Wynn showed, children require many months of experience with individual number words before acquiring their meanings. Even after acquiring the meaning of *one*, they may take as long as 6–9 months to acquire the meaning of *two*. In this case, it is clear that pragmatic competence, rather than semantic knowledge of the novel word, guides children's judgments (see also Condry & Spelke, 2008).

To conclude, children begin to exhibit pragmatic competence early in life and are able to make relatively sophisticated communicative inferences. This study shows one way in which children might use their pragmatic capacities to interpret novel words and, perhaps, to narrow their hypotheses about word meanings. Further, the study highlights the importance of distinguishing between semantics and pragmatics in the investigation of word learning. Without a consideration of pragmatics, researchers run the risk of overascribing semantic knowledge and thus positing overly powerful learning mechanisms to account for such knowledge. Similarly, where semantic competence is overestimated, children's pragmatic competence may be overlooked.

<sup>3</sup> We do not take a position here on whether word learning relies on domain-specific constraints, since it is possible both to have such constraints and to reason in a Gricean way when interpreting known words. Elsewhere, however, we argue that it is unsatisfying to posit distinct inferential mechanisms for word learning and for interpreting known words, especially since these inferences have almost identical formal structures (see Barner & Bachrach, 2010). We favor an account that explains differences between word learning and other language processing in terms of the different information structures required for each, and children's ability to represent and access these structures during sentence processing.

## References

- Akhtar, N., Carpenter, M., & Tomasello, M. (1996). The role of discourse novelty in early word learning. *Child Development, 67*, 635–645. doi: 10.2307/1131837
- Baldwin, D. A. (2000). Interpersonal understanding fuels knowledge acquisition. *Current Directions in Psychological Science, 9*, 40–45. doi: 10.1111/1467-8721.00057
- Barner, D. (2012). Bootstrapping numeral meanings and the origin of exactness. *Language Learning and Development, 8*, 177–185. doi: 10.1080/15475441.2012.635541
- Barner, D., & Bachrach, A. (2010). Inference and exact numerical representation in early language development. *Cognitive Psychology, 60*, 40–62. doi:10.1016/j.cogpsych.2009.06.002
- Barner, D., Chow, K., & Yang, S. (2009). Finding one's meaning: A test of the relation between quantifiers and integers in language development. *Cognitive Psychology, 58*, 195–219. doi:10.1016/j.cogpsych.2008.07.001
- Barner, D., & Snedeker, J. (2006). Children's early understanding of mass-count syntax: Individuation, lexical content, and the number asymmetry hypothesis. *Language Learning and Development, 2*, 163–194. doi:10.1207/s15473341l1d0203\_2
- Bloom, P. (2000). *How children learn the meanings of words*. Cambridge, MA: MIT Press.
- Bloom, P., & Wynn, K. (1997). Linguistic cues in the acquisition of number words. *Journal of Child Language, 24*, 511–533. doi:10.1017/S0305000997003188
- Brannon, E. M., & Van de Walle, G. A. (2001). The development of ordinal numerical competence in young children. *Cognitive Psychology, 43*, 53–81. doi:10.1006/cogp.2001.0756
- Briars, D., & Siegler, R. S. (1984). A featural analysis of preschoolers' counting knowledge. *Developmental Psychology, 20*, 607–618. doi: 10.1037/0012-1649.20.4.607
- Carey, S. (2009). *The origin of concepts*. New York, NY: Oxford University Press. doi:10.1093/acprof:oso/9780195367638.001.0001
- Carey, S. (2010). Beyond fast mapping. *Language Learning and Development, 6*, 184–205. doi:10.1080/15475441.2010.484379
- Carey, S., & Bartlett, E. (1978). Acquiring a single new word. *Proceedings of the Stanford Child Language Conference, 15*, 17–29.
- Clark, E. (1987). The principle of contrast: A constraint on language acquisition. In B. MacWhinney (Ed.), *Mechanisms of language acquisition* (pp. 1–33). Hillsdale, NJ: Erlbaum.
- Clark, E. V. (1990). On the pragmatics of contrast. *Journal of Child Language, 17*, 417–431. doi:10.1017/S0305000900013842
- Condry, K. F., & Spelke, E. S. (2008). The development of language and abstract concepts: The case of natural number. *Journal of Experimental Psychology: General, 137*, 22–38. doi:10.1037/0096-3445.137.1.22
- Davidson, K., Eng, K., & Barner, D. (2012). Does learning to count involve a semantic induction? *Cognition, 123*, 162–173. doi:10.1016/j.cognition.2011.12.013
- Diesendruck, G. (2005). The principles of conventionality and contrast in word learning: An empirical examination. *Developmental Psychology, 41*, 451–463. doi:10.1037/0012-1649.41.3.451
- Diesendruck, G., & Markson, L. (2001). Children's avoidance of lexical overlap: A pragmatic account. *Developmental Psychology, 37*, 630–641. doi:10.1037/0012-1649.37.5.630
- Fuson, K. C. (1988). *Children's counting and concepts of number*. New York, NY: Springer-Verlag.
- Gathercole, V. C. (1989). Contrast: A semantic constraint? *Journal of Child Language, 16*, 685–702. doi:10.1017/S0305000900010795
- Gelman, R., & Gallistel, C. R. (1978). *The child's understanding of number*. Cambridge, MA: Harvard University Press.
- Golinkoff, R. M., Mervis, C. V., & Hirsh-Pasek, K. (1994). Early object labels: The case for a developmental lexical principles framework. *Journal of Child Language, 21*, 125–155. doi:10.1017/S0305000900008692



- Grice, P. (1989). *Studies in the way of words*. Cambridge, MA: Harvard University Press.
- Landau, B., Smith, L., & Jones, S. (1988). The importance of shape in early lexical learning. *Cognitive Development, 3*, 299–321. doi:10.1016/0885-2014(88)90014-7
- Le Corre, M., & Carey, S. (2007). One, two, three, four, nothing more: An investigation of the conceptual sources of the verbal counting principles. *Cognition, 105*, 395–438. doi:10.1016/j.cognition.2006.10.005
- Le Corre, M., Van de Walle, G., Brannon, E. M., & Carey, S. (2006). Re-visiting the competence /performance debate in the acquisition of the counting principles. *Cognitive Psychology, 52*, 130–169. doi:10.1016/j.cogpsych.2005.07.002
- Lee, M. D., & Sarnecka, B. W. (2010). A model of knower-level behavior in number-concept development. *Cognitive Science, 34*, 51–67. doi:10.1111/j.1551-6709.2009.01063.x
- Lipton, J. S., & Spelke, E. S. (2006). Preschool children master the logic of number word meanings. *Cognition, 98*, B57–B66. doi:10.1016/j.cognition.2004.09.013
- Markman, E. M. (1990). Constraints children place on word meanings. *Cognitive Science, 14*, 57–77. doi:10.1207/s15516709cog1401\_4
- Piantadosi, S. T., Tenenbaum, J. B., & Goodman, N. D. (2012). Bootstrapping in a language of thought: A formal model of numerical concept learning. *Cognition, 123*, 199–217. doi:10.1016/j.cognition.2011.11.005
- Sarnecka, B. W., & Gelman, S. A. (2004). Six does not just mean a lot: Preschoolers see number words as specific. *Cognition, 92*, 329–352. doi:10.1016/j.cognition.2003.10.001
- Syrett, K., Musolino, J., & Gelman, R. (2012). Number word acquisition: cardinality, bootstrapping, and beyond. *Language Learning and Development, 8*, 190–195. doi:10.1080/15475441.2012.635545
- Tomasello, M. (1992). The social bases of language development. *Social Development, 1*, 67–87. doi:10.1111/j.1467-9507.1992.tb00135.x
- Tomasello, M., & Barton, M. (1994). Learning words in non-ostensive contexts. *Developmental Psychology, 30*, 639–650. doi:10.1037/0012-1649.30.5.639
- Wagner, K., Dobkins, K., & Barner, D. (2012). Slow mapping: Color word learning as a gradual inductive process. Manuscript submitted for publication.
- Wagner, S. H., & Walters, J. (1982). A longitudinal analysis of early number concepts. In G. Foreman (Ed.), *Action and thought: From sensorimotor schemes to symbolic operations* (pp. 137–161). New York, NY: Academic Press.
- Woodward, A. L., & Markman, E. M. (1998). Early word learning. In W. Damon, D. Kuhn, & R. Siegler (Eds.), *Handbook of child psychology, Volume 2: Cognition, perception and language* (pp. 371–420). New York, NY: Wiley.
- Wynn, K. (1990). Children's understanding of counting. *Cognition, 36*, 155–193. doi:10.1016/0010-0277(90)90003-3
- Wynn, K. (1992). Children's acquisition of number words and the counting system. *Cognitive Psychology, 24*, 220–251. doi:10.1016/0010-0285(92)90008-P

Appendix

Novel Objects From Experiment 2

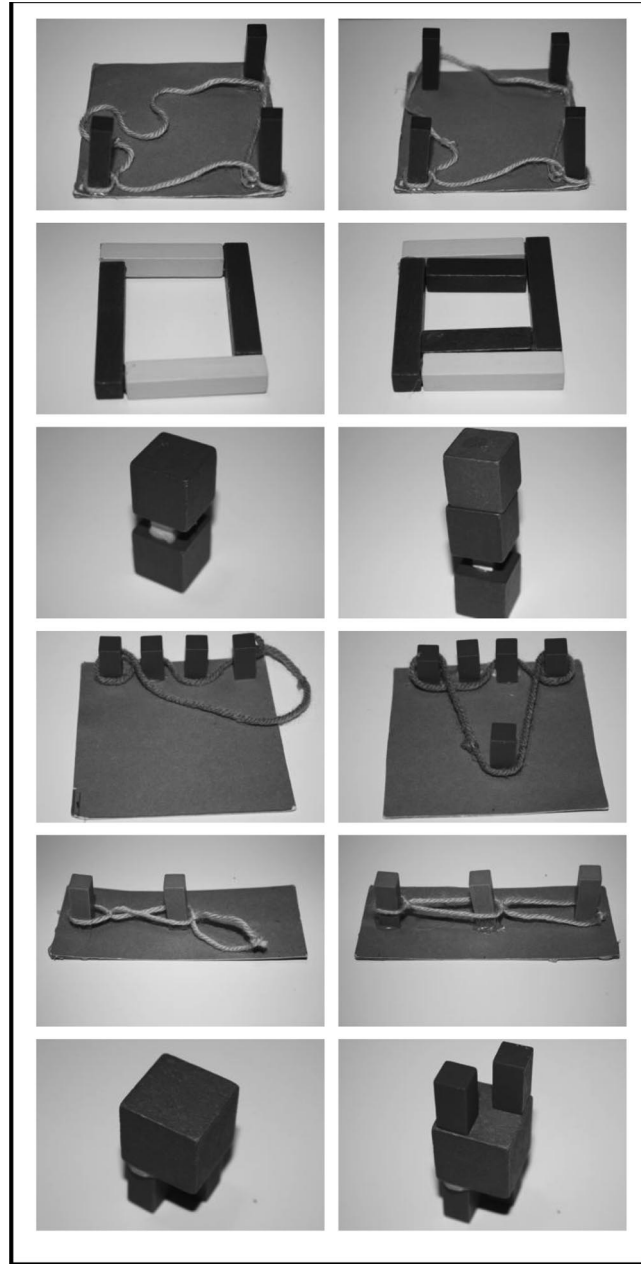


Figure A1. Items in the left column are depicted as they appeared prior to transformation, and in the right column as they appeared after the addition of a part.

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