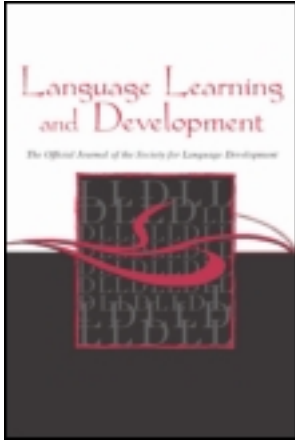


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How Can Syntax Support Number Word Acquisition?

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We expand upon a previous proposal by Bloom and Wynn (1997) that young children learn about the meaning of number words by tracking their occurrence in particular syntactic environments, in combination with the discourse context in which they are used. An analysis of the Childes database (MacWhinney, 2000) reveals that the environments studied by Bloom and Wynn (specifically, the partitive frame *x of the y*) do not on their own distinguish between number terms and those terms that are more generally quantity denoting. A set of novel word-learning experiments reveals that children (and adults) are aware of the semantic constraints of two of the syntactic environments targeted by Bloom and Wynn (the partitive frame and modification by *very*) but either rely upon or benefit from contextual information supporting learning where a number word can but need not be used in a sentence. We propose that children most likely combine their knowledge of counting principles (Gelman & Gallistel, 1978) with the discourse context to support the conclusion that a number word can appear in certain syntactic frames. Overall, the results indicate that recruiting syntax-semantics knowledge and assigning a number-word meaning to a new word is a delicate affair, even for adults, and suggest that there is a tight link between surface-level form, underlying constraints, and the discourse context in number word learning.

INTRODUCTION AND BACKGROUND

Number words present an interesting puzzle for theories of word learning. Their meaning is inherently abstract: “twoness” is not a property of individuals but rather of groups of individuals, be they concrete or abstract entities. Number words can also be used in a wide range of contexts for a variety of functions: a sequence, as in *One, two, three*; cardinal, as in *two cats*; ordinal, as in *the third house on the left*; measurement, as *eight minutes long or eight-minute mile*; and so on (cf. Fuson, 1988; Geurts, 2006 for discussion). What’s more, their distribution overlaps with that of other words, including nonexact quantifiers and adjectives (Bloom, 2000):

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the two/many/happy girls. How, then, given this complex and variable picture, do children manage to identify words as number words and acquire their meaning?

Two very different solutions have been proposed for how children go about acquiring the meaning of number words. One is based on the role of a set of nonverbal arithmetic and counting principles identified by Gelman and Gallistel (1978) (hereafter G & G), which constrain the properties of the sequence of words that can become the count list of a language. The counting principles include three “how-to-count” principles (one-one correspondence, stable order, cardinality) and two others (abstraction—anything can be counted—and order irrelevance). G & G hold that the nonverbal mental structure serves to help children identify the relevant data and use rules; this is because the principles underlying verbal counting are isomorphic to the nonverbal ones. Once the data and their use conditions are identified, a child can proceed to learn the verbal count list and where number words can be used. This position is often referred to as the “Principles before Skill” or the “Continuity Hypothesis,” which draws some support from young children’s ability to identify the difference between acceptable and unacceptable counting strings as well as the effect of unexpected changes in number (e.g., Cordes & Gelman, 2005; Gelman, 1993; Gelman and Gallistel, 1978; Gelman & Greeno, 1989; Greeno, Riley, & Gelman, 1984).

According to the “Skill before Principles” view or the “Discontinuity Hypothesis,” knowledge of these principles is emergent, and is therefore not what children initially rely on to identify and learn the meaning of number words (e.g., Briars & Siegler, 1984; Carey, 2004; Fuson, 1988; Karmiloff-Smith, 1992; Le Corre, Van de Walle, Brannon, & Carey, 2006; Le Corre & Carey, 2007; Spelke & Tsivkin, 2001). They set as their goal explaining how children identify and learn the meaning of number words from the verbal input as well as how knowledge of the principles is finally induced relatively late during the preschool years.

One line of the Discontinuity Hypothesis appeals to the possibility of bootstrapping number-word meaning from the language system (e.g., Barner, Libenson, Cheung, & Takasaki, 2009; Bloom & Wynn, 1997; Carey, 2004, 2009; Wynn, 1992). Although there are differences among these bootstrapping approaches, they all depend on there being a strong semantic similarity between number words and quantifiers and their having shared, but unique, distributions in the surface-level syntax. (See Clark & Nikitina, 2009, and Sarnecka et al., 2007, for relevant proposals that address how syntactic distinctions in the input could enable children to understand how plurality is encoded in a language.) Brown (1957) first discussed the possibility of relying on surface-level syntactic cues as a means of acquiring the meaning of words. Since then, subsequent experimental work has demonstrated the success of *syntactic bootstrapping* for the acquisition of nouns and proper names (Katz, Baker, & Macnamara, 1974; Hall, Lee, & Belanger, 2001; Macnamara, 1982), the meaning of verbs (Fisher, 2002; Fisher et al., 1994; Gleitman, 1990; Landau & Gleitman, 1985; Naigles, 1990), and adjectives (Booth & Waxman, 2003, 2009; Syrett, 2007; Syrett & Lidz, 2010). However, unlike previous accounts of word learning *within* the domain of language, a bootstrapping account of number-word learning would be an example of word learning *across* domains, whereby children would combine linguistic information with knowledge of the domain of natural number.

The clearest proposal for a syntactic bootstrapping of number-word meaning has come from Bloom and Wynn (1997) (hereafter B&W), following earlier suggestions by Wynn (1992). The motivation for their account is series of experimental findings by Wynn (1990, 1992)—since replicated in a number of laboratories—which appear to demonstrate that children go through a period of time during which they seem to know *that* number words refer to precise, unique numerosities without yet knowing *which* numerosity each number word picks out (cf. also

Condry & Spelke, 2008). According to Wynn, such behavior represents a transparent reflection of children's lack of knowledge of some of G&G's counting principles (most notably, cardinality), because if these principles were in place, children would know, for example, that *three* means "three" and not just "a numerosity that is not two."¹ Given this state of affairs, B&W offer an alternative to the Principles before Skills view and argue instead that in the absence of the counting principles, a constellation of "linguistic cues [in the input] may play a significant role in children's acquisition of number word meaning" (p. 514) and that "sensitivity to these different linguistic cues brings children to their initial stage of number word acquisition (knowledge that number words pick out numerosities)" (p. 515).

In this work, we ask whether a syntactic bootstrapping account of number-word learning is indeed viable and entertain two possible versions of such an account based on the role of language in learning about number-word meaning—one in which the cues unambiguously point to number-word meaning and one in which they perform a weaker function of pointing to the quantity-denoting status of number words. Taking as a starting point the set of linguistic cues identified by B&W, we ask whether such cues would be sufficient to bootstrap a specific-quantity-denoting interpretation of number words.² An analysis of these cues and a set of transcripts of child-directed speech from the CHILDES database (MacWhinney, 2000) demonstrate that while these cues are indeed informative about the semantic representation of words in these environments, they would need to be supplemented by additional information for children to arrive at the proper linguistic representation of number words.

In a set of two novel word-learning experiments, we then focus on two of these cues in particular—the partitive frame (e.g., *zav of the Y*) and modification by the adverb *very* (e.g., *very zav*)—and ask whether children are aware of the semantic constraints associated with these syntactic environments, and if so, whether they are capable of recruiting this knowledge when extending the meaning of a novel word to a number word interpretation in a particular discourse context. Anticipating our results, we find that children are indeed aware of the semantic constraints associated with the partitive frame and modification by *very*. Crucially, though, relying upon syntactic cues to arrive at number-word meaning appears to be a delicate affair, even for adults who possess the requisite linguistic and conceptual wherewithal to succeed (cf. Gillette, Gleitman, Gleitman, & Lederer, 1999). Even with the addition of a supporting discourse context that should allow the participant to narrow the denotation of a word in a quantity-denoting linguistic environment to that of a specific quantity, participants are still pulled toward an object-level, adjectival interpretation. We conclude that a syntactic bootstrapping account in conjunction with the counting principles could operate *in tandem* to help children identify number words and acquire their precise meaning.

¹Although note that G&G (1978) made clear that the three how-to-count principles are *interrelated*: the application of the cardinal principle depends on the child having first successfully tagged each item in a set using a stable-ordered list. Thus, it stands to reason that higher success rates would be positively correlated with smaller set sizes.

²A few notes on terminology. We do not assume that number words are 'quantifiers', given their variable function in language and relevant linguistic discussions about their compositional semantics and position in the syntactic structure (cf. Corver & Zwarts, 2006; Ionin & Matushansky, 2006). Here, we remain neutral and refer to them as denoting a specific quantity. However, by doing so, we do not mean to adopt one or the other semantic accounts of number word meaning. Finally, while we talk about the meaning of "number words," this position itself is not without controversy. To be more accurate, we could talk about the interpretation assigned to sentences with "numerals," or as G&G suggested, "numerlogs."

ROLE OF LINGUISTIC CUES IN NUMBER-WORD ACQUISITION

There are two distinct hypotheses about the role of the linguistic cues in a syntactic bootstrapping account of number-word meaning. The first hypothesis is that the linguistic cues could compel children to postulate a *new* lexical category (that of number words) or, if such a category is already in place in children's linguistic and/or conceptual space, the cues would allow children to identify novel words that belong to it. Such a hypothesis would limit the role played by G&G's counting principles since the linguistic cues would be doing all of the work, providing children with evidence about this linguistic category and the membership of number words in it. That is not to say that the counting principles would necessarily be absent, but that it would not be necessary to posit them, since the linguistic cues would accomplish the work for which they are supposed to be responsible.

The second hypothesis is that the linguistic cues could offer support for the quantity-denoting status of number words, putting them in the company of nonexact quantifiers (e.g., *some*, *many*, *all*) and would therefore allow children to make a first, important cut through the space of possible word meanings. However, additional refinements would then be necessary to further tease apart number words from these other quantity-denoting terms and narrow the interpretation of number words to lexical items denoting specific quantities marked by cardinality. This hypothesis leaves the door open for G&G's counting principles to play a role, since one of the main functions of these principles—in addition to rendering a cardinal numerosity that can be combined under arithmetic operations—is to help children identify and learn the relevant use rules not only for verbal counting but also for any other linguistic or communicative context in which number words can be used, and to constrain the process of acquiring number words in the same way that grammatical principles constrain the acquisition of language (cf. Gelman & Gallistel, 1978, p. 209).

Taking as a starting point the set of linguistic cues identified by B&W, we attempt to tease apart these two hypotheses. Our logic is as follows. If this complex of cues unambiguously points to a number-word meaning, then the strong version of the syntactic bootstrapping approach (the first hypothesis) remains a live possibility. However, if it does not, that severely weakens the plausibility of that approach. If, however, this set of cues is still informative about the quantity-denoting status of number words, then it would still be possible for them to provide the learner with evidence about the quantity-denoting status of number words, which would then need to be supplemented by other information (the second hypothesis).

B&W targeted the following four linguistic cues. First, number words can only appear with count, and not mass nouns (1a). Second, number words, unlike nonexact quantifiers and gradable adjectives, cannot appear with modifiers such as *too* or *very* (1b). Third, number words must precede and cannot follow adjectives (1c). Fourth, number words, unlike adjectives, can appear in the partitive frame (1d).

- (1) a. three bowls v. *three rice
- b. *too/very three v. too/very red
- c. three good children v. *good three children
- d. three of the children v. *happy of the children

Note that another surface-level cue that helps children to pick number words out of the speech stream is its appearance in a count list with a stable ordering. Because the counting principles and the arithmetic system include the requirement of an ordered list, children guided by these principles would recognize this ordered list in the environment. Presumably, because B&W were interested in cues arising from the syntax and the syntax-semantics interface, this cue was not included in their investigation. For discussion, see Bultinck (2005).

In their analysis of these cues, B&W took the following approach. They first argued that by comparing the distribution of words across these environments and capitalizing on the mapping between the surface-level syntax and the underlying semantic representations, children may begin to identify number words in the input. They then sought to establish (a) whether for three predetermined sets of lexical items (the number words *two* through *ten*, some quantifiers, and some adjectives) these distributional cues are present in caregiver speech in a way that is informative about number-word meaning and (b) whether these frequencies are also reflected in children's own productions, the latter being evidence that children are attending to the frequencies in the input. Restricting their focus to those utterances containing their targeted lexical items, B&W isolated the four linguistic cues and compared the distribution of the lexical items across these four syntactic environments. Their search led them to conclude that not only are these linguistic cues and the relevant lexical distributions found in caregiver speech, but that similar distributions are also found in children's speech.

Now, while B&W's corpus analysis yielded highly suggestive results about the viability of a syntactic bootstrapping approach to number-word learning, there are reasons to be cautious about their conclusions. First, it is not clear that these syntactic cues can, in B&W's words, "tell children that number words refer to absolute quantities of discrete individuals" (p. 519). None of these cues, either separately or in combination, uniquely picks out number words. Notice, for example, that the quantifiers *several* and *each* have the same distribution as number words with respect to these four cues (cf. Kayne, 2007; Sarnecka & Gelman, 2004).

(2) Count v. mass nouns

- a. *three rice (but three bowls)
- b. *several/each rice (but several bowls/each bowl)

(3) Modifiers

- a. *very three children
- b. *very several children/*very each child

(4) Position with respect to adjectives

- a. *good three children (but three good children)
- b. *good several children/*good each child (but several good children/each good child)

(5) Appearance in the partitive

- a. three of the children
- b. several/each of the children

Expanding the range of modifiers beyond those in (3) does distinguish between number words and, for example, *several*, since number words but not *several* can be modified by adverbs such

as *almost*, *approximately*, *exactly*, and *precisely*. This distinction highlights differences in their semantic representations, since number words but not *several* mark discrete points or intervals on a scale. Although this is an oversimplification, given debates surrounding semantic and pragmatic accounts of number words and scalar implicatures (cf. Carston, 1990, 1998; Chierchia, 2006; Fox & Hackl, 2006; Gazdar, 1979; Grice, 1989; Horn, 1972, 1989; Levinson, 2000).

However, even if we expand the list of surface-level cues, one problem remains: These cues are not universal. Cross-linguistically, language learners would need to rely on different syntactic cues to arrive at the same number word representation. It seems unlikely that children acquiring different languages would rely on a wholly different set of surface-level cues and yet converge on the same interpretation for these lexical items.

Restricting our attention to English, we are left with yet another problem, namely, that while the informativity of these cues may be promising when comparing a small set of hand-picked lexical items, such an approach does not do justice to the full range of candidates appearing across these syntactic environments. To take a concrete example, let us focus on the case of the partitive frame. Of the four linguistic cues discussed, this one in particular demonstrates the clearest mapping from the syntax to a part-whole or quantity denotation in the semantics and provides children with evidence about an environment in which number words can appear (as opposed to their inability to appear with mass nouns, follow adjectives, or be modified by *too* or *very*). (For discussion of the semantic constraints of the partitive frame, see Diesing, 1992; Jackendoff, 1977; and Link, 1987.)

While B&W began their corpus analysis with assumptions that the partitive frame picks out sets of individuals, and quantified the appearance of the partitive frame in the output results of a search for three sets of pre-selected lexical items, they did not turn their focus in the other direction and quantify the full range of lexical items occurring in the partitive frame. This omission is likely to oversimplify the learning process because it excludes other possible competitors for number words in that environment. At the same time, it also overestimates the parity of number words and other quantity-denoting expressions in this syntactic environment because it leaves out a host of other lexical items whose semantic representation allows them to appear in the same slot.

In the following section, we present the results of our corpus search of child-directed speech modeled after B&W's in order to test this hypothesis with the partitive frame. Our results demonstrated the partitive is, indeed, a powerful cue to the quantity-denoting status of words appearing in it, as argued by B&W (cf. p. 527); however, it is much less informative about a semantic representation encoding discreteness, individuals, or sets as their results may have indicated.

CORPUS ANALYSIS

Method

Following B&W, we analyzed transcripts of child-directed speech from the CHILDES database (MacWhinney, 2000), targeting an age range slightly beyond three years, as experimental work presented in Wynn (1990, 1992) suggests that it is not until around 3;6 that children reliably demonstrate knowledge of the cardinality principle. Details of the transcripts are given in Table 1. With this extended range, we were able to maintain two of B&W's target transcripts—Peter

TABLE 1
CHILDES corpora searched

<i>Child</i>	<i>Corpus</i>	<i>Age range</i>	<i>Files</i>
Peter	Bloom	1;9–3;1	1–20
Naomi	Sachs	1;9–3;5	6–89
Adam	Brown	2;3–3;5	1–31
Nina	Suppes	1;11–3;3	1–56

TABLE 2
Nonnumerical quantity-denoting lexical items found immediately before of

<i>Type of item</i>	<i>Examples</i>
amount terms (including quantifiers)	<i>all, any, bit, both, a couple, each, half, (a) lot, many, most, much, none, oodles, pair, plenty, (the) rest, some</i>
segment terms	<i>back, beginning, bits, bottom, edge, end, front, part, piece, side, top; body parts (e.g., head, neck)</i>
units of measurement	standard: <i>foot, hour, inch, minute, pint, pound, quart, week, year</i> non-standard: <i>bite, bottle, bowl, box, bucket, bunch, can, chunk, cup, drink, glass, pail, plate, reel, taste</i>

(Bloom et al., 1974, 1975) and Naomi (Sachs, 1983). However, since Eve's transcripts do not extend beyond the age of 3, we replaced hers with Adam, another selection from the Brown (1973) corpus. We also included an additional set of transcripts from the Suppes (1974) corpus, Nina.

We began with a wide filter, first searching for all occurrences of the word *of* in the selected transcripts.³ We then excluded instances where no lexical item or an uninterpretable utterance followed *of*, or where it was part of a *wh*-question, yielding frames such as *X of Y*. We then worked to narrow our results to what we term “potential partitives,” which are all phrases that have the potential to be partitives. We first tallied and categorized all of the lexical items occurring immediately to the left of the word *of*, the word in the *X* slot. We identified two categories of *X*—those that were quantity-denoting (see Table 2) and those that were not (see Table 3)—and kept only the quantity-denoting instances to feed forward into the next filter.⁴ For example, a phrase such as *afraid of you* where *X* is a predicate (i.e., *afraid*) would not count as a partitive, since the predicate does not denote a quantity. Together, these occurrences accounted for more than 40% of all instances involving *of*.

Here, we do not actually propose a means by which children would distinguish between quantity- and non-quantity-denoting instances of *X* in the partitive, since our goal is to determine whether children use the semantic constraints of the partitive frame—namely, that it restricted

³The first author performed the search and coded the results. A research assistant, blind to the goals of the research, performed reliability coding.

⁴We distinguished between two uses of *kind* and *sort*: one in which they refer to an object kind (e.g., *That's a kind of dog called a Basenji*. (Naomi, file 68)) and another that has a comparative sense (e.g., *It's kind of hard to understand*. (Naomi, file 13)). On the surface, the only way to distinguish these meanings is by attending to what precedes the lexical item in question. In either case, however, *X* does not denote a quantity.

TABLE 3
 Non-quantity-denoting) lexical items found immediately before *of*

<i>Type of item</i>	<i>Examples</i>
comparative	<i>enough, kind, less, more, (too) much, sort</i>
conjunction	<i>because, instead</i>
noun	<i>day (of the week), god, mommy, name, picture, president, story</i>
predicate	<i>afraid, ashamed, careful, full, made (out), nice, scared, tired</i>
preposition	<i>in front, on top, out, off</i>
type	<i>kind, sort</i>
verb ⁵	<i>build, get a hold, get rid, hear, make NP out, speak, take care/hold, think</i>

appearance to quantity-denoting lexical items—to deduce something about the meaning of number words. Of course, in a real word-learning scenario, one of the means by which children arrive at this conclusion is to attend to the distribution of lexical items in the *X* slot, so there is some inherent degree of circularity in the learning process (see Syrett & Lidz, 2010, for discussion). Notice, though, that if the child is not equipped with knowledge about what counts as quantity-denoting (and for example, includes all instances of *kind* and *sort*, as well as predicates, in their calculation), it becomes even harder to conclude that number words denote a specific quantity based on their presence in this linguistic environment.

We then turned our attention to the *Y* slot and identified instances of *Y* that were compatible with the partitive frame and a quantity interpretation. We kept those instances where *Y* was a definite or indefinite determiner (e.g., *the, a*) followed by a noun; a possessive or demonstrative (either followed by a noun, e.g., *his/those toy*, or as a full DP, e.g., *his/those*); an adjective-noun or quantifier-noun combination; a bare noun; or a pronoun. Again, we excluded instances where *Y* was a predicate (e.g., *orange* or *bumpy*). Note that including bare nouns such as *lots of animals* (Nina, file 3) or *spoonfuls of sugar* (Nina, file 53) also let in *pseudopartitives*. As these phrases also capture a part-whole relation (cf. Schwarzschild, 2006), they, too, are consistent with a quantity interpretation. Again, we do not make any claims about how the child would know to include or exclude certain lexical items to arrive at the partitive frame, since our interest is in the conclusions children can make about words appearing in this linguistic environment, provided they can identify the relevant frame. As with any other syntactic bootstrapping approach, we assume that the frame in question is a syntactically plausible unit and is identifiable to the learner.

Results

Table 4 illustrates the distribution of quantity-denoting words in the *X* slot of the potential partitives. The total number of tokens in which *of* appears is presented in Column A; the total number of “potential partitives” tokens (as defined in the previous section) is presented in Column B; and the distribution of categories within these tokens is captured in each of the columns in C, where the percentage is the number in that cell divided by the total number of ‘potential partitives’ tokens for that set of transcripts (from B).

⁵Verbs were in their conjugated forms.

TABLE 4

X of *Y* frames in caregiver utterances. *X* are number words and other 'quantity-denoting' terms; *Y* are words that allow for a part-whole relation, as defined in the previous section

transcript	column A <i>of</i>	column B 'potential partitives'	column C (relevant category/B)				
			number words		general quantity-denoting terms		
			number words >1	<i>one</i>	amount terms	segment terms	units of measurement
Peter	72	40	3	5	23	7	2
		55.6%	7.5%	12.5%	57.5%	17.5%	5.0%
Naomi	208	97	1	14	39	32	11
		46.6%	1.0%	14.4%	40.2%	33.0%	11.3%
Adam	377	178	3	19	45	75	36
		47.2%	1.7%	10.7%	25.3%	42.1%	20.2%
Nina	1286	545	6	29	188	277	45
		42.4%	1.1%	5.3%	34.5%	50.8%	8.3%
Total	1943	860	13	67	295	391	94
		44.3%	1.5%	7.8%	34.3%	45.5%	10.9%
		Average	2.8%	10.7%	39.4%	35.9%	11.2%

Inspection of the table makes it immediately clear that for every child, the appearance of "amount" terms and "segment" terms dwarfs that of number words greater than one and the number word *one* (with the exception of Peter's transcripts, where amount and segment terms do appear more often in the partitive than *one* does, but less dramatically than for the other children where segment terms are concerned). On average, "amount" and "segment" terms each represents over a third of the potential partitive tokens (39.4% and 35.9%, respectively) compared to only 2.8% for number words greater than one, and 10.7% for *one*. Analyzing the totals and collapsing the two number word categories, the difference in frequencies is more significant than would be predicted by chance ($\chi^2 = 613.26$, $p < 0.0001$).

To put these results in perspective, we revisit the results presented by B&W, who found that while usage of the partitive frame was rare in caregiver speech (both overall and relative to the other three targeted linguistic cues), quantifiers and number words appeared in it with similar frequency, and adjectives never did (see Table 5).

This pattern led B&W to suggest that the partitive can help tell children that "number words refer to absolute quantities of discrete individuals" (p. 519). However, once we consider the whole range of expressions occurring in this frame, we see that an occurrence of an expression *X* in a potential partitive at best allows the learner to conclude with some nontrivial probability that the expression, by virtue of being able to appear in a partitive, is most likely "quantity-denoting." Even this conclusion, however, is not without its caveats.

B&W argued that children could use the appearance of lexical items in the partitive frame to conclude that such words are "predicates over sets of individuals, and not individuals themselves." (p. 527). However, the sizable percentage of "segment terms" and "units of measurement," as seen in the last two columns of Table 4, suggests that it might be difficult to arrive at this conclusion. Expressions such as *bottom of the glass* (Adam, file 25), *neck of the*

TABLE 5
Results of partitive usage reported by Bloom and Wynn (1997), adapted from their figure 4 and text, p. 527

<i>transcript</i>	<i>number words (>1)</i>	<i>quantifiers</i>	<i>adjectives</i>
Eve	3/64 4.7%	12/572 2.1%	0 0%
Peter	3/22 13.6%	11/229 4.8%	0 0%
Naomi	1/22 4.5%	19/407 4.7%	0 0%

giraffe (Nina, file 13), or *top of the truck* (Peter, file 13) may indicate that the discourse entity referred to by the word following *of the* can be broken down into parts, but they do not indicate that the word preceding *of* quantifies over *sets* of individuals or picks out a *plurality* denoted by the *Y* item, which is what number words do. In these examples, the singular count nouns *glass*, *giraffe*, and *truck* are individual, whole objects, rather than collections of discrete individuals. (See Ferenz & Prasada, 2002, for relevant findings concerning children's knowledge of when plural marking on the *Y* item is necessitated or not.)

Finally, we note that while B&W found no occurrences of the partitive in the results from their adjective search, our results turned up 94 instances of "predicate" (or "adjective") tokens (see Table 3 for a description). Twelve of these 94 tokens involved the adjective *careful*, and 12 involved the adjective *nice*, both of which are frequent in both child-directed speech and children's early vocabularies (Dale & Fenson, 1996), and neither of which were on the list of adjectives searched for by B&W. Thus, once we consider the entirety of the expressions occurring in the partitive frame, we see appearance in the partitive frame could lead a word learner to assign a high probability to a *quantity* denotation (which is perhaps not surprising, given our sequence of filters to identify potential partitives), but that additional information would be needed to narrow down the interpretation to that of a *specific quantity*.

Given the occurrence of nouns and predicates in the *X* slot of the partitive frame, a reviewer suggested (similar to B&W) that the distribution of a word across syntactic environments, including the partitive, could allow children to correctly deduce that a word is a quantifier or denotes a quantity. Based on observations by Jackendoff (1977), the reviewer notes that because a partitive can appear as an argument of a verb (e.g., *Two/some of the cookies are missing, Who ate two/some of the cookies?*), the word in the *X* slot could only be a noun or a quantifier with a null noun, and not an adjective. Appearance in the preadjectival position (e.g., *two/some yummy cookies*) should rule out a nominal interpretation. Still, further information would still be needed to arrive at a number word interpretation.

Discussion

The combination of our review of the syntactic environments analyzed by B&W and the results of our corpus analysis leads us to be skeptical about whether these linguistic cues suffice for children

TABLE 6
X of Y frames in *child* utterances, excluding imitations of caregiver speech

<i>transcript</i>	<i>column A</i> <i>of</i>	<i>column B</i> 'potential <i>partitives</i> '	<i>column C (relevant category/B)</i>				
			<i>number words</i>		<i>general quantity-denoting terms</i>		
			<i>number words > 1</i>	<i>one</i>	<i>amount terms</i>	<i>segment terms</i>	<i>units of measurement</i>
Peter	158	81	3	12	33	31	2
Naomi	69	35	4	14	7	8	2
Adam	218	130	37	24	33	13	22
Nina	436	187	6	39	63	71	14
Total	881	441	50	89	136	123	41
		Average	11.7%	23.4%	29.7%	27.0%	8.3%

to unambiguously posit or identify a number word category, as a strong syntactic bootstrapping approach would require. However, the overall pattern suggests that the cues may perform another function, offering support for the quantity-denoting status of number words. The task at hand is now to determine whether these cues actually signal to children that words occurring in these environments are quantity denoting. As B&W did, we performed a search of the complementary child utterances in our targeted corpora, excluding direct imitations of caregiver utterances from previous lines in the same discourse. These results are presented in Table 6.

Not surprisingly, the results from the children closely parallel those of the adults. Minor divergences in percentages are easily accounted for by occasions in which a target phrase was uttered quite frequently (e.g., *two of them*, which occurs 35 times in Adam's files, or *one of these/those (noun)*, which occurs 13 times in Naomi's files and 25 times in Nina's).

However, there is a problem with making claims about a learning account based on children's productions. While they show that children are paying attention to the input and presumably performing an analysis of the frequency of the target lexical items as they co-occur with the relevant cues, we cannot tell whether learners can or do use such information to deduce something about the semantic representation of *newly encountered* words. B&W were well aware of this limitation and wrote that their corpus "analyses do not show a causal relationship between linguistic cues and children's knowledge, only that the requisite linguistic cues to number word meaning exist in the input to children, and that children have some understanding of the nature of these cues" (p. 529). They furthermore suggested directly testing their hypothesis with experiments: "One could expose two-year-olds to novel words presented in the linguistic contexts explored here to see if this leads them to interpret the words as referring to specific numerosities" (p. 529). Encouraged by this idea, we decided to pursue their suggestion.

In two word-learning experiments, we investigate whether children can use their knowledge of the syntax-semantics mapping to deduce whether a novel word appearing in a particular

syntactic environment should be assigned a quantity-denoting interpretation. Further, we investigate whether the discourse context in which the word appears performs the additional function of highlighting a specific quantity interpretation, allowing the learner to converge on a number-word meaning. For reasons outlined above, in these experiments, we focus on appearance of the partitive frame. We compare it with modification by the adverb *very*, an environment in which the appearance of number words are barred and for which we have independent evidence that even younger children are aware of some of its semantic constraints (cf. Syrett & Lidz, 2010).

EXPERIMENT 1: CONTRIBUTIONS OF THE PARTITIVE FRAME AND THE DISCOURSE CONTEXT

The goal of Experiment 1 was to expose children to a novel word occurring in the partitive frame (e.g., *pim of the cars*) to determine whether they are aware of the semantic constraints associated with this syntactic environment. We tested this by contrasting a quantity interpretation (i.e., “two”) with an adjectival one (i.e., “red”). We further manipulated the context of the word-learning scenario to make numerosity salient, thereby increasing the chance that children would narrow down their interpretation to that of a number word.

Method

Participants. Sixty children (28 girls, 32 boys; mean = 3;9, median = 3;10; range = 2;8 to 4;8) participated in this experiment and were randomly assigned to one of four different experimental conditions (baseline—no frame, no partitive frame at test, no partitive frame at test with quantity adjustment, partitive frame throughout). There were 15 children in each condition, and gender and age were comparable across the four conditions. Data from an additional 11 children who appeared to have a side bias and chose only one side or one character for all trials ($n = 6$), had difficulty paying attention ($n = 3$), or did not succeed on the baseline number task with quantities of two ($n = 2$) were excluded from the analysis. The children in both experiments were recruited from preschools or daycare centers in the New Brunswick, Lawrenceville, and Pennington, N.J., areas.

Participants were tested individually in a quiet room made available on the premises. All children were fluent speakers of American English, and most parents indicated that their children were native English speakers. Two parents of children in Experiment 1 indicated that another language was also spoken at home. (The data for these children were not excluded because they did not exhibit nonnative production during the task and patterned no differently from the other children.) Three parents did not provide information on native language. The majority of the participants in the experiments were White/Caucasian, although a small number of children were African American, Asian, Hispanic/Latino, or Indian.

Materials and procedure. Participants were told they were going to play a game in which they would learn a new word. The task employed a forced-choice paradigm. Participants were shown a series of images on each side of a MacBook Pro or Dell laptop computer screen

and asked to point to the image being labeled. The first author manipulated all stimuli and administered the experiments to the child participants.

The experiment was divided into two sessions: a *practice* session and a *test* session. The purpose of the *practice* session was to help children feel comfortable responding to the experimenter's question and to train them to point unambiguously to one of the two sides of the screen. Only one child across all experiments had difficulty pointing at the screen; this child was praised for her participation in our study but did not continue to the actual experimental session. The visual stimuli were .jpeg images of real objects (e.g., a bunny, a cupcake). The size of the images was controlled so that the size of the objects was comparable across trials (2–4" × 2–4"). The laptop screen was positioned on a table approximately 1.5 feet in front of the participants.

The *test* session was divided into four trials, each with two distinct phases: a familiarization phase and a test phase. See Table 7 for a representative trial. Participants were randomly assigned to one of two presentation orders.

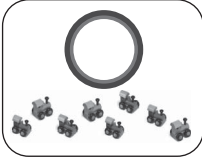

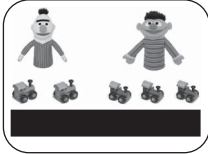
During the familiarization phase, children saw a set of eight objects at the bottom of the screen and were told that they were going to play a game with the objects. The objects were of the same kind (e.g., toy trains, balls, toy cars, toy horses), and each was one of three different colors (red, blue, green, or yellow). An area of containment (e.g., a circle or rectangle) then appeared in the open space above the objects. The experimenter indicated that she was going to place objects (e.g., trains) into the space and instructed the child to watch as she put two red objects into the area, one at a time. In the baseline "no frame" condition, the experimenter placed the novel word in a prenominal position (e.g., *pim trains*). In the other three conditions, she placed it in the partitive frame (*pim of the trains*). She then remarked twice that either *pim trains* or *pim of the objects* (depending on the condition) were in the space, encouraging children to notice this on the screen.

Numerosity and color were intentionally confounded, creating a cue-conflict situation: The number of objects placed in the space was two, and both objects were always red. Thus the word *pim* could, at least as far as the visual display was concerned, refer to either quantity or color. Likewise, in the baseline condition, in which the novel word was in prenominal position, its meaning was ambiguous. However, in the conditions in which *pim* occurred in a partitive frame (*pim of the objects*), the meaning of this novel word was restricted. To the extent that participants are aware of the semantic constraints associated with this syntactic environment, they should know that *pim* can be assigned a quantity interpretation (e.g., "two") but not an adjectival one (e.g., "red").

In the "no frame at test with quantity adjustment" condition, after the second object was placed in the space, a third red object was also placed there. The experimenter then remarked that this was too many objects and removed the third object, commenting that the resulting situation was better. This move was inspired in part by a suggestion in Wynn (1992) that a salient change in the numerosity of a set of objects accompanied by explicit commentary on the appropriateness of the application of a number word could benefit the child learning number words. (An experiment directly following her suggestion would have contrasted two distinct numerosities with two distinct number words.)

In all four conditions, after the objects were placed in the area of containment, a new screen appeared in which the objects were back in their initial position, but there was no area of containment, and the experimenter indicated that they would do something different with the objects. Two characters (Bert and Ernie) then appeared in the space above the objects. The experimenter

TABLE 7
Selected scenes from a representative trial in Experiment 1: Contributions of the Partitive Frame
and the Discourse Context (four conditions)

	<i>familiarization phase</i>	<i>test phase</i>	
	(1)  (green, blue, red trains)	(2)  (two red trains in circle)	
<u>condition</u>	(1): <i>Do you see these trains? Let's play a game with these trains. I'm going to put <u>pim of the trains</u> into this circle. Watch. Here's one. And here's another.</i> [no frame at test, quantity adjustment condition: third train added. <i>Oh no, wait, that's too many!</i> Train removed. <i>That's better!</i>] (2): <i>Look, <u>pim of the trains</u> are in the circle.</i> <i>Do you see that? <u>Pim of the trains</u> are in the circle.</i> <i>Now let's do something different with the trains.</i>	(Bert: two green; Ernie: three red) (trains returned to original positions)	
'frame'	<i>I'm going to give <u>pim of the trains</u> to either Bert or Ernie, and you're going to tell me [who has <u>pim of the trains</u>.] Get ready!</i>	<i>OK, look!</i> <i>Who has <u>pim of the trains</u>?</i>	
'no frame at test'	<i>. . . [who has <u>pim trains</u>.] Get ready!</i>	<i>OK, look!</i> <i>Who has <u>pim trains</u>?</i>	
'no frame'	(All underlined phrases were <u>pim trains</u> . The partitive did not appear anywhere.)	<i>OK, look!</i> <i>Who has <u>pim trains</u>?</i>	

said that she was going to give *pim objects* (in the “no frame” condition) or *pim of the objects* (in the other three conditions) to one of the two characters, and that the child would have to decide which one had them.

It is at this point, the “frame” and the two “no frame at test” conditions diverged. In the frame condition, the experimenter continued to use the partitive and said to the children that they would have to tell her who had *pim of the objects*. In the two no-frame at test conditions, the experimenter dropped the partitive frame and told the children that they would have to tell her who had *pim objects*. (Recall that in the baseline “no frame” condition, the partitive frame was never used, and the novel word always appeared in the phrase *pim objects*.) A black screen then went up over the objects, and the experimenter told the child to get ready.

At the start of the *test phase*, the black screen was lowered so that all of the objects were revealed and children could see which character received which set of objects. At this point, the numerical (e.g., two) and the adjectival (e.g., red) interpretations of *pim* were teased apart, so that one character had two objects which were not red (e.g., blue), while the other character had a set of red objects whose numerosity was different from two (always three). In the frame condition, the experimenter asked the child, “Who has *pim of the objects*?” In the other three conditions, the experimenter asked, “Who has *pim objects*?” The child was encouraged to point to one of the two characters. When possible, the child was asked for a brief justification of his/her choice. While some children provided a justification, most did not. The characters always remained in the same position, but the left-right orientation of the objects—and therefore which character was given the target set—was counterbalanced throughout the session.

Within two to three weeks of participating in the experiment, children were invited to participate in the “What’s on the Card?” task (Gelman, 1993) in order to assess their number knowledge up to the numerosity of five. This task ensured that each child who participated in the experiment knew the word *two* and could accurately identify a set of two objects. In brief, children were shown up to three different sets of cards, each with a row of stickers (e.g., butterflies, teddy bears) representing the numerosities one through five, and were asked to identify the set size. In response to the experimenter’s question (“What’s on this Card?”), children answered accordingly (e.g., “Two,” “That’s a two-butterfly card,” “There are two butterflies.”). Every child succeeded with *two* (labeling the cards correctly and reserving the target number for cards of that specific numerosity), and nearly all of the children succeeded through *four*. (Those who did not succeed with *two* were not included in the study.) We therefore predicted that the children should be able to arrive at the target number meaning.

Coding of participants’ responses. The dependent measure was the percentage of occasions on which participants chose the character with two non-red objects. This was averaged for each participant across the four trials, then across all participants for each of the four conditions. In the results section, we refer to this measure as the percentage of “quantity” interpretations rather than the percentage of “numerical” interpretations, since we cannot unambiguously say that if a child chose the character that had two objects s/he thought that the word meant “two.” Indeed, it is possible that a child (at least initially) assigned another quantity interpretation to the novel word (e.g., “some”), but in the test phase, where the numerosities of two and three were pitted against each other, s/he chose the character with two objects, because that numerosity represented a better match with what was seen during the familiarization phase (where a set of two was referred to as *pim*). What is important, however, is that children who chose the character with two non-red objects apparently did not assign an adjectival interpretation along the lines of red to the novel word.

Results

Of interest is the percentage of time children assigned a quantity—as opposed to an adjectival—interpretation to the novel word. Because we found no effects of age, items, or order, we average together all participants and items within a condition. In the baseline no frame condition, in

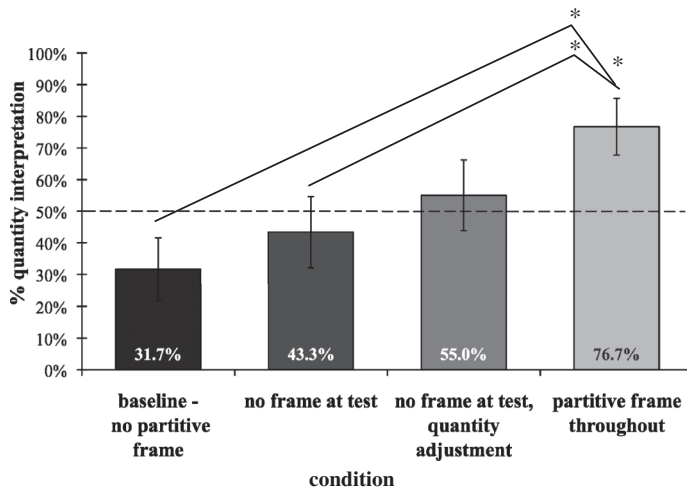


FIGURE 1 Percentage of children's quantity interpretations in the four conditions in Experiment 1: Contributions of the Partitive Frame and the Discourse Context.

which the novel word never appeared in the partitive frame and always appeared in the ambiguous prenominal slot, only four of the 15 children assigned the novel word a quantity interpretation (i.e., they chose the character with the two non-red objects) for more than half of the trials, resulting in an overall quantity interpretation of 31.7%. When the novel word appeared in the partitive frame during familiarization but not at test, six of the 15 children assigned a quantity interpretation for more than half of the trials for an overall percentage of 43.3%. While the explicit adjustment of the numerosity to which the novel word applied increased the percentage of quantity interpretations to 55.0%, this percentage still remained at chance level, with eight of the 15 children assigning a quantity interpretation for more than half of the trials. The highest percentage of quantity interpretations (76.7%) was observed in the frame condition. In this condition, in which the novel word appeared in the partitive frame throughout the experiment, 11 of the 15 children assigned the novel word a quantity interpretation more than half of the time (see Figure 1).

A Kruskal-Wallis test comparing the percentage of quantity interpretations across the four conditions revealed a significant difference between conditions ($H = 8.69$, $p = 0.03$), with paired Wilcoxon signed rank tests revealing significant differences between the frame condition and the no frame ($U_A = 181$, $p < .01$) and "no frame at test" ($U_A = 162.5$, $p = .02$) conditions, but not from the "no frame at test, quantity adjustment" condition ($U_A = 148$, $p = .07$). There was not a significant difference between the no frame and no frame at test for the quantity adjustment conditions ($U_A = 144.5$, $p < .10$), and the no frame at test did not differ from the other two conditions in which the frame did not appear at test (v. no frame ($U_A = 128.5$, $p = .26$); v. no frame at test, quantity ($U_A = 127$, $p = .28$)). Single-sample Wilcoxon signed rank tests comparing the four conditions to a .5 median chance level revealed that only the frame condition differs

significantly from chance ($p = 0.01$; p values in other conditions: no frame = 0.85, no frame at test = 0.53, no frame at test, quantity adjustment: = 0.83).

The consistent presence of the partitive frame in the experimental context therefore appears to have helped constrain the meaning of the novel word, guiding children to assign a quantity-denoting interpretation to *pim*. While presence of the frame during familiarization put children on the path to increased percentage of quantity interpretations, mere introduction of the frame was not enough. In fact, not even an explicit adjustment of quantity boosted the percentage above chance level. This is not to say, however, that children were not attending to quantity at all in the three no frame conditions. Indeed, we were struck by the fact that a small number of children in the baseline no frame condition who apparently chose based on color remarked on the difference in numerosity between the two characters during the experimental session. Despite this observation, though, the most likely candidate for the interpretation of the novel word was not one referring to quantity and that other possible interpretations were considered without further linguistic information constraining the hypothesis space at that time. It seems unlikely that in the no frame at test condition children simply forgot that the partitive had been used just one sentence earlier (for multiple trials).

Discussion

In this experiment we asked whether children are aware of the semantic constraints of the partitive by evaluating their ability to map a novel word occurring in this frame to a quantity denotation. The results suggest that they are. Given a choice between a property such as “red” and a numerosity such as “two,” children presented with a novel word in a phrase such as *pim of the trains* assigned the novel word a quantity interpretation significantly more often than what would be expected by chance. They also assigned a quantity interpretation significantly more often than if the novel word never appeared in the partitive frame at all.

Still, we note that the partitive frame alone did not uniquely control children’s interpretation of the novel word. Since the target subset seen during familiarization was always composed of two red objects, and the characters at test always had two non-red or three red objects, number (two v. three) was always pitted against color (red v. non-red) for the interpretation of the novel word *pim*. Thus, the discourse context served to narrow the range of possible interpretations by supporting a specific-quantity-denoting interpretation.

As demonstrated by the two no frame at test conditions, although children are aware of the semantic constraints of the partitive frame they nevertheless seem to experience difficulty extending word meaning to a quantity interpretation when the novel word appears outside the test frame. Even though children initially heard the novel word in the partitive and even when they were shown a salient contrast in quantity when the novel word was applied to the set, they were either unwilling or unable to assign this word a quantity interpretation once the partitive frame was dropped at test (e.g., *Who has pim trains?*) or never gave the word a quantity interpretation.

The pattern observed with the no frame and no frame at test conditions is also reminiscent of a pattern we have observed when running the “what’s on the card” task. When children are first shown a card with one or more objects on it and asked, “What’s on the card?” more often than not their initial response is one that refers to the object kind (e.g., *A teddy bear!* or *Teddy bears!*) The experimenter then responds affirmatively with a number word (e.g., *You’re right! That’s*

ONE bear! This is a ONE-BEAR card!). After this, most children then follow suit when asked about subsequent cards, providing a number word in their response. It is not entirely surprising that children's inclination in the nonframe conditions would be to map the novel word onto an interpretation that picks out an object-level property.

Our results further raise the following questions: Is word extension itself difficult when the two competing interpretations are within the Determiner Phrase (DP)-level (i.e., adjective and number), or is it *extension to number-word meaning* itself that is difficult? This distinction bears upon any syntactic bootstrapping hypothesis that calls upon a learner to use the rules of language to arrive at a number word interpretation. The possibility that *two* within-DP interpretations could be responsible for the chance-level performance in the nonframe conditions arises from the observation that studies in syntactic bootstrapping often pit two across-category interpretations against each other (e.g., noun v. adjective, or noun v. verb) (cf. Bernal, Lidz, Millotte, & Christophe, 2007; Booth & Waxman, 2003, 2009; Waxman & Booth, 2001) or two variants of the same category (e.g., count v. mass or count v. proper nouns, or causativity or transitivity in verbs) (cf. Arunachalam & Waxman, 2010; Fisher, 2002; Hall et al., 2001; Katz et al., 1974; Naigles, 1990; Scott & Fisher, 2009; Yuan & Fisher, 2009). Could it be that when the two interpretations being considered are from different grammatical categories (i.e., adjective, numeral) but share similar syntactic positions (i.e., are both located in the Determiner Phrase) that this makes the assignment of a word meaning difficult? Or is it the case that word extension is made more difficult when the target interpretation is that of a number word (perhaps by virtue of it referring to a set-level, and not an object-level property)? We explore these questions in Experiment 2.

EXPERIMENT 2A: CONTRASTING OBJECT AND SET SIZE WITH THE PARTITIVE AND *VERY*

Of interest in this experiment is whether children in the previous experiment had difficulty with word extension within the DP or extension to number-word meaning when the novel term(s) were not in the frame condition. To pursue these alternatives, we devised a new word-learning task in order to compare participants' ability to extend the meaning of a novel word used in a partitive frame to their ability to extend meaning when the word is modified by *very*. Importantly, appearance in the partitive frame and modification by *very* (followed by a noun) both place the novel word in the DP. To the extent that performance differs between the two conditions, we attribute this to a difference in the interpretation being accessed for the novel word, all else being equal.

As in the no frame at test conditions of Experiment 1, we are interested in how often participants assign the novel word a quantity interpretation when it is presented in an ambiguous surface-level position at test, after having been presented in a context that either allows such an interpretation—the partitive—or one that does not—modification by *very*. In addition, in order to control for conceptual and linguistic development, in this experiment we also included a group of adult native speakers of English. If adults behave like the children in our experiment, we have evidence about the relative difficulty of word extension, independently of the role played by potential conceptual or linguistic limitations in younger children.

Method

Participants. Twenty-four children (14 girls, 10 boys; mean = 3;10, median = 3;6, range = 2;7 to 4;4) participated. They were randomly assigned into one of two experimental conditions (12 per condition). Data from an additional seven children who had an apparent side bias ($n = 4$) or had difficulty paying attention ($n = 3$) were not included in the analysis. As in Experiment 1, two parents indicated that another language was spoken at home, but these children behaved no differently from the others in the class or in terms of their participation during the experiment, so their data were included. Twenty-six undergraduates (13 females, 13 males; range = 18–21 years with one 27-year-old outlier) from Rutgers University who were fulfilling an experimental requirement for a Psychology course also participated, 13 per condition. Data from three additional participants who were confused by task instructions before the task even began and even after repetition were not used. All participants were native speakers of English.

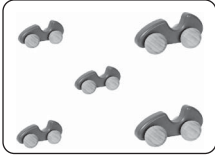
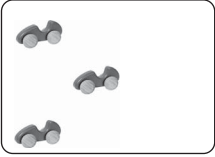
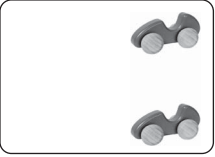
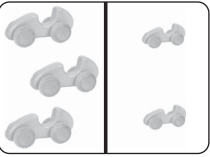
Materials and procedure. The “cover story” for the experiment was that a dragon liked learning new words, and the participants were playing a game with him to help him learn about the word *zav*. Adult participants were told that the experiment was intended for preschoolers and that the experiment was indeed as easy as it seemed, so that they did not overinterpret the task. Before the beginning of each session, the dragon appeared on the computer screen and announced, “I like learning new words. Today we’re going to play a game to learn about the word *zav*. If you listen carefully, you can help me figure out what the word *zav* means. Are you ready? Let’s play!” The dragon reappeared briefly throughout the experiment and at the end to encourage participants to continue and remind them about the purpose of the game. A male native speaker of American English recorded the voice of the dragon. These sound files were edited in the same way as the female speaker’s stimuli.

Participants were randomly assigned to one of two between-subject conditions: one in which the novel word was in the partitive frame (e.g., *zav of the cars*) and one in which the novel word was modified by *very* (e.g., *the very zav cars*). In each case, participants were asked to respond to five trials with five different objects across the experimental session. Participants were randomly assigned to one of two predetermined trial orders. An analysis revealed no item or order effects. Each trial had the same structure, modeled after the intermodal preferential looking paradigm (cf. Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987; Hirsh-Pasek & Golinkoff, 1996; Hollich, Rocroi, Hirsh-Pasek, & Golinkoff, 1999; Spelke, 1979) and previous word-learning studies (cf. Booth & Waxman, 2003, 2009; Waxman & Booth, 2001). See Table 8 for a representative trial. (The “control” condition indicated on the bottom row is included as part of Experiment 2b.)

A four-second screen displaying an animated animal (a spider or a snail) accompanied by a musical sound effect signaled the beginning of each trial. A blank screen then appeared for three seconds, and a female voice invited the participants to look at some objects (e.g., “Let’s look at cars!”). The trial then proceeded, and was segmented into three distinct phases: *familiarization*, *contrast*, and *test*.

During the *familiarization phase*, participants were shown a set of objects and had their attention drawn to them (e.g., “Yay! Cars!”). They then heard a subset of the objects labeled with the target word *zav* (e.g., “Look! Zav of the cars are different! Can you see that zav of the cars are different?” or “Look at the very zav cars! Can you see the very zav cars?”). The target subset was composed of two big objects and was contrasted with three small objects on the other side of the

TABLE 8
Representative trial for Experiment 2a

	<i>familiarization phase</i>	<i>contrast phase</i>		<i>test phase</i>
	10 seconds	8 seconds	5 seconds	12 seconds
				
partitive condition	Look! <u>Zav of the cars</u> are different. Can you see that <u>zav of the cars</u> are different?	Oh no! What happened? <u>Zav of the cars</u> are missing! Where did those cars go?	Yay! Here they are!	Yay! Look at these cars! Where do you see <u>zav cars</u> ?
very condition	Look at the <u>very zav cars</u> ! Can you see the <u>very zav cars</u> ?	Oh no! What happened? The <u>very zav cars</u> are missing! Where did those cars go?	Yay! Here they are!	Yay! Look at these cars! Where do you see <u>zav cars</u> ?
prenominal control condition	Look at <u>those zav cars</u> ! Can you see <u>those zav cars</u> ?	Oh no! What happened? <u>Those zav cars</u> are missing! Where did those cars go?	Yay! Here they are!	Yay! Look at these cars! Where do you see <u>zav cars</u> ?

screen. As in Experiment 1, the visual stimuli were .jpeg images of real objects and included pictures of toy cars, balls, toy horses, boots, and hats. The size of the images was comparable across trials, and the ratio of big to little objects during the familiarization and test phases remained constant (approximately 1.5:1).

Note that during familiarization, the wording in both conditions serves to draw participants' attention to the objects on the screen. In the partitive condition, the wording not only indicates to the participants *that* a subset of items differs in some way but should also invite participants to determine *which* subset is different and *how* it differs. Furthermore, semantic constraints of the partitive should highlight a quantity, be it vague or precise. Note that whatever this quantity is, it cannot be the entire set, since all of the objects do not differ from each other; two of the objects are the same as each other on every dimension, and three of the objects are the same as each other on every dimension. Moreover, the members of these two sets differ from each other only with respect to the dimension of size. While the wording in the *very* condition also highlights a salient property of the objects on the screen, it is perhaps not as effective at singling out a proper subset of items at this point. This is because *very* appears with a wide range of adjectives as an intensifier and could be understood as referring to a property of a proper subset (e.g., the "big" or "small" cars) or the entire set of objects on the screen (e.g., the "pretty," "shiny," "nice" cars, etc., which could be all of them).

A female native speaker of American English (the first author) recorded the auditory stimuli in a sound-attenuated recording booth. The speaker read from a script and produced the stimuli in

a style modeling the prosody of child-directed speech. The first author then edited the sound files using Praat software (Boersma & Weenink, 2007), controlling for articulation, pitch, amplitude, length, and overall consistency.

Next, during the *contrast phase*, the target subset disappeared, and the speaker asked what happened, again placing the target word in the syntactic context for the condition (e.g., “Oh, no! What happened? Zav of the cars are missing!” or “The very zav cars are missing!”). The subset then reappeared, and the voice announced their return. Before the test phase, a blank screen appeared for four seconds, and the speaker invited the participants to look at more of the same kind of object (e.g., “Let’s look at more cars!”).

During the *test phase*, two new sets of objects of the same kind but of a different color appeared on either side of the screen. On one side of the screen there were two small objects, while on the other side there were three big objects. A thick black line separated the two sides. Thus the two competing interpretations were teased apart, such that number (two v. three) was always pitted against size (big v. small). Left-right orientation of the objects was counterbalanced throughout the session. In each of the conditions, the speaker said the same thing during this phase. She first directed the participants’ attention to the objects on the screen and then asked them which side had the “zav” objects, placing the novel word in the prenominal position, thereby asking participants to extend the word meaning beyond the target linguistic context for their specific condition. Participants’ choice of side during the test phase was then analyzed.

Children were asked to point to the objects to indicate their selection. Adult participants were given a response booklet at the beginning of the experimental session and were asked to record their responses for the five trials on separate, consecutive pages. On each page, the words “LEFT” and “RIGHT” were written, and participants were asked to circle one of the two choices and then turn the page. “LEFT” and “RIGHT” labels were also placed on either side of the computer screen for adult participants and their attention was drawn to these labels at the beginning of the session, so that there would be no confusion about the choice of side. Adults were run individually or in groups of two, while the experimenter was in the room with them. They were given clipboards to shield their responses from each other, and were asked to resist reviewing their responses during the experimental session.

Coding of participants’ responses

The dependent measure was the percentage of occasions on which participants chose the side of the screen with two small objects. This percentage was averaged over the five trials for each participant, then across all participants in each condition. As in Experiment 1, we refer to this measure as the percentage of “quantity” interpretations, since we cannot unambiguously say that if a participant chose the side of the screen with two objects they thought that the number word meant “two.” We can conclude, however, that participants who chose the side with two objects did not assign an adjectival interpretation along the lines of “big” to the novel word (and likewise for the “very” condition).⁶

⁶The term *adjective* or *adjectival* is shorthand for (*relative*) *gradable adjective*, since only adjectives that allow for such an interpretation can be modified by *very* (e.g., *very big* v. **very wooden*) (cf. Bartsch & Venneman, 1972; Kennedy, 1999).

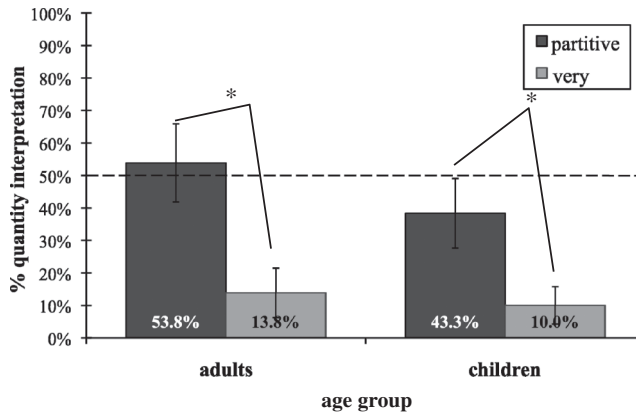


FIGURE 2 Percentage of adults' and children's quantity interpretations in the two conditions in Experiment 2a: Contrasting Object and Set Size with the Partitive and *Very*

Results

We begin by analyzing the performance of the adult participants presented in Figure 2. As before, the dependent measure is the percentage of occasions on which participants assigned a quantity interpretation. In the partitive condition, adults assigned the novel word a quantity interpretation 53.8% of the time. By contrast, in the *very* condition, they assigned *zav* a quantity interpretation only 13.8% of the time. A Mann-Whitney test revealed a reliable difference between the two conditions ($U_A = 45$, $z = 2$, $p = .02$). Furthermore, a single-sample Wilcoxon signed rank tests comparing each condition to a .5 median chance level revealed that the partitive condition did not differ significantly from chance ($p = .75$), while the *very* condition did ($p = .008$).

However, further examination of performance in the partitive condition revealed a split among participants. Four adults accessed the quantity interpretation 100% of the time, and four adults never accessed it. Of the remaining five, one accessed the quantity interpretation on the first trial only then patterned with the 0% acceptance group for trials 2–5. While the remaining four did not access this interpretation on trial 1 and maybe trial two, they favored it on trials 3–5 100% of the time. If we restrict our analysis to trials 3–5, we observe a categorical difference between two groups of participants: eight at 100% acceptance and five at 0% acceptance. Thus, the apparent chance pattern is the result of a misleading outcome of averaging responses (see Restle, 1962).

Turning now to the children's responses, also in Figure 2, we once again see a qualitative difference between the two conditions. Not only were children in the partitive condition unable to consistently access a quantity interpretation, but they also never supplied a justification that suggested such an interpretation when their choice was correct. This was so, despite some children having tagged and counted the objects they saw during training or familiarization. By contrast, children in the *very* condition almost never accessed a quantity interpretation, and half of these children explicitly said that *zav* means “big” or pointed out its role in distinguishing the “mommies” from the “babies” among the objects.

In the partitive condition, children assigned the novel word a quantity interpretation only 38.3% of the time, and only four of the 12 children accessed a quantity interpretation more than half of the time, which is no different from chance performance (binomial probability $p = .12$). In the *very* condition, children assigned the novel word a quantity interpretation only 10% of the time, and only one of the 12 children in this condition accessed a quantity interpretation more than half of the time, which is significantly below chance performance (binomial probability $p < .01$). Likewise, a single-sample Wilcoxon signed rank tests comparing each condition to a .5 median chance level revealed that the partitive condition did not differ significantly from chance ($p = .43$), while the *very* condition did ($p = .002$). This pattern is similar to that of the adults. While neither condition exhibited a trend towards the quantity interpretation, a Mann-Whitney test revealed a significant difference between the two conditions ($U_A = 110.5$, $z = -2.19$, $p < .02$), and adults were no more likely than children to access a quantity interpretation in the ‘partitive’ condition ($U_A = 90.5$, $z = -0.65$, $p = .26$).

Discussion

Experiment 2a served to determine whether word extension itself is difficult when the two competing interpretations are within the DP-level (i.e., adjective and number word interpretations) or whether it is extension to number-word meaning that is difficult for children.

The results suggest that what is difficult is *extension to number-word meaning*, for both children and adults. Indeed, both groups performed at chance level in the partitive condition, thereby replicating the results of the no frame at test condition in Experiment 1 for children. Of note is that both groups patterned similarly and rarely assigned the novel word a quantity interpretation in the condition where it was modified by *very* (13.8% and 10% for adults and children, respectively). The behavior of children and adults in this condition indicates that word extension itself is not what causes difficulty in the partitive condition. Instead, extension to number-word meaning given this frame seems to be the source of difficulty. It is noteworthy that even adults were not universally successful in mapping the novel word to a number word interpretation in the partitive condition.

Further consideration of the adults’ performance in the partitive condition, especially given the split between the two subgroups, led us to wonder whether size—and consequently an interpretation of the novel word as something like “big”—was a more salient property than numerosity (cf. Clearfield & Mix, 1999). Perhaps if numerosity were better highlighted during the familiarization and contrast phases, a number word interpretation would be more accessible and the percentage of quantity interpretations in the partitive condition would increase. We explore this possibility in Experiment 2b with adult participants.

EXPERIMENT 2B: INCREASING SET SIZE TO MAKE NUMEROSITY SALIENT FOR ADULTS

In this experiment we manipulated the number of objects in the display during the familiarization and contrast phases. We hypothesized that this manipulation would better highlight the difference between the numerosity of the two sets. Increasing the distance between two set sizes renders the

numerosity more salient (for a review, see Gallistel & Gelman, 2005). Therefore, a number word interpretation for the novel word should be more accessible given a contrast between set sizes of 2 vs. 5 as opposed to 2 vs. 3. By targeting adults in this experiment, we sought to obtain baseline information about how the relative salience of numerosity could provide contextual support for a numerical interpretation for young number-word-learners.

Method

Participants. Forty-five undergraduates from Rutgers University who were fulfilling an experimental requirement for a psychology course participated (25 females, 20 males; age range: 18–23). Participants were randomly assigned to one of three conditions, 15 per condition. Data from one inattentive adult participant were not used. All participants were native speakers of English.

Materials and procedure. The materials and procedure were identical to Experiment 2a, with three exceptions. First, in Experiment 2b, two big objects were contrasted with five small objects, instead of the three small objects in Experiment 2a. For reasons give above, the contrast between the two sets was increased from 2 vs 3 to 2 vs 5. We also added a new control condition to assess whether adult participants have a bias towards a number or adjectival interpretation when the novel word is in a syntactically neutral position, i.e., prenominal position, following a demonstrative (see Table 7). Finally, after participants were done viewing the video, the experimenter asked them to write down their best guess as to the meaning of the word *zav*, along with a brief justification for their response, thereby providing another clue about their interpretation of the novel word.

Results

As before, the dependent measure was the percentage of occasions on which participants chose the side of the test screen with two small objects (i.e., how often participants assigned a quantity interpretation). The results are captured in Figure 3.

A Kruskal-Wallis test revealed a significant difference between the three conditions ($H(2) = 15.57, p < .001$). Further pairwise comparisons between the two conditions using a Mann-Whitney test revealed a significant difference between the partitive condition and both the *very* condition ($U_A = 23, z = 3.69, p < .0001$) and the control condition ($U_A = 41, z = 2.94, p < .002$), but no difference between the *very* and control conditions ($U_A = 130, z = -0.71, p = .24$). In addition, single-sample Wilcoxon signed rank tests revealed that all three conditions were significantly different from chance, with responses for the partitive condition diverging from the other two conditions (partitive: $p = .04$; *very*: $p < .001$; and prenominal control: $p < .02$).

In contrast to the results from Experiment 2a, adults in the partitive condition in Experiment 2b had a reliable tendency to assign the novel word a quantity interpretation. Thus, the increase in the difference between the sizes of the two sets of objects had the anticipated effect.⁷ Still, once

⁷Manipulating the object property pitted against numerosity could also influence the interpretations accessed. A pilot experiment with six adults using the same design as Experiment 2b, but with number pitted against color (instead of

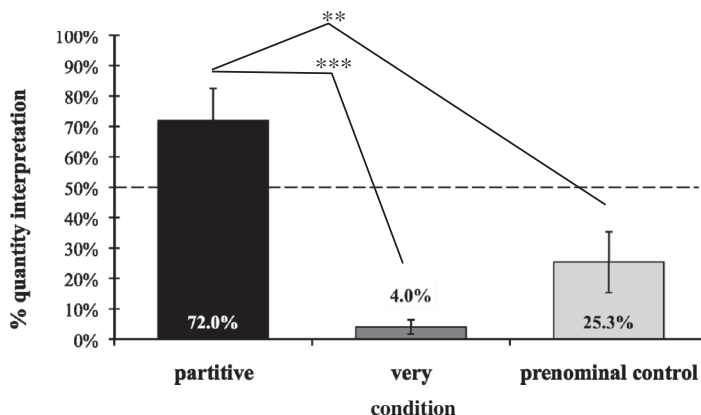


FIGURE 3 Percentage of adults' quantity interpretations in the three conditions in Experiment 2b: Increasing Set Size to Make Numerosity Salient.

again a within-group difference emerged within the partitive condition. Nine adults accessed the quantity interpretation 100% of the time, and two did so for at least trials 3–5. This time, only two adults never accessed the quantity interpretation, and two were at 0% acceptance for trials 2–5. Restricting our focus to trials 3–5, we observe a split between 11 participants at 100% acceptance, and 4 at 0% acceptance.

The participants also provided their interpretation of the novel word immediately following presentation of the video. These were in line with the choice data. The same group of 11 who chose on the basis of quantity said that the novel word meant “two,” while none of the adults in the *very* condition gave this response and only four in the prenominal control condition did. A typical response in the partitive condition was that whenever the speaker used the novel word, two items disappeared or were different. By contrast, all of the participants in the *very* condition and 11 of the 15 participants in the prenominal control condition said that the novel word meant “big” or “large(r),” but only four in the partitive condition did (from the adults with a 0% quantity interpretation on the final trials). A typical response in this condition was that the larger items always disappeared or were removed.

It is not the case that *any* modifier would have led to an adjectival interpretation. Ten additional adults participated in an experiment with similar design in which the novel word *zav* was modified by *exactly*, and color was pitted against numerosity. In this case, adults assigned a quantity interpretation 91.7% of the time, which was significantly above chance ($t(11) = 7.25$, $p < 0.0001$). Only two adults obtained a quantity interpretation less than 100% of the time. In addition, almost every adult commented that the novel word had to be a number (specifically *two*) because it was modified by *exactly*, and that color words cannot be modified by this adverb.

size) produced similar results, although with a slightly higher percentage of quantity interpretations (83%). All six adults responded that they thought the novel word meant “two.”

Discussion

In this experiment, we expected that a manipulation of the numerosity of the contrast set of objects displayed during the familiarization and contrast phases would enhance participants' ability to assign the novel word a quantity interpretation in the partitive condition. It did. Adults in Experiment 2b compared to those in Experiment 2a generally settled on a quantity interpretation in the partitive condition in contrast to Experiment 2a. Performance in the *very* condition replicated what we found in Experiment 2a: participants almost never chose the side corresponding to a quantity interpretation in this condition. Participants' interpretations of the novel word in different conditions buttress this conclusion. Eleven of 15 participants in the partitive condition said that *zav* meant "two" (as opposed to a nonnumerical interpretation or a nonspecific quantity interpretation such as "some"). No one in the *very* condition provided a quantity interpretation; instead, they all said that the word *zav* meant "big" or "large(r)." Thus, the ability to extend word meaning to a number word interpretation may be compromised when otherwise robust syntactic cues are paired with perceptually salient object properties (see also Subrahmanyam, Landau, & Gelman, 1999).

Although participants benefited from a manipulation of the experimental context that made a quantity interpretation more salient than a competing object property interpretation, a subset of the participants continued to assign an interpretation to the novel word that was inconsistent with the semantic constraints of the given syntactic environment. Thus, even adults who might never say or judge as grammatical a phrase such as **big of the cars* nevertheless allowed a novel word appearing in the *big* slot to have this interpretation. By contrast, participants unequivocally recognized that a novel word modified by *very* should have an adjectival, and not a number, interpretation.

Also of interest is the fact that participants were reluctant to assign the novel word a quantity interpretation in the prenominal condition, an environment in which both an adjective (e.g., *those big cars*) and a number word (e.g., *those two cars*) can occur. One possibility is that a number word interpretation is less likely than an adjectival interpretation in this environment. This may indicate that the default for a novel word interpretation is at the individual object level rather than the group/set level (see Bloom & Kelemen, 1995; Markman, 1990; Markman & Hutchinson, 1984; and Markman & Wachtel, 1988, for relevant discussions). However, it also may be that adjectives more naturally yield a restrictive interpretation in the prenominal position, providing essential or unique identifying information about a discourse referent in existence (Link, 1987; Alan Munn, personal communication, 2008).

GENERAL DISCUSSION AND CONCLUSIONS

We asked whether syntactic patterns in the input can aid children when acquiring number-word meaning. We began by distinguishing two possible implementations of a syntactic bootstrapping approach—one in which language is able to uniquely identify the number word category for the word learner and one in which language serves to highlight the quantity-denoting status of number words and would need to be supplemented by additional information (e.g., in the discourse context) for the word learner to pick out number words. We took as our starting point

a proposal by Bloom and Wynn (1997). Our analysis of the four linguistic cues identified by B&W and a follow-up analysis of a set of CHILDES transcripts of child-directed speech led us to propose the targeted linguistic cues do not suffice for an unambiguous classification of novel words as number words. We therefore turned to a set of word-learning experiments to determine what additional information child participants need to know in order to learn that a novel word refers to number.

In Experiment 1, we found that children are aware of the semantic constraints associated with the partitive frame, and that the discourse context can provide support for a specific quantity interpretation (e.g., “two” rather than “some”). When a novel word occurred in this frame (i.e., *pim of the cars*), children were more likely to assign it a quantity interpretation such as two than an adjectival one such as red. However, we also found that children were less likely to extend the meaning of the novel word to a quantity interpretation after the partitive frame was dropped in the test phase. They also did not perform as well as they did when they received consistent linguistic support throughout the familiarization and test phases when a contrast in quantity was highlighted.

Results from Experiments 2a and 2b sharpened this picture. In Experiment 2a, children and adults experienced no difficulty extending the meaning of a novel word to an adjectival interpretation in contexts in which the novel word in question was modified by *very* (e.g., *very zav cars*). This suggested that what is difficult is extension to number-word meaning. This conclusion was reinforced by the fact that even some adult participants in Experiment 2a could not reliably extend the meaning of a novel word to a number word interpretation. However, the adults were more successful in extension when numerosity was made more salient in Experiment 2b. As a result, in this experiment adults were not only more likely to assign a quantity rather than an adjectival interpretation to the novel word, but they also provided a specific quantity interpretation when asked for their interpretation. In sum, these results indicate that it is possible, at least in principle, for children to use distributional cues such as occurrence in the partitive frame to deduce that a novel word occurring in this environment is quantity-denoting. This might indicate that part of number-word learning entails an implicit comparison with other quantificational lexical items to assign the right set of linguistic properties to number words.

Interestingly, Barner et al. (2009) independently arrive at a strikingly similar conclusion about the viability of bootstrapping number-word meaning. In a comparison of the developmental pattern of number word and quantifier acquisition in Japanese- and English-acquiring children, they find that while Japanese children either meet or exceed English children in their knowledge of quantifiers, they have delayed comprehension of number words. Barner et al. conclude that Japanese children’s difficulty in acquiring number words must lie in determining that number words denote properties of sets. After reviewing various bootstrapping accounts of number-word learning, including B&W’s, the authors argue in favor of what they term “quantifier bootstrapping.” Under this account, children rely upon the shared distributional properties of quantifiers and number words in the input to infer that number words are quantity-denoting. In languages in which the “distributional profiles” of these lexical items are only weakly related—such as Japanese, where, for example, classifiers are used frequently with number words but not quantifiers—the acquisition of number-word meaning should be delayed relative to that of quantifiers.

Note that although we have shown that children *can* appeal to the sort of syntactic cues discussed here to learn something about the quantity-denoting nature of number words, we have not shown that this is what children *actually do* in the course of number word acquisition. After all, the children in these experiments already knew the meaning of the word *two* (as witnessed by their performance on the “What’s on this card?” task). The experiments presented here provide evidence that children are at least sensitive to the semantic constraints associated with certain syntactic environments, which supports the corpus data presented by B&W and by us—a necessary step to determining the role of natural language syntax in number word learning.

Recall that in addition to linguistic information, children still need to use additional information, such as what is provided by the discourse context, to further tease apart number words from the broader class of quantity-denoting expressions, which includes a host of quantifiers (e.g., *many, some, a few, several*). This, then, leaves the door open for counting and the counting principles identified by G&G to contribute to the learning process. Almost any view of number-word learning assigns special status to the count list. Note, however, that under this account of learning, the underlying principles of counting help children to identify number words in a language and to recognize the range of environments in which number words can appear in natural language. This process is not restricted to a search for an ordered count list or verbal counting but applies more generally to those communicative contexts that license the appearance of number words (see also Gelman, 2000).

It is important to remember that a fundamental aspect of G&G’s view is that the counting principles do not stand alone. Rather, they generate entities whose meaning and the results of their combination through the operations of addition and subtraction, are governed by the arithmetic principles. For example, the combination $2 + 2$ yields 4 and not “some more” or “a bunch.” In contrast, “some” and “some” logically combine to mean “some (more).” Furthermore, there is no rule in syntax that corresponds to the stable-order counting principle, which dictates that a count list must be used in exactly the same order for every count. Absent this requirement, the final tag, the cardinal value, would not be conserved across multiple counts of the same set. There is no corresponding ordering rule in language; one needs to specify something like *in that order* or *respectively*, and such language is most likely not part of child-directed speech. For these reasons, Grinstead, MacSwan, Curtiss, and Gelman (1998) argued that while there is an interface between the number and language faculties, the development of counting (number) words and their meaning neither depends on nor derives from the syntax of language. Consequently, number-word learning cannot proceed *only* from bootstrapping dependent upon the linguistic system. This view is consistent with our empirical results.

The model of number-word learning we propose combines both G&G’s view with one that provides the learner with information about the number-relevant properties of language. Number-word learning benefits from syntax and its interface with semantics. There are clear (semantically motivated) rules regarding the grammaticality of number words’ appearance across a variety of syntactic environments, and the consequences are observable to the learner on the surface. The goal of the language learner is to identify the relevant linguistic environments in a given language and then to compare the denotations of lexical items with overlapping distribution in order to deduce something about their semantic properties. It seems reasonable to argue that a beginning language learner would take advantage of any and all clues that can facilitate the acquisition of the natural number words and rules of their acceptable use.

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