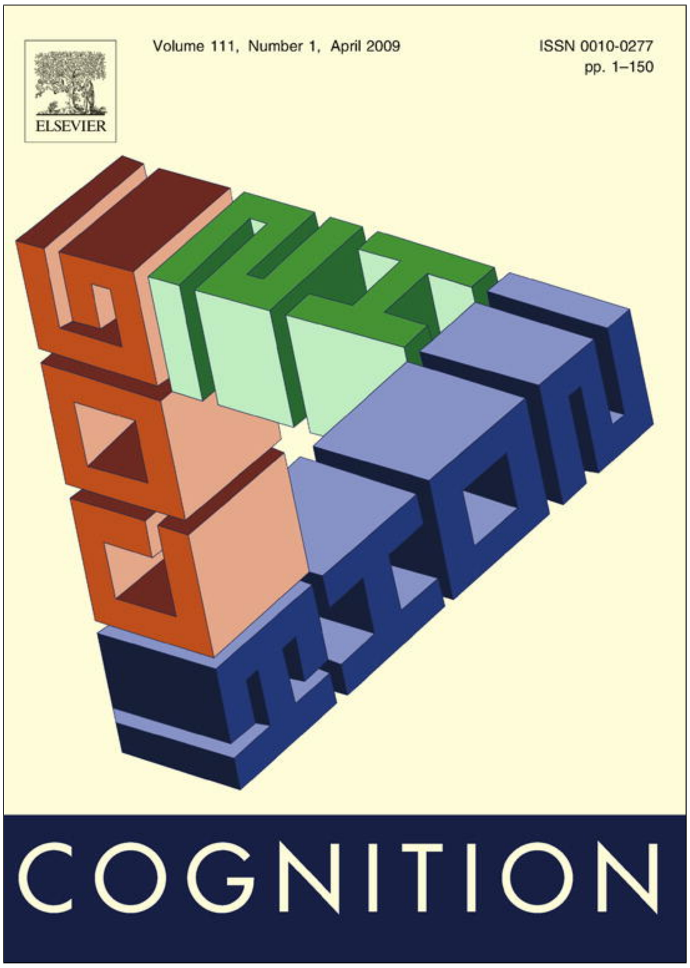
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# The logical syntax of number words: Theory, acquisition and processing

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Recent work on the acquisition of number words has emphasized the importance of integrating linguistic and developmental perspectives [Musolino, J. (2004). The semantics and acquisition of number words: Integrating linguistic and developmental perspectives. *Cognition 93*, 1–41; Papafragou, A., Musolino, J. (2003). Scalar implicatures: Scalar implicatures: Experiments at the semantics-pragmatics interface. *Cognition*, *86*, 253–282; Hurewitz, F., Papafragou, A., Gleitman, L., Gelman, R. (2006). Asymmetries in the acquisition of numbers and quantifiers. *Language Learning and Development*, *2*, 76–97; Huang, Y. T., Snedeker, J., Spelke, L. (submitted for publication). *What exactly do numbers mean?*]. Specifically, these studies have shown that data from experimental investigations of child language can be used to illuminate core theoretical issues in the semantic and pragmatic analysis of number terms. In this article, I extend this approach to the logico-syntactic properties of number words, focusing on the way numerals interact with each other (e.g. *Three boys are holding two balloons*) as well as with other quantified expressions (e.g. *Three boys are holding each balloon*). On the basis of their intuitions, linguists have claimed that such sentences give rise to at least four different interpretations, reflecting the complexity of the linguistic structure and syntactic operations involved. Using psycholinguistic experimentation with preschoolers ($n = 32$) and adult speakers of English ($n = 32$), I show that (a) for adults, the intuitions of linguists can be verified experimentally, (b) by the age of 5, children have knowledge of the core aspects of the logical syntax of number words, (c) in spite of this knowledge, children nevertheless differ from adults in systematic ways, (d) the differences observed between children and adults can be accounted for on the basis of an independently motivated, linguistically-based processing model [Geurts, B. (2003). Quantifying kids. *Language Acquisition*, *11(4)*, 197–218]. In doing so, this work ties together research on the acquisition of the number vocabulary with a growing body of work on the development of quantification and sentence processing abilities in young children [Geurts, 2003; Lidz, J., Musolino, J. (2002). Children's command of quantification. *Cognition*, *84*, 113–154; Musolino, J., Lidz, J. (2003). The scope of isomorphism: Turning adults into children. *Language Acquisition*, *11(4)*, 277–291; Trueswell, J., Sekerina, I., Hilland, N., Logrip, M. (1999). The kindergarten-path effect: Studying on-line sentence processing in young children. *Cognition*, 73, 89–134; Noveck, I. (2001). When children are more logical than adults: Experimental investigations of scalar implicature. *Cognition*, *78*, 165–188; Noveck, I., Guelminger, R., Georgieff, N., & Labruyere, N. (2007). What autism can tell us about every . . . not sentences. *Journal of Semantics, 24*(1), 73–90. On a more general level, this work confirms the importance of integrating formal and developmental perspectives [Musolino, 2004], this time by highlighting the explanatory power of linguistically-based models of language acquisition and by showing that the complex structure postulated by linguists has important implications for developmental accounts of the number vocabulary.



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## 1. Introduction

This article investigates the way we use the combinatorial power of natural language to express numerical relations. To be more precise, I will be concerned with the logical syntax of numerically quantified expressions (NQE) (e.g. *three boys*, *two balloons*). Given the pivotal role that numbers play in our lives, understanding how children acquire numerical concepts and how they learn to express these concepts through the medium of language represents an important goal for developmental psychology. Reflecting the importance of this goal, the past 30 years of research in developmental and cognitive psychology have witnessed the emergence of a growing body of work on the nature of numerical concepts and the acquisition of the number vocabulary (Carey, 2001; Dehaene, 1997; Gallistel & Gelman, 1992; Gallistel & Gelman, 2000; Gelman & Gallistel, 1978; Mix, Huttenlocher, & Levine, 2002; Sarnecka & Gelman, 2003; Spelke, 2000; Wynn, 1990; Wynn, 1992; Wynn & Bloom, 1997; LeCorre and Carey, 2007, among many others). Within this line of research, one of the key questions has been to try to explain *how* children learn the meaning of number words. In contrast, *what* has to be learned – that is, what number words mean – has been taken for granted from the start because it seems so obvious. To quote a recent study by Huang, Snedeker, and Spelke (submitted for publication) "The meaning of a word like "two" appears self-evident: it functions as part of a phrase that picks out sets with exactly two members ..." (p. 1).

During the same period, number words have also figured prominently on the research agenda of theoretical linguists (Breheny, 2008; Carston, 1998; Gadzar, 1979; Horn, 1972; Horn, 1989; Horn, 1992; Koenig, 1991; Levinson, 2000; Sadock, 1984; Chierchia, 2004; Geurts, 1999, Geurts, 2006; Musolino, 2004). Surprisingly however, it is only within the last few years that linguists and psychologists have become aware of the existence – and the relevance – of each other's work (Musolino, 2004). What makes this late convergence particularly interesting is that the very question that psychologists have taken for granted regarding the meaning of number words is one that linguists have struggled over for more than two decades. Indeed, for linguists, understanding what number words mean has been one of the central questions since Horn's (1972) seminal analysis. Moreover, the standard orthodoxy in much of the philosophical and linguistic literature is that number words do not have an 'exact' semantics, as is assumed by developmental psychologists. On this view, a phrase like *two cats* does not literally mean *exactly two cats*, but rather *at least two cats* (Barwise & Cooper, 1981; Horn, 1972; Horn, 1989; Levinson, 2000). Thus, *John has two cats* is strictly speaking true, even if John has three, four, or fifty cats. On the other hand, theoretical linguists have never really seriously worried about *how* children manage to learn what number words mean – a question that has driven research in developmental psychology for over three decades.

Recently, the two lines of research described above have made contact under the impetus of a small set of studies designed to bridge the gap between linguistics and psychology (Musolino, 2004; Papafragou & Musolino, 2003. See also Huang et al., submitted for publication; Hurewitz, Papafragou, Gleitman, & Gelman, 2006 for similar developments). Specifically, these studies have shown that data from experimental investigations of child language can be used to illuminate core theoretical issues in the semantic and pragmatic analysis of number terms. Thus, the thrust of this new approach so far has been to highlight the implications of developmental work for linguistic theory.

In this article, I focus on the other side of this equation and show that the work of theoretical linguists has important implications for developmental accounts of the number vocabulary. In order to do so, I consider the logico-syntactic properties of number words, focusing on the way numerals interact with each other (e.g. *Three boys are holding two balloons*) as well as with other quantified expressions (e.g. *Three boys are holding each balloon*). On the basis of their intuitions, linguists have claimed that such sentences give rise to at least four different interpretations, reflecting the complexity of the linguistic structure and syntactic operations involved. Using psycholinguistic experimentation with preschoolers and adult speakers of English, I show that (a) for adults, the intuitions of linguists can be verified experimentally, (b) by the age of 5, children have knowledge of the core aspects of the logical syntax of number words, (c) in spite of this knowledge, preschoolers nevertheless differ from adults in systematic ways, (d) the differences observed between children and adults can be accounted for on the basis of an independently motivated, linguistically-based processing model (Geurts, 2003). In doing so, this work ties together research on the acquisition of the number vocabulary with a growing body of work on the development of quantification and sentence processing abilities in young children (Geurts, 2003; Lidz & Musolino, 2002; Musolino & Lidz, 2003; Noveck, 2001; Trueswell, Sekerina, Hilland, & Logrip, 1999). At a more general level, this work confirms the importance of integrating formal and developmental perspectives (Musolino, 2004), this time by highlighting the explanatory power of linguistically-based models of language processing and by showing that the complex structure postulated by linguists has important implications for developmental accounts of the number vocabulary.

## 2. Theoretical background

The goal of this section is to describe the linguistic complexity underlying the interpretation of NQE and to show that NQE have a unique logico-syntactic profile that distinguishes them from other quantificational expressions. Specifically, I will show that NQE (a) allow distributive, collective and cumulative readings, (b) give rise to scope-dependent readings, (c) also give rise to scope-independent readings, (d) given two possible scope-dependent readings, the one where the object takes distributive scope over the subject is dispreferred, and (e) given two possible scope-independent readings, the cumulative reading is dispreferred. Having described the complexity underlying the interpretation of NQE, we will then briefly turn to the question of how such facts can be acquired by children, and consider the hypothesis that the various readings of

NQE described below are not learned per se, but rather that they are implicitly deduced by young children. The purpose of the psycholinguistic experimentation presented in this article is to test this hypothesis by assessing knowledge of the properties in (a–e) in preschool children and adult speakers of English.

### *2.1. The interpretation of NQE*

Let us begin with a simple observation regarding the interpretation of NQE. Notice that the sentence in (1), which contains the NQE *three boys*, is ambiguous between a *distributive* and a *collective* reading, (1a) and (1b), respectively. On the distributive reading, (1) is understood to mean that there were three separate visits. In other words, each of the three boys visited Mary on a specific occasion (which was different for each boy). On the collective reading, (1) is understood to mean that there was only one visit and so that the three boys must have visited Mary together.

(1) Three boys visited Mary.
  a. There is a set M, M is a set of boys of cardinality 3, and for each boy b in M, b visited Mary (distributive reading)
  b. There is a set M, M is a set of boys of cardinality 3, and M visited Mary (collective reading)

Let us now consider what happens when a sentence contains two NQE. Given that each NQE can in principle be interpreted either distributively or collectively, it would seem that the resulting sentence could receive, at least in principle, four interpretations. However, this picture is complicated by an additional factor, namely the fact that NQE are scope-bearing expressions. The notion of scope, in turn, can be illustrated using a simple mathematical analogy. Consider the expressions in (2) and (3):

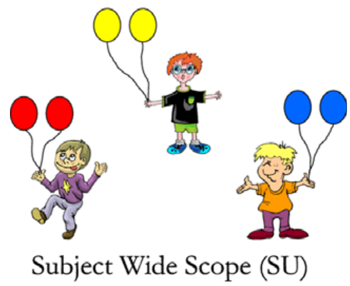
(2) $2 \times (3 + 5) = 16$
(3) $(2 \times 3) + 5 = 11$

The scope of 2× (the number 2 followed by the multiplication sign) can be thought of as its domain of application. So in (2), *(3 + 5)* falls within the scope of 2×. By contrast, in (3), 3 falls within the scope of 2× whereas 5 falls outside of its scope. Finally, notice that different scope relations give rise to different results once the expressions are computed. We can now turn to the concept of scope as it applies to language by considering a sentence like (4) which contains two NQE.

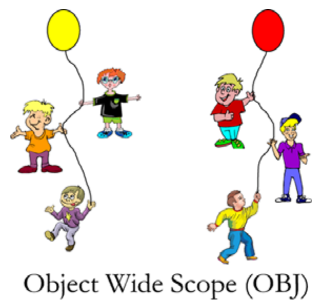
(4) Three boys are holding two balloons.
  a. There are three x, x is a boy, and for each x, there are two y, y is a balloon, such that x is holding y. (subject wide scope)
  b. There are two y, y is a balloon, and for each y, there are three x, x is a boy, such that x is holding y. (object wide scope)

In order to single out the effect of scope, let us hold the interpretative value of the two NQE constant and assume that both are interpreted distributively. Since NQE are scope-bearing expressions, a possible interpretation of (4) is one on which the object noun phrase, *two balloons,* is interpreted within the scope of the subject noun phrase, *three boys*, (4a). On this interpretation, the sentence can be paraphrased as *Three boys are such that they are each (distributive interpretation) holding two balloons* (picture 1).[1] Notice that this reading reflects a dependency between the two NQE in that the choice of the set of balloons depends on, or varies as a function of, which of the three boys is selected. Thus, the quantity associated with the object NQE is multiplied by the value of the subject NQE. Consequently, *Three boys are holding two balloons* is true in a context in which six balloons are present (picture 1) even though the number of balloons mentioned in the sentence itself is only two.

Another possible interpretation of (4) is one on which the object noun phrase takes scope over the subject noun phrase, (4b). On this interpretation, (4) can be paraphrased as meaning that there are two balloons such that each balloon (distributive interpretation) is being held by a different set of three boys (picture 2). In this case, the set of three boys varies as a function of which balloon one chooses. So as in the case of our mathematical analogy, different scope relations give rise to different interpretations.




**Picture 1**




**Picture 2**

[1] Notice here that due to the nature of the predicate, *hold*, and the way the sentences are represented graphically (see picture 1), a collective or a distributive reading of the object NP *two balloons* would yield the same visual configuration. In other words, whether each of the three boys is holding his two balloons together (collective reading) or one after the other (distributive reading), would be represented as shown in picture 1. The same holds of the wide scope reading of the object NQE, *two balloons*. Here, once *two balloons* is interpreted distributively and takes scope over the subject NQE, *three boys*, whether the subject is in turn interpreted collectively or distributively yields the same visual configuration (see picture 2).

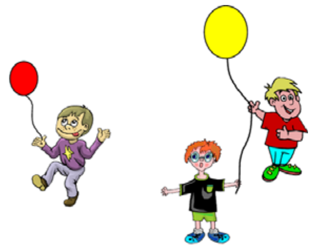
In addition to the scope-dependent readings described above, linguists have also noticed that sentences containing NQE allow scope-independent readings (Barwise, 1979; Beghelli, Ben-Shalom, & Szabolcsi, 1997; Gil, 1982; Hintika, 1974; Sher, 1990). On such readings, the subject and the object noun phrase are interpreted independently of each other and a variety of connections are established between the members of each set (in this case the set of boys and the set of balloons). One such interpretation is one on which each member of one set is connected to all the members of the other (each-all reading). In other words, each of the three boys is holding both balloons (picture 3). Another way to see this is to consider the fact that when both NQE are interpreted collectively, scope becomes irrelevant (hence the notion of scope-independence). Thus, the reading that can be paraphrased as *There are three boys who, together, are holding two balloons* (wide scope reading of the subject) and the one that can be paraphrased as *There are two balloons which, together, are being held by three boys* (wide scope reading of the object), are logically equivalent, as can be seen in picture 3.

Yet another possible scope-independent interpretation is one on which the three boys, when considered cumulatively, are holding a total of two balloons (cumulative reading) (picture 4). At first sight, it might seem that the cumulative reading is the same as the collective reading. However, the example in (5) reveals that the two interpretations are distinct. To see this, consider what would have to be the case for (5) to be true on a collective reading. Here, each of the three men would have to co-own each of the houses. In other words, house 1 would have to be owned by all three men, and so would house 2, 3 and 4. By contrast, the cumulative interpretation does not require such co-ownership. So one way to make the sentence true on the cumulative reading – but false on the collective reading – would be to have two of the three men each (uniquely) own a separate house and the third man (uniquely) own the remaining two (see picture 5).

(5) Three men own four houses.

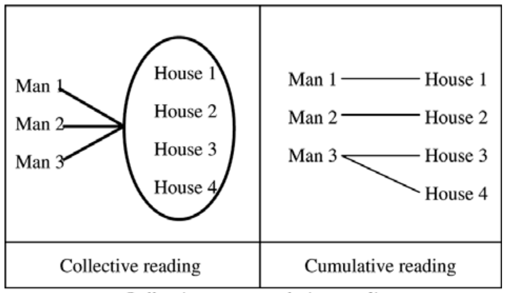
Each-all (EA)

**Picture 3**



Cumulative (CU)

**Picture 4**




Collective vs. cumulative reading

**Picture 5**

So far, we have seen that sentences like (4) give rise to (at least) four possible readings which I will refer to as SU (for the subject wide scope reading, picture 1), OBJ (for the object wide scope reading, picture 2), EA (for the each-all reading, picture 3) and CU (for the cumulative reading, picture 4). While all these readings are in principle available, linguists have reported certain interpretive preferences. First, given the availability of two scope-independent readings, EA and CU, Gil (1982) reports a preference for EA. Second, several investigators have noticed that object NQE do not easily take scope over quantified subjects (Beghelli et al., 1997; Liu, 1990; Liu, 1992. For experimental evidence in children, see Lidz and Musolino (2002). For evidence in adults, see Musolino and Lidz (2003)). Thus, given SU and OBJ, SU appears to be the preferred reading.

Another important aspect of the logical syntax of NQE – and quantifiers more generally – is that these expressions tend to be very choosy with respect to the kinds of readings they allow as well as the scopal preferences they induce. To be more precise, not all quantifiers give rise to scope-independent readings, some quantifiers do not allow collective or cumulative readings, and finally, different quantifiers induce different scopal preferences. Regarding the first of these three facts, Liu (1990), Liu (1992 proposes a classification of quantifier types and shows that depending on the kind of quantifier involved, a sentence may or may not have a scope-independent reading. Next, consider the fact that only some quantifiers allow collective readings. The contrast between (6) and (7) illustrates this property. Recall that sentences like (6) are ambiguous. On the collective reading, (6) can be paraphrased as meaning that three boys, when considered as a set, gave a gift to Mary. In this case, Mary only receives one gift. Alternatively, (6) may be interpreted on a distributive reading in which case each of the three boys gave Mary a different gift. So in this case, Mary receives three gifts. By contrast, notice that if the relevant situation involves three boys, (7) cannot receive a collective reading. It must be interpreted as meaning that Mary received three gifts – one from each boy. So *each* is obligatorily distributive.

(6) Three boys gave a gift to Mary.
(7) Each boy gave a gift to Mary.

Let us continue to use *each* to illustrate the fact that different quantifiers induce different scopal preferences. Consider the contrast between (4), repeated here as (8), and (9) in which *two balloons* has been replaced by *each balloon*. Recall that for sentences like (8), the wide scope reading of the object, corresponding to picture 2, does not obtain as easily as the wide scope reading of the subject, picture 1. In the case of sentences like (9), these preferences are reversed. That is, (9) very naturally describes picture 2, but not picture 1. The preferred scopal readings of these two sentences are paraphrased in (8a) and (9a).

(8) Three boys are holding two balloons.
a. There are three x, x is a boy, and for each x, there are two y, y is a balloon, such that x is holding y (subject wide scope)
(9) Three boys are holding each balloon.
a. For each y, y is a balloon, there are three x, x is a boy, such that x is holding y. (object wide scope)

Finally, let us briefly consider the kind of mechanism that allows quantifiers to take their scope. In a sentence like *Three boys are holding each balloon*, notice that *each balloon* occurs within the scope of *three boys* in surface syntax. To yield the interpretation on which *each balloon* takes scope over *three boys*, the phrase *each balloon* must be displaced from its surface syntactic position to a higher position from which it will take scope over *three boys*. In the generative literature, the standard mechanism which is responsible for the displacement of quantifiers to their scope position is called quantifier raising (QR) (Hornstein, 1995; May, 1977; May, 1985). The operation of QR is illustrated in (10) in which the quantifiers have moved out of their argument positions (subject and object) to a sentence initial position where they can take their scope. (10a) corresponds to the interpretation on which *three boys* takes scope over *two balloons*, SU; in (10b) *two balloons* takes scope over *three boys* and in (10c), *each balloon* takes scope over *three boys*.

(10) a. [three boys$_i$ [two balloons$_j$ [IP t$_i$ are holding t$_j$ ]]]
b. [two balloons$_j$ [three boys$_i$ [IP t$_i$ are holding t$_j$ ]]]
c. [each balloon$_j$ [three boys$_i$ [IP t$_i$ are holding t$_j$ ]]]

The kind of displacement illustrated in (10) is 'covert' since there are no phonological consequences associated with it. The level of linguistic representation at which covert displacement takes place is called logical form (LF). Finally, it should also be pointed out that several alternatives to QR have been proposed in the linguistic literature (e.g. Hornstein, 1995; Reinhart, 1997). For our purposes however, whether quantifiers take their scope via QR or some other mechanism is of no direct consequence.

### 2.2. The learning question

As the previous section illustrates, the linguistic properties associated with NQE are complex and yield an intricate array of interpretive options. Indeed, to say that a sentence like *Three boys are holding two balloons* can receive at least four different interpretations does not sound immediately obvious. To be sure, explaining why this is the case requires several pages of theoretical background and explanation. This fact raises an obvious question: to what extent are the interpretations described in the previous section 'psychologically real'? In other words, would a naïve speaker – i.e., a person who does not have an advanced background in linguistic theory or logic – nonetheless be aware (if only implicitly) of all the interpretations described above? To the extent that the answer to this first question is affirmative, a second, important question arises: how are these facts acquired?

One possibility is that such knowledge, because it is intricate and linked to knowledge of logic, may be acquired late, perhaps as a byproduct of instruction in arithmetic and basic logic. If so, we would certainly not expect preschoolers – because of their obvious lack of experience in the two domains just mentioned – to display knowledge of such facts. However, it should be noted that although possible in principle, to the best of our knowledge, this type of account has not been explicitly endorsed in the linguistic or psychological literature. Another possibility is that such knowledge, however intricate it may be, is a manifestation of core linguistic knowledge. In other words, knowledge of the grammar of English (along, of course, with knowledge of the meaning of English words), would entail (tacit) knowledge of the complex array of facts described above. In this regard, there exist a number of proposals in the semantic literature bearing on how learning of such complex properties might take place. One such proposal, by Gennari and MacDonald (2005/2006), is that such knowledge is mostly derived from experience with the relevant expressions and the contexts and situations in which they are used. To quote these authors " We argue that children ... are sensitive to the distributional patterns of language use ... and their pairing with specific situations, and that children's experience of such patterns shapes their comprehension of scope ambiguous sentences" (p. 128/129).

Here, we explore an alternative hypothesis regarding how such learning might take place. In fact, on this scenario, the logico-syntactic properties of NQE need not be *learned* per say but rather they are *tacitly deduced* by young children. This prediction follows straightforwardly from a core property of natural language, namely the fact that semantics is compositional. In other words, the meaning of a sentence can be systematically deduced from the meaning of its part and the way they are arranged. To be sure, language, to reiterate a classic observation, allows its speakers to make infinite use of finite means, and so there is little doubt that brains, which are finite, must contain general principles for generating sentences – what linguists call grammars - rather than long lists of possible and impossible sentences. A direct consequence of this observation is that semantics must be compositional. This follows from the fact that language allows its speakers to *interpret* a potentially unbounded number of sentences.

What we predict then is that to the extent that children have acquired (a) the lexical meaning of NQE – i.e. the meaning of expressions like *two N*, *three N*, etc. – and to the extent that (b) they have a command of the core grammatical principles of their language and know that semantics is compositional, they should be able to (tacitly) deduce the range of meanings arising from the interaction of multiple NQE. If so, the only learning that would have to take place would be *indirect* (i.e. learning the meaning of the words, and the core properties of English grammar). There is massive evidence in the literature on language acquisition that (a) and (b) are in place by the age of 5. We then predict that by the age of 5, children should have knowledge of the range of interpretations arising from interacting NQE. As we will see, this prediction is indeed borne out.

## 3. Developmental background

As mentioned earlier, since the publication of Gelman and Gallistel's (1978) seminal study (henceforth G&G), a voluminous body of work on children's growing conception of number has emerged. A review of this literature, in turn, reveals that developmental psychologists have been concerned with two fundamental and interrelated questions, namely (a) what is the nature of the conceptual apparatus underlying our ability to grasp numerical relations, and (b) how do children acquire the meaning of number words. The first question, while no doubt extremely interesting, is not directly relevant to our current purposes (see Dehaene (1997) for an overview). In regard to the second question, much of this literature has grown out of a reaction to G&G's proposal that the representation of integers is part of our built-in cognitive endowment and that children's acquisition of the number vocabulary is guided by innate counting principles. While there is universal agreement that G&G defined the principles governing the domain, there is great controversy over the role of these principles in explaining development. One view, sometimes referred to as the 'principles before skill' (e.g. Gelman & Meck, 1983; Freeman, Antonucci, & Lewis, 2000) or the 'continuity hypothesis' (Le Corre, Van de Walle, Brannon, & Carey, 2006) endorses G&G's nativist position vis-à-vis the representation of integers and knowledge of the counting principles (Cordes & Gelman, 2005; Gallistel & Gelman, 1992; Gelman, 1993; Gelman & Greeno, 1989; Greeno, Riley, & Gelman, 1984, among others). An alternative position, sometimes called the 'skill before principles' view or the 'discontinuity hypothesis' holds that knowledge of integers and the counting principles is in part derived from experience, or, as Le Corre et al. (2006) put it that "the acquisition of the verbal count list may involve the construction of a system that is not innately available" (p. 133). Although the details of how this new representational system emerges are still of matter of debate, many seem to have adopted this general position (Bialystok & Codd, 1997; Briars & Siegler, 1984; Carey, 2004; Cooper, 1984; Fuson, 1988; Karmiloff-Smith, 1992; Mix et al., 2002; Spelke & Tsivkin, 2001; Starkey and Cooper, 1995; Wynn, 1990; Wynn, 1992).

From the perspective of the present study, there is one important thread that runs through the developmental literature in the domain of number word acquisition: to the extent that this body of work is concerned with the linguistic properties of number words, the focus has almost exclusively been on how such expressions are used in the counting system. However, as discussed in the previous section, the linguistic behavior of number words extends far beyond counting and into the realm of syntax, semantics, and pragmatics. Thus, any account of how children learn to express numerical relations through the medium of language would be incomplete without a consideration of the linguistic properties described earlier. Moreover, it is only very recently that the two perspectives described earlier, represented by work in theoretical linguistics and developmental psychology, have been brought together into a single framework. The first study to do so is by Papafragou and Musolino (2003) (henceforth P&M).

P&M's work was motivated by the recent observation that preschoolers, who are otherwise semantically competent, often show a remarkable lack of sensitivity vis-à-vis scalar implicatures in tasks designed to assess language comprehension (Chierchia, Crain, Guasti, Gualmini, & Meroni, 2001; Musolino & Lidz, 2006; Noveck, 2001). The generalization emerging from this recent line of research is that although adults tend to favor the pragmatic interpretation of weak scalar terms (e.g. *some* as being incompatible with *all*), young children often interpret the same terms semantically (e.g. *some* as being compatible with *all*). P&M's goal was to determine whether this observation would extend to all scalar terms, and in particular to NQE. P&M tested preschoolers (and adults) on their interpretation of scalar terms such as *some*, *two* and *start* in contexts which satisfied the semantic content of stronger terms on each scale, i.e. *all*, *three* and *finish*. For example a situation in which all/three horses jumped over a fence would be described as *some/two horses jumped over the fence*. What P&M found is that while preschoolers overwhelming accepted such descriptions in the case of sentences containing *some* and *start*, they massively rejected these descriptions in the case of sentences containing *two*. Thus, P&M's results show that preschoolers treat NQE differently from other scalar terms (also see Hurewitz et al. (2006) for a similar conclusion).

Building on P&M, Musolino (2004) further explored the way preschoolers represent NQE semantically. Musolino's study grows out of the observation that in addition to their 'exactly *n*' interpretation, NQE also give rise to 'non-exact' readings, namely 'at least/most *n*' (Carston, 1998; Horn, 1972; Koenig, 1991; Sadock, 1984). Imagine for example a story in which one of the characters has to throw hoops at a pole and is told that he needs to get two hoops on the pole in order to win a prize. Suppose now that the character in question gets three hoops on the pole. Should he win the prize? If *two hoops* in *you need to get two hoops on the pole* is interpreted as *exactly two hoops*, then the character should not win. On the other hand, if *two hoops* is interpreted as *at least two hoops* (two hoops or more), then the character should win the prize. Imagine now that in the same situation our character is told that he can miss two shots and still win the prize. Suppose now that the character only misses one shot. Should he win the prize? If *two shots* is interpreted as *exactly two shots*, then the answer is no (the character missed one shot, not two). On the other hand, if *two shots* is interpreted as *at most two shots*, then the answer is Yes. Using scenarios like these, Musolino (2004) showed that by the age of 5, preschoolers have implicit knowledge of the fact that expressions like *two hoops* can, in addition to their exact reading, be interpreted as *at least two hoops* and *at most two hoops*.

Results from these two studies have been used to tease apart competing analyses of the semantics of NQE. Specifically, these results have been taken as evidence against the standard, neo-Gricean analysis of NQE (Horn, 1972; Horn, 1989; Levinson, 2000) according to which NQE have a lower bounded (i.e. at least *n*) semantics (Musolino, 2004; also see Hurewitz et al. (2006), Huang et al. (submitted for publication), Geurts (2006) and Breheny (2008) for similar conclusions). Thus, these recent studies have shown that the integration of linguistic and developmental perspectives is not only feasible but that it is also a fruitful endeavor. So far, this work has focused on the semantic and pragmatic properties of NQE. However, as we saw in the previous section, NQE are also associated with complex logico-syntactic properties. The next step in this integrative research program is therefore to determine when and how such properties are acquired by young children. The research presented in this article is designed to address these questions.

Before turning to the experimental section of the paper, one more study deserves mention.[2] This is a study by Lidz and Musolino (2002) which examined the way preschoolers (and adults) interpret sentences containing negation and an object NQE, e.g. *The Smurf did not catch two birds*. Notice that this sentence is scopally ambiguous. On the wide scope reading of negation, it can be paraphrased as meaning that it not the case that the Smurf caught two birds (so perhaps the Smurf caught only one bird). When the object NQE takes wide scope over negation however, the sentence can be paraphrased as meaning that there are two specific birds that the Smurf did not catch. The main finding from Lidz and Musolino's (2002) study is that children, unlike adults, display a strong preference for the narrow scope reading of the object NQE, i.e. *It is not the case that the Smurf caught two birds.* This result might suggest that preschoolers do not yet have a complete mastery of the logical syntax of NQE, or, alternatively, that they have a strong preference for the interpretation of quantificational expressions which corresponds to their surface syntactic position. For evidence supporting this latter conclusion, see Lidz (2004), Musolino and Lidz (2003), and Musolino and Gualmini (2003).

## 4. Experimental investigation

The goal of this experiment is two-fold. First, for adults, the aim is to determine whether the intuitions of linguists regarding the logical syntax of NQE can be verified experimentally. As mentioned earlier, the relevant facts are that NQE (a) give rise to scope-dependent readings, (b) also give rise to scope-independent readings, (c) given two possible scope-dependent readings, the object wide scope reading (OBJ) is dispreferred, and (d) given two possible scope-independent readings, the cumulative reading (CU) is dispreferred. The second, more important, goal is to experimentally investigate the learning question, and in particular test the hypothesis that by the age of 5, children have knowledge of the logico-syntactic properties associated with the use of NQE.

In order to achieve these goals, I will use an experimental technique which has proved to be very successful in assessing children's (and adults') interpretation of a broad range of complex linguistic constructions, often involving ambiguous sentences and intricate interactions between quantificational expressions (Lidz & Musolino, 2002; Musolino, Crain, & Thornton, 2000; Musolino & Lidz, 2003; Musolino & Lidz, 2006). This technique is called the Truth Value Judgment Task (TVJT) (Crain & Thornton, 1998). In a nutshell, I will show that knowledge of the facts in (a-d) can be assessed by asking child and adult participants to judge sentences like *Three boys are holding two/each balloon* in a range of configurations corresponding to the different interpretations that such sentences are claimed to give rise to. The details are provided below.

### 4.1. Method

#### 4.1.1. Participants

We tested 32 English-speaking preschoolers (16 boys and 16 girls) between the ages of 4;2 and 6;2 (year, month) ($M$ = 5;0, $SD$ = 7 months). The children were recruited at daycare centers in the Bloomington, Indiana area. We also tested 32 adult native speakers of English, all undergraduate students at Indiana University.

#### 4.1.2. Procedure

We tested participants' interpretation of sentences containing NQE using the TVJT. Participants watched short

[2] There is also a study by Lee (1996) which would be relevant here. Although Lee's study is on the acquisition of quantification in Chinese, and not specifically on the acquisition of NQE, it does include sentences containing two NQE, e.g. *you sange shushu tiaozhe liang tong shui* (*Three men are carrying* (*on their shoulder*) *two buckets of water*). Lee reports two main findings. The first is that Chinese-speaking adults accept the subject wide scope reading only about 20% of the time whereas Chinese-speaking preschoolers do so much more often. The second is that the acceptance rate for the cumulative reading was lower in children than in adults. Although these results are certainly interesting and relevant, they are difficult to evaluate because certain critical experimental details are omitted from Lee's study and no statistical analyses of the data are provided.

animated vignettes involving various characters and objects imported from Microsoft ClipArt. The vignettes were created and animated using Microsoft PowerPoint software and they were displayed on a computer monitor. A prerecorded female voice described each vignette as events unfolded, and at the end a statement describing the outcome of each vignette was made. All the statements were of the form "I know ... statement ... am I right?", e.g. "I know, three boys are holding two balloons, am I right?". The participants' task was to determine whether the computer was 'right' or 'wrong'. The task was identical for both children and adult participants. Adult participants were told that the task was designed for use with young children and that we needed to obtain a baseline measure in order to make sense of the responses we would get from children.

It is worth pointing out that there is now overwhelming evidence that children in the 4–5 age range experience no difficulty whatsoever with the TVJT and that they are perfectly capable of giving either Yes or No answers when appropriate, including appropriate justifications for their answers. Moreover, the TVJT has now been used successfully to test young children's knowledge of complex linguistic constructions in different languages, including English (Musolino, 2004), Greek (Papafragou & Musolino, 2003), Kannada (Dravidian) (Lidz & Musolino, 2002) and Korean (Han, Lidz, & Musolino, 2007).

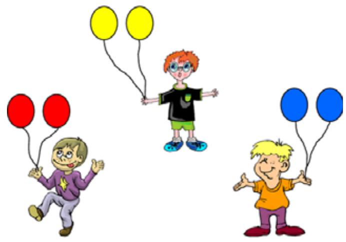
The children were first introduced to the task as a group during 'circle time' and then tested individually at their preschools in a quiet room away from the class or in the Psycholinguistics Laboratory at Indiana University. Each child and adult participant was first shown two pretest vignettes and if they could answer those appropriately (including appropriate justifications for their responses), they were then given the complete experimental package which consisted of a total of 36 vignettes.

*4.1.3. Materials*

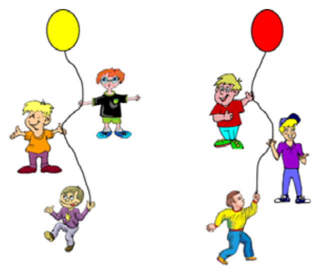
Participants were tested on their interpretation of sentences like (11) and (12) which differ only with respect to the type of the quantified object (*two N* vs. *each N*). Quantifier type was manipulated because, as discussed in Section 2, object NQE differ from other quantified objects in their ability to take scope over the subject. Thus, this condition was included to test the claim that different quantifiers induce different scopal preferences and to determine whether children distinguish NQE from other quantifiers in this regard. Specifically, recall that while an object NQE does not easily take scope over a quantified subject, quantifiers like *each N* seem to require a wide scope interpretation.

(11) Three boys are holding two balloons
(12) Three boys are holding each balloon

For both sentence types, four experimental conditions and four control conditions were created. The four experimental conditions were designed to assess participants' ability to assign sentences containing NQE scope-dependent (subject wide scope, SU and object wide scope OBJ) and scope-independent readings (each-all, EA and cumulative, CU). The four control conditions were designed to test children's ability to correctly interpret phrases like *two N*, *three N* and *each N* in contexts in which they do not combine with each other and to ensure that children would correctly reject sentences containing two NQE in situations which do not satisfy the truth conditions associated with such sentences (control false condition). Pictures depicting configurations corresponding to the four experimental conditions, SU, OBJ, EA and CU, as well as the two control false conditions are shown below.[3]



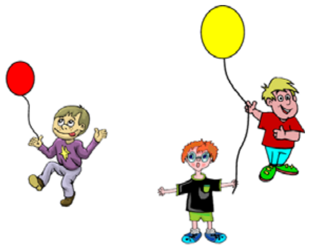
Subject Wide Scope (SU)

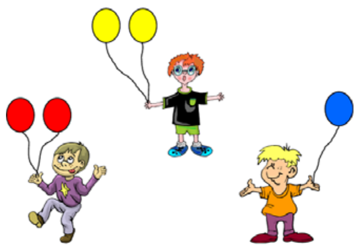


Object Wide Scope (OBJ)

Each-all (EA)

[3] Recall that participants were not shown static pictures but rather animated vignettes in which who was holding what was made very clear so as to remove any possible doubt or confusion regarding the final configurations. In doing so, great care was of course taken to not use phrases like *two N* or *each N* or anything else that might give away the answer. Instead, as objects and characters appeared, the voice would say things like 'look, here's a red balloon and this boy is holding it. This boy is holding it too' etc.




**Picture 6.**


**Picture 7.**

In all eight conditions (four experimental and four control), four repetitions of each outcome/configuration were presented involving different combinations of characters and objects (e.g. boys and balloons, girls and kites, clowns and flowers etc.) (see Appendix A for a complete list). An additional four repetitions were presented in the control false condition, thereby yielding a total number of 36 trials (eight conditions × four outcomes + four additional repetitions for control false). The reason for adding four additional trials to the control false condition was motivated by the need to ensure that the number of Yes and No responses was balanced. For both quantifier types (*two* and *each*), the 36 trials were arranged in two orders of two blocks of 18 trials (eight experimental and 10 control trials). In each case, the two most accessible and least accessible readings – as per the intuitions of linguists – were blocked. Thus, in the case of *two*, one block contained SU and EA (the two most accessible readings) and the other block contained OBJ and CU (the two least accessible readings). Within each of these two blocks, order of presentation of the material was randomized. In the case of *each*, one block contained OBJ and EA (the two most accessible readings) and the other block contained CU and SU (the two least accessible readings). Within each block, order of presentation was randomized. Finally, order of presentation of the two blocks was counterbalanced across subjects.

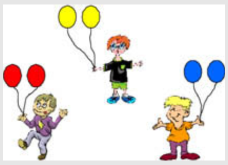
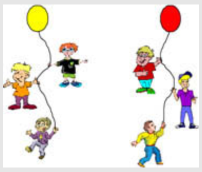
These manipulations gave rise to a 2 (age: children/adults) × 2 (quantifier type: two/each) × 4 (interpretation: SU/OBJ/EA/CU) design where age and quantifier type were treated as between subjects variables and interpretation was treated as a within subjects variable. Finally, the 32 adults and 32 preschoolers were randomly assigned to the two levels of quantifier type (i.e. *each* and *two*). The group of 16 preschoolers (8 boys and 8 girls) assigned to the *two N* condition ranged in age between 4;2 and 6;1 ($M$ = 5;0, $SD$ = 7 months) and the 16 children (eight boys and eight girls) assigned to the *each N* condition ranged in age between 4;2 and 6;2 ($M$ = 5;0, $SD$ = 7 months).

### 4.2. Predictions for adults and children

The facts reviewed in Section 2 allow us to make a number of predictions regarding the way adult participants will interpret sentences like *Three boys are holding two/each balloon(s)*. For sentences like *Three boys are holding two balloons*, three different readings have been claimed to be available, namely SU, EA and CU and a fourth reading, OBJ, is believed to be much more difficult to access. One can therefore expect relatively high acceptance rates for SU, EA and CU (at least significantly above chance) and a comparatively lower acceptance rate for OBJ. Quantifiers like *each N*, unlike NQE, are known to have an inherent tendency to take wide scope with respect to other logical expressions. Therefore in sentences like *Three boys are holding each balloon*, the quantified object will have a strong tendency to take scope over the subject NQE. The resulting interpretation is one on which each of the two balloons – in a scenario that involves two balloons – is being held by three boys. We therefore expect high acceptance rates for OBJ and EA (at least significantly above chance) because in both cases, the two balloons are indeed each being held by three boys (see pictures 2 and 3). On the other hand, we expect comparatively lower acceptance rates for SU and CU where each balloon is not being held by three boys (see pictures 1 and 4). These predictions are summarized in Table 1 where high and low stand for predicted high or low acceptance rates.

Turning to children, a number of specific predictions can also be made. Recall that there is solid evidence from the developmental literature that by the age of 5, children know the meaning of NQE like *two N* and *three N* (Gelman & Gallistel, 1978; Wynn, 1990; Wynn, 1992; Le Corre and Carey, 2007 among many others). Moreover, there is also good evidence that children in that age range know the grammatical mechanisms involved in the logical syntax of quantified expressions, e.g., QR (Crain & Thornton, 1998; Lidz et al. 2004, Syrett and Guasti, 2000; Lidz et al., 2004). On the compositional hypothesis described in Section 2.2, these observations lead to the prediction that preschoolers should know that NQE are scope-bearing expressions, and thus that sentences like *Three boys are holding two balloons* can be interpreted along the lines of SU. Moreover, based on the results of the study by Lidz and Musolino (2002) showing that preschoolers have difficulty assigning an object NQE wide scope with respect to other logical expressions, one would expect a low accep-

**Table 1**
Predicted response patterns for adult participants.

| Quantifier type | SU | OBJ | EA | CU |
|---|---|---|---|---|
| *Two N* | High | Lower than SU, EA and CU | High | High |
| *Each N* | Lower than OBJ and EA | High | High | Lower than OBJ and EA |
| Pictures |  |  |  |  |

tance rate for OBJ. In the case of EA and CU, the compositional hypothesis would again predict relatively high acceptance rates. However, an additional consideration suggests that the acceptance rate for CU may in fact be lower than expected. Indeed, based on the results from Lee's (1996) study on Chinese – and to the extent that Chinese and English are comparable in the relevant respects – one would expect to find acceptance rates for CU lower than those found in adults. Finally, given the well-known difficulties that preschoolers experience with universal quantification (*every*, *all* and *each* are all universal quantifiers) (Crain et al. 1996; Donaldson & Lloyd, 1974; Drozd & van Loosbroek, 1999; Geurts, 2003; Inhelder & Piaget, 1964; Philip, 1995), one might expect a less adult-like profile for sentences like *Three boys are holding each balloon* as compared to sentences like *Three boys are holding two balloons.* Moreover, work by Brooks and Braine (1996) suggests that preschoolers do indeed experience difficulty with quantifiers like *each*.

### *4.3. Results*

Let us first consider participants' performance on the control conditions designed to test knowledge of the meaning of individual quantifiers (*each N*, *two N* and *three N*). Here the dependent measure was the proportion of correct responses. On average, across both quantifier types, adults responded correctly 98.9% of the time to statements containing *two N*, 100% of the time for *three N* and 100% of the time for *each N*. On average, across both quantifier types, children responded correctly 98.9% of the time to statements containing *two N*, 99.35% of the time for *three N* and 97.65% of the time for *each N*. Since participants' performance was virtually flawless in these control conditions, no further statistical analyses were conducted. Finally, recall that a fourth control condition was added in order to ensure that children were able to reject sentences containing two NQE in situations which do not satisfy the truth conditions associated such sentences. In the *two N* condition, children gave correct responses 98.4% of the time, compared to 100% of the time for adults. However, in the *each N* condition, children displayed significantly higher acceptance rates compared to adults (85.1% vs. 23.4%, respectively, $t(30) = 6.5$, $p < 0.001$, two-tailed). We return to this interesting difference in Section 5.3.3.

**Table 2**
Percentages of Yes responses for children and adults in both quantifier type conditions (*two N* and *each N*) and on each interpretation (SU, OBJ, EA, CU).

| | Adults | | Children | |
|---|---|---|---|---|
| | *Two N* (%) | *Each N* (%) | *Two N* (%) | *Each N* (%) |
| SU | 82.8 | 31.2 | 78.1 | 90.6 |
| OBJ | 7.8 | 100 | 28.1 | 84.3 |
| EA | 100 | 85.9 | 98.4 | 79.6 |
| CU | 78.1 | 17.1 | 23.4 | 54.6 |

Let us now turn to the experimental conditions. Here the dependent measure was the proportion of Yes responses. Table 2 provides the percentages of Yes responses for children and adults in both quantifier type conditions (*two N* and *each N*) and for each interpretation (SU, OBJ, EA, CU).

The proportions of Yes responses were entered into a 2 (age: children/adults) by 2 (quantifier type: two/each) by 4 (interpretation: SU/OBJ/CU/EA) mixed design ANOVA in which age and quantifier type were treated as between subjects variables and interpretation as a within subject variable. The analysis revealed a significant main effect of interpretation ($F(3,180) = 32.17$, $p < 0.001$), no main effect of age or quantifier type ($F(1,60) = 0.9$, $p = .34$ and $F(1,60) = 1.6$, $p = .19$, respectively). There were also significant interactions between age and quantifier type ($F(1,60) = 10.26$, $p < 0.01$), interpretation and age ($F(3,180) = 4.8$, $p < 0.01$), interpretation and quantifier type ($F(3,180) = 39.34$, $p < 0.001$) and interpretation, quantifier type and age ($F(3,180) = 16.66$, $p < 0.001$).

In order to further examine these interactions and test the predictions made for adults, separate analyses breaking down the results by age and quantifier type are presented below. Recall that for adults, high acceptance rates for SU, EA and CU were predicted, as well as a comparatively lower acceptance rate for OBJ in the *two N* condition. By contrast, high acceptance rates for OBJ and EA and low acceptance rates for SU and CU were predicted in the *each*

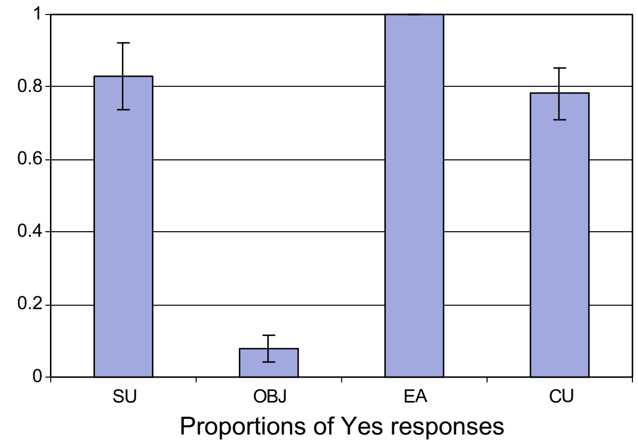



**Fig. 1.** Adults, *two N*.

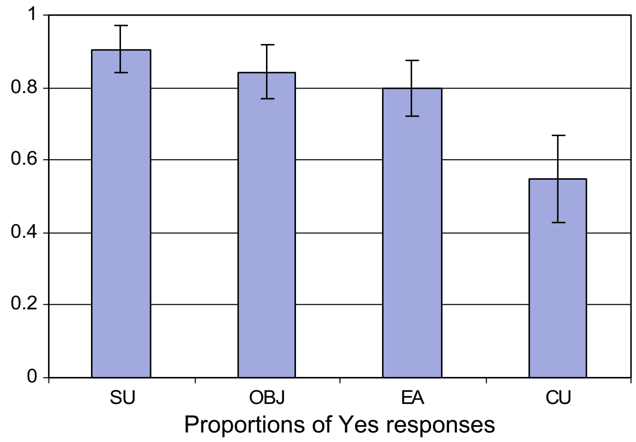



**Fig. 4.** Children, *each N*.

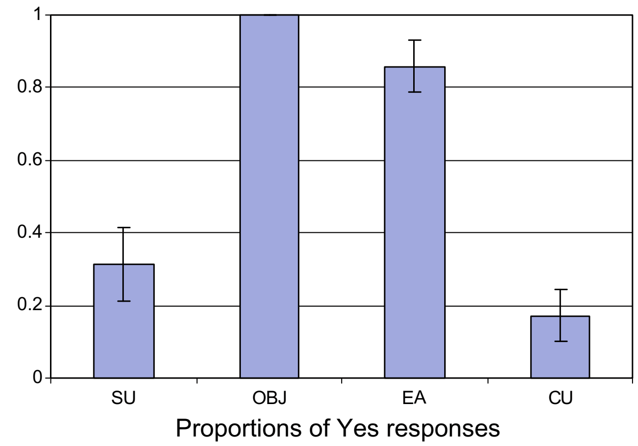



**Fig. 2.** Adults, *each N*.

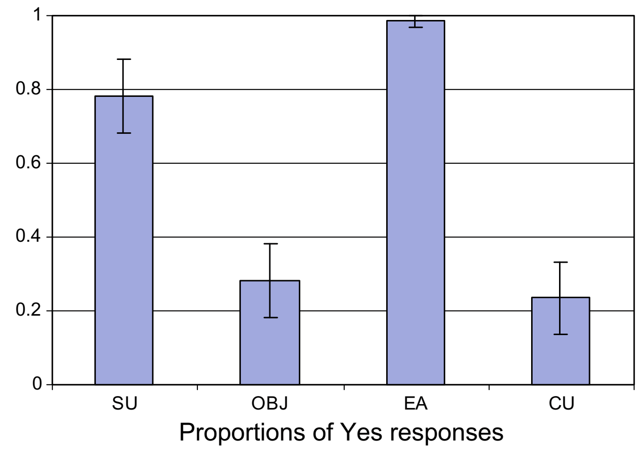



**Fig. 3.** Children, *two N*.

*N* condition. As can be seen from Figs. 1 and 2 below, these predictions are born out.

The percentages of Yes responses for adults in the *two N* condition were entered into a separate, repeated measures ANOVA which revealed a significant effect of interpretation ($F(3,45) = 46.08$, $p < 0.001$). Post-hoc, pairwise comparisons (with Bonferroni adjustment) between the different means indicated that the mean for OBJ is significantly lower than each of the other three means (SU, EA and CU), $p < 0.001$. The mean for CU was also found to be significantly lower than the mean for EA, $p < .05$. No other significant differences were found. Further analyses revealed that the acceptance rates for SU, EA and CU (82.8%, 100% and 78.1%, respectively) were significantly above what would be expected by chance performance ($p < 0.001$) and that the acceptance rate for OBJ (7.8%) was significantly below what would be expected by chance ($p < 0.001$).

The percentages of Yes responses for adults in the *each N* condition were also entered into a separate repeated measures ANOVA which revealed a significant effect of interpretation ($F(3,45) = 39.86$, $p < 0.001$). Post-hoc, pairwise comparisons between the different means (with Bonferroni adjustment) indicated that the mean for SU and CU, while not significantly different from each other ($p = 0.5$), were each significantly different from the means for OBJ and EA ($p < 0.001$). The means for OBJ and EA, in turn, were not significantly different from each other ($p = 0.5$). Further analyses revealed that the acceptance rates for OBJ and EA (100% and 85.9%) were significantly above chance ($p < 0.001$) and that the acceptance rates for SU and CU (31.2% and 17.1%) were significantly below what would be expected by chance performance ($p < 0.01$). Figs. 3 and 4 illustrate the pattern of responses for children in the *two N* and *each N* condition for each of the four interpretations, SU, OBJ, EA and CU.[4]

[4] As one of the reviewers pointed out, blocking the various readings in the design of the experiment might be a concern here, given children's notorious tendency to perseverate. In other words, blocking might lead to undesirable order effects. However, further statistical analyses revealed that no such effects can be found in the data. For each quantifier condition, *Two N* and *Each N*, a separate mixed design ANOVA was conducted with ordering as a between subjects variable and reading (SW, OBJ, EA and CU) as a within subjects variable. In the case of *Two N*, the analysis revealed no significant effect of order ($F(1,14) = 0.697$, $p = 0.41$) and no interaction between ordering and reading ($F(3,14) = 2.1$, $p = 0.11$). In the case of *Each N*, the analysis revealed no significant effect of order ($F(1,14) = 0.756$, $p = 0.39$) and no interaction between ordering and reading ($F(3,14) = 0.65$, $p = 0.58$).

The percentages of Yes responses for children in the *two N* condition were entered into a separate, repeated measures ANOVA which revealed a significant effect of interpretation ($F(3,45) = 18.75$, $p < 0.001$). Post-hoc, pairwise comparisons (Bonferroni adjustment) indicated that the mean for OBJ and CU, while not significantly different from one another, were each significantly different from the mean for SU and EA ($p < 0.05$). SU and EA, in turn, were not significantly different from one another ($p = 0.43$). Further analyses revealed that the acceptance rates for SU and EA (78.1% and 98.4%) were significantly above what one would expect by chance ($p < 0.001$) and that the acceptance rates for OBJ and CU (28.1% and 23.4%) were significantly below what one would expect by chance ($p < 0.01$).

The percentages of Yes responses for children in the *each N* condition were also entered into a separate, repeated measures ANOVA which revealed a significant effect of interpretation ($F(3,45) = 4.05$, $p < 0.05$). Post-hoc, pairwise comparisons (Bonferroni adjustment) indicated that the only significant difference was between the means for SU and CU ($p < 0.05$). Further analyses revealed that the means for SU, OBJ and EA (90.6%, 84.3% and 79.6%, respectively) were significantly above what one would expect by chance performance ($p < 0.001$) but that the mean for CU (54.6%) was not different from chance performance ($p = 0.5$).[5]

Figs. 5 and 6 directly compare patterns of responses obtained for children and adults in each of the two quantifier type conditions (*two N* and *each N*).

We can see that the age by quantifier type interaction is due to the fact that children have a more adult-like profile for *two N* than for *each N*. The interaction between interpretation and age is driven by the way children and adults differ on their acceptance rates for CU in the *two N* condition and for CU and SU in the *each N* condition. The interaction between interpretation and quantifier type arises from the fact that *two N* and *each N* give rise to different response patterns for children and adults. Finally, children display a more adult-like response pattern on *two N* than on *each N* only on certain interpretations, which accounts for the interaction between age, quantifier type and interpretation.

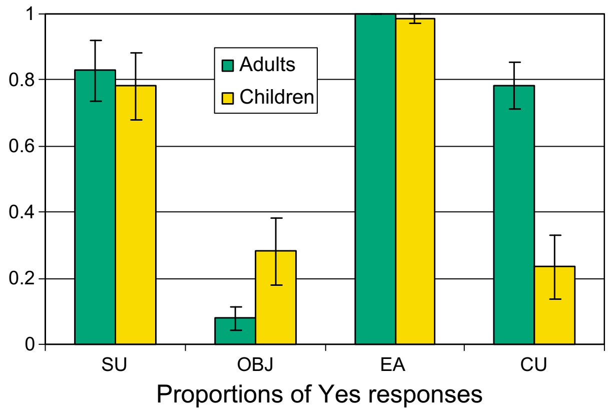



**Fig. 5.** Adults vs. children, *two N*.

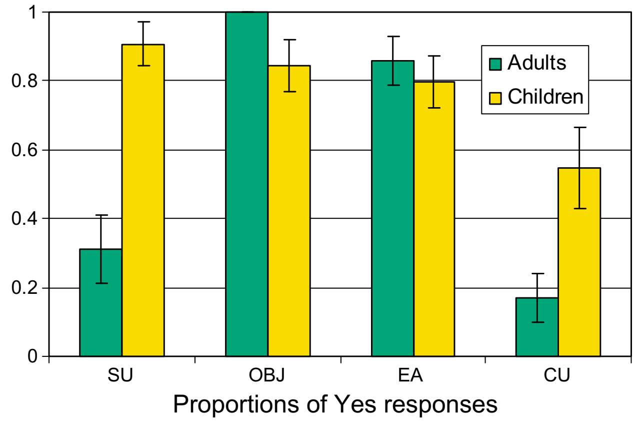



**Fig. 6.** Adults vs. children, *each N*.

## 5. Discussion

### 5.1. Adults

Theoretical linguists, on the basis of their intuitions, have claimed that sentences containing two NQE, such as *Three boys are holding two balloons*, can receive four different interpretations. This means that such sentences are true in at least four different types of configuration involving boys holding balloons. Two of the readings involve scopal interactions between the two NQEs, namely SU and OBJ and the other two, EA and CU are scope-independent readings. Explaining what these readings are and precisely how they arise from the interaction of the expressions involved requires several pages of theoretical background (see Section 2) and a fair amount of exposure to formal linguistic theory and logical analysis. Yet, as the results of the present experiment demonstrate, individuals who do not hold advanced degrees in logic or linguistics routinely access such interpretations in the course of language comprehension. To be sure, as predicted, adult participants accepted SU, EA and CU 82.8%, 100% and 78.1% of the time, respectively and in all cases, significantly above what would be expected by chance performance ($p < 0.001$). Another prediction was that given SU and OBJ, two scope-dependent readings, OBJ would be much more difficult to access and that given two scope-independent readings, EA and CU, EA would be preferred. Here again, these predictions are confirmed by the data, albeit with noticeable differences in the size of the preferences: EA was preferred over CU 100% vs. 78.1% ($p < 0.05$) whereas SU was preferred over OBJ 82.8% vs. 7.8% ($p < 0.001$). In interpreting these results, one might be tempted to conclude that OBJ is simply not a possible reading for sentences like *Three boys are holding*

[5] Children's acceptance rate for CU, namely 54.6%, might at first glance suggest that they were performing at chance in this condition. A closer look at the pattern of responses however, reveals a bimodal distribution with 13 of the 16 children either accepting the relevant sentences 100% of the time (7 children) or 0% of the time (6 children). The other three children accepted the sentences 25%, 75% and 75% of the time.

*two balloons*. However, this conclusion would be premature as the very low acceptance rate in this case might simply reflect the fact that OBJ is massively dispreferred. In this regard, a recent study by Musolino and Lidz (2003) shows that adult speakers of English very seldom accept sentences like *Two frogs did not jump over the rock* on a narrow scope interpretation of the NQE with respect to negation (*It is not the case that two frogs jump over the rock*). However, when certain contextual factors are manipulated, the acceptance rate for the same sentences is almost at ceiling. The moral here is that low acceptance rates on a given reading should not automatically lead to the conclusion that the reading in question is in principle unavailable.

Another observation made by linguists is that different quantifiers induce different scopal preferences. Thus, while an object NQE cannot easily take scope over a quantified subject, a quantifier like *each* seems to require a wide scope interpretation. This prediction is confirmed by adults' different acceptance rates for OBJ in the *two N* and *each N* condition, namely 7.8% vs. 100%, respectively. More generally, the fact that *each* seems to require a wide scope reading predicts that sentences like *Three boys are holding each balloon* (in a situation in which there are two balloons) will be interpreted as meaning that for each of the two balloons, there are three boys holding the balloons. This, in turn, predicts that in addition to OBJ, adults should accept any configuration in which each of the two balloons is being held by three boys and tend to reject configurations in which this is not the case. This predicts a high acceptance rate for EA and comparatively lower rates for SU and CU which is confirmed by the data (85.9% acceptance rate for EA vs. 31.2% and 17.1% for SU and CU, respectively with the mean for EA significantly higher than those for SU and CU, $p < 0.001$)

### 5.2. Children

Children's near perfect performance on the control conditions designed to test knowledge of the individual meaning of expressions like *two N*, *three N* and *each N* (98.9%, 99.35% and 97.65% correct, respectively) indicates that preschoolers experienced no difficulty with the task, and that they were able to provide both Yes and No answers when appropriate (since approximately half of the control items required a Yes answer and the other half a No answer). Turning to the experimental conditions, recall that this experiment was designed to test knowledge of the core logico-syntactic properties of NQE shown in Table 1.

Children's performance in the *two N* condition suggests that by the age of 5, knowledge of these core properties is in place, as predicted by the compositional hypothesis discussed in Section 2.2. Specifically, children's adult-like acceptance rate in the SU condition (78.1% acceptance rate vs. 82.8% for adults, $t(30) = -0.34$, $p = 0.73$, two-tailed) demonstrates knowledge of the scopal properties of NQE. Recall that in this condition, each of the three boys is holding two balloons and so that the total number of balloons is six. Nevertheless, children readily accept sentences like *Three boys are holding two balloons*, even if the total number of balloons, six, is different from the one explicitly mentioned in the sentence, two. This shows that preschoolers truly understand the scopal nature of NQE and the fact that in this case, the interpretation of the object NQE is dependent on that of the subject NQE.[6]

Children's adult-like acceptance rate in the EA condition (98.4% for children vs. 100% for adults) indicates that preschoolers can assign NQE scope-independent readings.[7] The asymmetry observed in children's acceptance rate of SU and OBJ (78.1% vs. 28.1%, respectively, $p < 0.05$) demonstrates that given two scope-dependent readings, children, like adults, display a strong preference for SU over OBJ. Finally, given two scope-independent readings, EA and CU, children, like adults, displayed a preference for EA (98.4% acceptance rate vs. 23.4%, respectively, $p < 0.05$). In this regard, it should be noted that the size of this preference is different in the two populations. For adults, EA is preferred over CU (100% vs. 78.1%, respectively), but the acceptance rate for CU nevertheless remains high and significantly above chance (as high as SU, 82.8% and significantly higher than OBJ, 7.8%). For children, EA is also preferred over CU (98.4% vs. 23.4%, respectively) but the acceptance rate for CU is significantly lower than that for SU (23.4% vs. 78.1%, $p < 0.05$) and not different from that for OBJ (23.4% vs. 28.1%).

Given the availability of both distributive and cumulative interpretations for NQE, the previous observation suggests that preschoolers tend to assign NQE a distributive reading. Whether children's low acceptance rate in the case of CU reflects an inability to assign NQE a cumulative interpretation or a strong preference for a distributive reading is a question that cannot be answered given the data available. On the assumption that this pattern reflects preschoolers' preferences – and not a lack of ability – we may be witnessing in children an exaggerated version of the adult preference for EA/SU over CU. A similar phenomenon, also involving NQE, has been recently reported in the developmental literature on quantification (Musolino & Lidz,

[6] This result is noteworthy, especially in light of recent findings on the scalar behavior of NQE showing how reticent preschoolers are to deviate from the 'exactly *n*' interpretation (Huang et al., submitted; Hurewitz et al., 2006; Musolino, 2004; Papafragou & Musolino, 2003). For example, Musolino (2004) tested 4 and 5-year-olds on their interpretation of phrases like *two N* in contexts which license an 'at least *n*' interpretation. This was done in the context of a game in which the main character had to get two hoops on a pole to win a prize. At the end, the character in question managed to get four hoops on the pole. The test question was whether he should win the prize. Adult participants almost always answered affirmatively thereby assigning the phrase *two N* an 'at least n' interpretation (*You need to get two hoops on the pole* was thus interpreted as *You need to get at least two hoops on the pole*). Preschoolers on the other hand answered negatively two thirds of the time, arguing that the character should not win because the number of hoops on the pole was four, and not two. This result shows that preschoolers, unlike adults, have a strong tendency to assign NQE an 'exactly n' reading. In spite of this bias, the children in the present experiment, who were the same age as those used in Musolino (2004), had no difficulty accepting sentences containing the phrase *two balloons* in a context in which the total number of balloons was six.

[7] Here again, one may argue that EA is just a special case of OBJ and so that children (and adults) know EA by virtue of knowing OBJ. However, what would be puzzling on this view is the asymmetry between EA and OBJ seen in both children and adults. If EA is just a special case of OBJ, then what would explain that both children and adults find it so difficult to access OBJ as compared to EA?

2003). To begin, Lidz and Musolino (2002) showed that preschoolers, when given a truth value judgment task, display a strong preference for the narrow scope reading of the NQE with respect to negation in sentences like *The Smurf did not catch two birds* (i.e., *It is not the case that the Smurf caught two birds*). To be more precise, in a context in which the narrow scope reading is true and the wide scope reading is false, children readily accept sentences like *The Smurf did not catch two birds*, on the grounds that the narrow scope reading is true. However, in a context in which the wide scope reading is true and the narrow scope reading is false, children overwhelmingly *reject* the same sentences on the grounds that the narrow scope reading is false. In contrast, adults in the same task can access the two scope readings equally often (the wide scope reading of the NQE can be paraphrased as *There are two birds that the Smurf did not catch*). What Musolino and Lidz (2003) showed is that in a context in which both scope readings are true, adults justify their (necessarily) affirmative answers by invoking the fact that the narrow scope reading is true. This result shows that the preference seen in children for the narrow scope reading of an object NQE is an exaggerated version of a preference also observable in adults.

One way to interpret these results is in the context of recent findings on the development of sentence processing abilities in young children (Trueswell et al., 1999). What emerges from the work of Trueswell and collaborators is the observation that preschoolers do not yet resolve ambiguity as efficiently as adults. The main difference between the two populations lies in their respective ability to revise an initial parse which at a later point in time turns out to be incorrect. While this process is quick and efficient in adults, the same is not true of preschoolers who often end up getting stuck with the initial (incorrect) parse. If so, the kind of exaggerated preference described above is precisely what one would expect to find. In the case of sentences like *The Smurf did not catch two birds*, children and adults initially access the narrow scope reading but only adults are later able to revise their initial interpretation and access the wide scope reading. The same kind of reasoning would apply to sentences like *Three boys are holding two balloons*. In both populations, the initial parse would correspond to a distributive interpretation of the NQE which would explain high acceptance rates for SU and EA.[8] On this view, adults would be able to revise their initially distributive parse and assign the NQE a cumulative interpretation, but this would be much more difficult for children and would explain the lower acceptance rate for CU compared to EA and SU. The initial preference for a distributive parse of the NQE, in turn, might come from differences in the frequencies with which NQE are used on the distributive/cumulative readings.

Next, let us consider children's performance in the *each N* condition. This condition was included mainly to test the claim that different quantifiers induce different scopal preferences. Specifically, recall that while an object NQE does not easily take (distributive) scope over a quantified subject, quantifiers like *each N* seem to require a wide scope interpretation. This effect was thus expected to manifest itself in the OBJ condition and was verified for adults (7.8% acceptance rate for OBJ in the *two N* condition vs. 100% in the *each N* condition). The data obtained from children indicate that the distinction between NQE and quantifiers like *each N* is also in place by the age of 5 (28.1% acceptance rate for OBJ in the *two N* condition vs. 84.3% in the *each N* condition, $p < 0.05$). This result is worth emphasizing because it suggests that young children have knowledge of the mechanism whereby quantifiers are interpreted in a position that is different from their surface syntactic position, namely quantifier raising (QR) – or whatever mechanism may be responsible for its effects. Indeed, recall from the discussion in Section 2 that in order to obtain an interpretation of the sentence *Three boys are holding each balloon* on which *each balloon* takes scope over *three boys*, the phrase *each balloon* must be (covertly) displaced from its surface syntactic position to a higher position from which it will take scope over *three boys*. We thus have evidence that by the age of 5, young children have knowledge of one of the core linguistic mechanisms underlying the logical syntax of natural language quantification (for related evidence, see Brooks & Braine, 1996; Guasti, 2000 and Lidz et al., 2004).

The other noteworthy observation regarding children's performance in the *each N* condition concerns their acceptance rates for SU and CU which are significantly higher than those observed in adults (90.6% for children vs. 31.2% for adults in the case of SU, $t(30) = 4.9$, $p < 0.001$, two-tailed, and 54.6% for children vs. 17.1% for adults in the case of CU, $t(30) = 2.7$, $p < 0.01$, two-tailed). The importance of this difference as well as its implications are the topic of the next section.

To summarize, the results of our experimentation with preschoolers reveal that, by the age of 5, children know that (a) NQE give rise to scope-dependent readings, (b) NQE also give rise to scope-independent readings, (c) given two possible scope-dependent readings, the wide scope reading of the object (OBJ) is dispreferred, and (d) given two possible scope-independent readings, the cumulative reading (CU) is dispreferred. Moreover, children's behavior in the *each N* condition indicates that they have knowledge of QR – or its theoretical equivalent – one of the core mechanisms underlying the logical syntax of natural language quantification. Notice that these results are compatible with the compositional and the learning hypothesis described in Section 2.2. We come back to this question in Section 5.4. Finally, in spite of their impressive command of the logical syntax of NQE, we have also seen that preschoolers differ from adults in their ability to assign NQE a cumulative reading and in their elevated acceptance rates for SU and CU in the *each N* condition.

### 5.3. Explaining differences between children and adults

An important feature of the integrative approach advocated in this article is the claim that linguistically-based models can be used to explain developmental phenomena. In order to substantiate this claim, I will now show that the differences between children and adults uncovered in the

[8] Notice that both SU and EA, even though one reading is scope-dependent and the other is not, can be interpreted as distributive in the sense that in both cases, each of the three boys is indeed holding two balloons.

preceding section can be accounted for by an independently motivated, linguistically-based, processing model originally proposed to account for children's non-adult behavior in the domain of universal quantification (sentences containing *every*) (Geurts 2003). In order to do so, I will proceed in the following manner. First, I provide a summary of the main features of Geurts' (2003) model. Second, I show that this model naturally extends to the kind of sentences that we have been concerned with and that it provides a principled explanation of some of the differences we observed in the behavior of children and adults. Third, I consider further predictions of Geurts' (2003) model and show that they can also be verified using the data reported here. Finally, I briefly discuss alternative accounts of the differences under consideration as well as related issues arising from the use of Geurts' (2003) model.

*5.3.1. Geurts' (2003) processing model*

It is well-known in the developmental literature on quantification that preschoolers – and even older children – often give strikingly non-adult responses to statements containing the universal quantifier *every*. For example, when shown a picture in which three boys are each ridding a different elephant and a fourth elephant is left without a boy, and asked whether every boy is riding an elephant, children, unlike adults, often answer 'No' and justify their answer by pointing out that one of the elephants is *sans* boy (Drozd et al., 1999; Philip, 1995, among many others).

The most recent account of this phenomenon is a proposal by Bart Geurts (2003). Although the account itself is fairly technical, and thus requires a good working knowledge of linguistic theory to fully appreciate, the core intuitions are relatively easy to grasp. I will therefore focus here on these core intuitions and try to make them intelligible to readers who do not possess the relevant linguistic background. Readers interested in a more thorough – and more technically accurate – exposition of Geurts' ideas can turn to his original 2003 article. As a first step, let us try to think about what a sentence like (13) means. Given a contextually determined set of individuals (say the ones shown in a picture), (13) expresses the idea that all the individuals that happen to be boys have at least one property in common, namely that of being an elephant rider. This, in turn, tells us that there are three important parts to the meaning of a sentence like (13): the quantifier itself, *every*, the noun that the quantifier combines with, *boys* and finally, the property that all the boys have in common, namely that of being elephant riders. Accordingly, linguists find it useful to represent the logical structure of (13) roughly as given in (14). In plain English, the representation in (14) is simply saying that for every x, if x is a boy, then there is a y, y is an elephant, such that x is ridding y.

(13) Every boy is riding an elephant.
(14) a. Every (x) [boy (x) → (y: elephant (y) and x rides y)]
b. Every (A) (B)

More generally, we can think of a sentence like (13) as having the structure in (14b) where *every* is the quantifier, (A) is the noun that combines with the quantifier (called the restriction) and (B) is the property that Every (A) must satisfy for the sentence to be true.

The next step is to observe that quantifiers do not all give rise to the tripartite structure described above. In fact, linguists have long recognized (for reasons that need not concern us here) that quantifiers fall into two categories: those that give rise to a tripartite structure like (14b), called strong quantifiers, and those that only give rise to a two-part structure, as shown in (15), called weak quantifiers.

(15) Quantifier (B)

We are now in a position to express the key insight underlying Geurts' proposal. Based on the assumption that a three-part structure is more costly to build than a two-part structure, Geurts proposes that when children parse a sentence which contains a strong quantifier like *every*, they initially treat the quantifier as though it were weak, and thus only 'build' a two-part structure of the type shown in (15). Crucially however, children know that *every* is strong, and thus requires a tripartite structure. This means that the final representation for a sentence like (13) will contain three parts indeed but that one of them, the (A) part, will be left underspecified. This is shown in (16a).

(16) a. Every (. . ..) (boy, elephant, boy rides elephant)
b. Every (boy) (elephant, boy rides elephant)
c. Every (elephant) (boy, boy rides elephant)

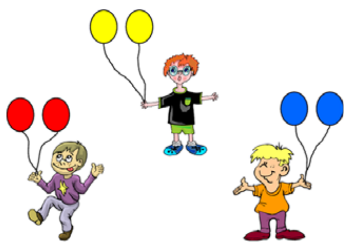
Given the representation in (16a), there is now a choice as to which of the two nouns, *boy* or *elephant*, will end up serving as the restriction on the quantifier *every*. On Geurts' account, pragmatic/contextual factors ultimately determine which of the two nouns ends up serving as the restriction on the quantifier. In case the noun *boy* ends up in the restrictor, as shown in (16b), we get the adult representation, and the sentence means that for every boy there is an elephant that that boy is riding. However, if the noun *elephant* ends up serving as the restriction on the quantifier, as shown in (16c), we get a representation which would make the sentence true just in case, for every thing that happens to be an elephant, there is a boy riding that elephant. This latter representation is what accounts for children's classic interpretative 'error'. Indeed, recall that preschoolers often reject a sentence like *Every boy is riding an elephant* in a context in which one of four elephants is *sans* boy. On the account developed here, this makes sense if children incorrectly take the sentence *Every boy is riding an elephant* to mean that for every elephant, there must be a boy riding that elephant, (16c).

*5.3.2. Using Geurts' (2003) model to account for children's non-adult behavior*

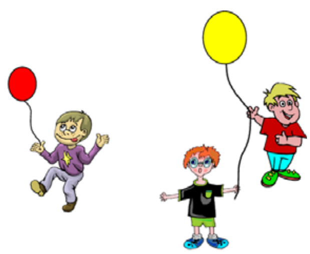
Let us now see how Geurts' account extends to sentences like *Three boys are holding each balloon*. What needs to be explained here is why children's acceptance rates for pictures 1 and 4, corresponding to SU and CU, are significantly higher than those of adults (31.2% and 17.1% for adults, vs. 90.6% and 54.6% for children, $p < 0.01$). First it is important to point out that *each*, like *every*, is a strong quantifier.[9] Also recall from Section 2 that *each* has a strong tendency to take wide scope with respect to other logical expressions. Thus, in the case of a sentence like *Three boys are holding each balloon*, *each balloon* will tend to take scope over *three boys*. With these facts in mind, consider now the adult representation of *Three boys are holding each balloon* given in (17a). Since *each* combines with the noun *balloon*, *balloon* serves as the restriction on the quantifier and thus, on a wide scope reading of *each balloon*, (17a) can be paraphrased as meaning that for each balloon, there are three boys holding that balloon. Clearly, this is not true of pictures 1 and 4, corresponding to SU and CU, which explains adults' low acceptance rates in these cases.

(17) a. Each (balloon) (three boys, boys hold balloon)
b. Each (. . ..) (balloon, three boys, boys hold balloon)
c. Each (three boys) (balloon, three boys hold balloon)

(17b) shows the representation corresponding to a weak construal of *each* – with the restriction left underspecified – and (17c) illustrates the representation in which *boys* – and not *balloons* – serves as the restriction on *each*. (17c), also on a wide scope reading of *each*, can be paraphrased as meaning that for each of the three boys, there is a balloon that that boy is holding, which is true of pictures 1 and 4 and thus accounts for children's higher acceptance rates in these cases.[10]



Subject Wide Scope (SU)



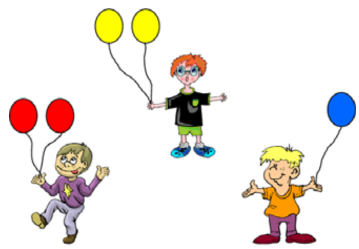
Cumulative (CU)

[9] As witnessed by the unacceptability of a sentence like *There is/are each student(s) in the room*. See Appendix 2 for further discussion.

[10] Notice that *three boys* in (17c) would need to be interpreted distributively, a fact that can be captured in the system proposed by Geurts (Bart Geurts, personal communication).

*5.3.3. Testing further predictions of Geurts' (2003) model*

As we have just seen, Geurts' (2003) model, initially formulated to account for children's non-adult interpretation of *every*, naturally extends to other strong quantifiers and nicely captures the non-adult pattern reported here. What's more, Geurts' account makes another specific prediction in the present context. Recall that pictures like 6 and 7 were used as controls in the *two N* and *each N* condition. These configurations were introduced to make sure that participants could reject sentences like *Three boys are holding two balloons* when the truth conditions associated with such sentences were not satisfied.



Control False 1

Control False 2

If the account developed so far is correct, we should expect to find that children and adults respond differently to pictures 6 and 7 in the *each N* condition, that is when sentences like *Three boys are holding each balloon* are used to describe these pictures. Let us see why. If *Three boys are holding each balloon* tends to be interpreted by adults as meaning that for each of the balloons there are three boys holding it, (17a), we would expect adults' acceptance rate to be rather low in the case of the configurations corresponding to pictures 6 and 7. By contrast, if children tend to interpret the same sentence as meaning that for each of the three boys there is a balloon that that boy is holding, (17c), then we would expect children's acceptance rate to be comparatively higher for pictures 6 and 7. As already mentioned in the results section, an analysis of the data obtained from preschoolers and adults in response to configurations corresponding to pictures 6 and 7 indicate that this prediction is indeed borne out. Recall that adults accepted sentences like *Three boys are holding each balloon* 23.4% of the time in the context of configurations corresponding to pictures 6 and 7 whereas children accepted the same sentences significantly more often, i.e. 85.1% of the time ($t(30) = 6.5$, $p < 0.001$, two-tailed). Moreover, notice that the difference in size between these two acceptance rates, roughly equal to a factor of 3.5, nicely corresponds to the size of the difference in acceptance rates between children and adults for pictures 1 and 2

(31.2% vs. 90.6% and 17.1% vs. 54.6%, respectively). Finally, notice that this difference emerges only in the *each N* condition (in the *two N* condition, recall that children's (correct) rejection rates were not different from that of adults (98.4% vs. 100%, respectively).

### 5.3.4. Qualifications and further predictions

Anybody familiar with the literature on the acquisition of quantification will be aware of the fact that Geurt's is not the only account of children's non-adult interpretation of the universal quantifier currently available. Since Piaget and collaborators uncovered the basic phenomenon some 40 years ago (Inhelder & Piaget, 1964), a number of accounts have been proposed, sometimes leading to vigorous debate (Crain et al., 1996; Drozd et al., 1999; Geurts, 2003; Philip, 1995 among others). My aim here is not to add to this discussion by trying to decide between these competing accounts – a task which clearly falls beyond the scope of the present article – nor even to suggest that Geurts' is the only account capable of accounting for the data presented here. Rather, in using Geurts' (2003) account, my goal has been to illustrate the explanatory power of linguistically-based models when it comes to explaining developmental patterns. To the extent that the results presented here are compatible with a different linguistically-based account of children's non-adult interpretation of sentences containing the universal quantifier, my point remains unaffected.[11]

What is worth emphasizing here in the context of the relationship between linguistic theory and linguistic development – and more generally the relationship between linguistics and psychology – is that the explanatory force of the type of account proposed by Geurts comes from two separates sources. First, the formal constructs and technical vocabulary involved in the proposal, such as quantifier, domain, nuclear scope, weak, strong, etc., are independently needed to account for the competence of mature speakers. The fact that an explanation of the behavior of children can be formulated in terms of the same constructs and vocabulary illustrates the explanatory power of formal accounts of language through what is known as the continuity assumption (Pinker, 1984). Second, the model proposed by Geurts is independently motivated in another way as well: it is needed to explain the kind of non-adult responses that children often give to sentences like *Every boy is riding an elephant.*

Having said that, I would now like to briefly consider an alternative account of the developmental pattern under consideration and discuss two further issues arising from the analysis discussed above. Recent work on the acquisition of quantification shows that children often interpret sentences containing multiple quantificational elements on the basis of the surface syntactic position of these elements. This phenomenon has come to be known as 'isomorphism' (Lidz & Musolino, 2002; Musolino, 1998; Musolino & Gualmini, 2003; Musolino & Lidz, 2003; Musolino et al., 2000; Noveck, Guelminger, Georgieff, & Labruyere, 2007). The question I would like to consider is whether the difference observed between children and adults in the *each N* condition may be a manifestation of the isomorphism effect. Recall that for adults, sentences like *Three boys are holding each balloon* require assigning *each balloon* wide scope and thus interpreting it in a position that is different from its surface syntactic position. Suppose now that an isomorphic child were to interpret *each balloon* where it occurs in surface syntax, that is in the scope of *three boys*. If so, children would tend to interpret *Three boys are holding each balloon* as meaning that three boys are such that they are holding all the balloons (recall that *each* is universal quantifier). At this point, two further options would present themselves. Given a narrow scope reading of *each balloon*, children could still in principle interpret *three boys* distributively or cumulatively. If the former option is chosen, one would expect children to accept *Three boys are holding each balloon* only in configurations in which each of the three boys is holding all the balloons. This in turn would fail to account for children's elevated acceptance rates in the SU and CU conditions since in these configurations it is not the case that each boy is holding all the balloons. Suppose now that children assign *three boys* a cumulative interpretation. In this case, one would expect children to accept *Three boys are holding each balloon* only in configurations in which the three boys, when considered cumulatively, are holding all the balloons. This would indeed account for children's elevated acceptance rates in SU and CU since in these two cases, the boys, when considered collectively, are holding all the balloons. The problem with this explanation though is that it would require that children assign the NQE a cumulative interpretation. However, results from the *two N* condition indicate that children have a massive preference for the distributive interpretation of NQEs. Another problem with this account is that isomorphism arises in cases involving the interaction of quantified NPs and *negation* and not in cases involving the interaction of two quantified NPs.

Another issue that deserves clarification is the fact that accounts like Geurts' (or any other for that matter) do not predict that children will always resort to the strategy described in these accounts. In other words, as a matter of empirical fact, children do not always interpret statements containing the universal quantifier in a non-adult manner (see Philip, 1995 for discussion). Nor is it the case that adults never do so (Freeman, Sinha, & Stedmon, 1982. Also see Musolino and Lidz (2003) for related evidence) – the term 'non-adult' here can thus be somewhat misleading. The main thrust of the kind of accounts under consideration is not to predict the frequency with which children will resort to non-adult interpretations but rather to explain the nature of the representations and processes involved when they do, as well as specify the contexts in which such non-adult interpretations are expected to occur. Thus, given the availability of a strategy S, which deviates from the 'standard' strategy used in interpreting

[11] It is now generally accepted that the kind of errors involving the universal quantifier originally reported by Piaget and his collaborators are not due to conceptual deficits in the young child, as originally proposed. It is now clear that the problem is linguistic, not conceptual (see Philip (1995) and Lidz and Musolino (2002) for relevant discussion).

universally quantified statements, the observation is that children resort to S more often than adults.

This last point leads to an important question regarding the results presented here, namely whether children resort to the kind of interpretation predicted by Geurts' model across the board, that is in all four conditions, SU, OBJ, CU and EA, or just in the two conditions in which they differ from adults, namely SU and CU (as well as the control conditions discussed above). This issue arises because children's apparent adult-like behavior in the OBJ and EA condition would also be what one would expect on the analysis based on Geurts' model. Recall that on this view, the key difference between children and adults is that preschoolers tend to interpret sentences like *Three boys are holding each balloon* as meaning that for each of the three boys, there is a balloon that that boy is holding. Since this is obviously true of the configurations corresponding to OBJ and EA, one could argue that children are giving the right answer for the wrong reason. This, in turn, one might think, would undermine the conclusions reached earlier on the basis of children's apparent adult-like behavior in the OBJ condition. Recall that we took this observation as evidence for knowledge of the mechanism of quantifier raising – or its equivalent – in preschoolers.

Fortunately, a closer look at the phenomenon reveals that this potential objection should not be a concern. On the account discussed so far, children are claimed to often interpret *Three boys are holding each balloon* to mean that each of the three boys is holding a balloon. Notice now that in order to get to this interpretation, two things need to happen. First, as described by Geurts' model, children need to 'incorrectly' let the noun *boys* serve as the restriction on *each*. But this is not all. The issue of the relative scope of (incorrectly derived) *each boy* and *a balloon* still needs to be settled. On a wide scope reading of *each boy* over *a balloon*, we get the desired reading, namely that for each of the boys there is a balloon that that boy is holding. This would account for the high acceptance rate in the OBJ condition since in this case, each boy is indeed holding a balloon. Consider now the narrow scope interpretation of *each boy* with respect to *a balloon*. Here, we would get a reading that would be true just in case there is a particular balloon that all the boys are holding (recall that *each* is a universal quantifier). This, however, would not be true of the configuration corresponding to the situation depicted in the OBJ condition where three boys are holding one balloon and another balloon is being held by a different group of three boys. We can therefore conclude that for children to behave in a seemingly adult-like fashion in the OBJ condition, they must, even if they resort to the kind of interpretation predicted by Geurts' model, interpret *each* as taking wide scope. In other words, children must interpret *each* in a position which is different from its surface syntactic position. This, in turn, amounts to knowing the mechanism (QR or other) which covertly displaces quantifiers. Thus, even if children behave in a adult-like fashion in the OBJ condition for the 'wrong reasons' the conclusion that preschoolers know QR (or its equivalent) remains a valid one.

Finally, the reader will also have noticed that in the *each N* condition, adults accept sentences like *Three boys are holding each balloon* in the configurations corresponding to SU and CU approximately a third and a fifth of the time (31.2% vs. 17.1%, of the time, respectively, to be more precise). One way to think about this observation is that the difference between children and adults is only quantitative, and not qualitative, which brings us back to considerations of sentence processing abilities in the two populations and again ties the present research to other work on the acquisition of quantification and the development of sentence processing abilities. One could argue that both children and adults are prone to the kind of misparse described by Geurts' (2003) model, but that children resort to this strategy much more often than adults do. This interpretation, advocating for continuity of representation and process, would be compatible with the finding that in certain contexts, children can be made to behave more like adults when it comes to their interpretation of universally quantified statements (Crain et al., 1996) and also that the 'errors' observed in children can be induced in adults (Freeman et al., 1982. Also see Musolino and Lidz (2003) for related evidence). The interesting question in the case at hand is whether children could be 'turned into adults' – and vice-versa – if the context and the experimental conditions in which the relevant sentences are presented were appropriately manipulated. For example, Geurts (2003) predicts that the contextual salience of the various characters and objects determines which of the nouns in the sentence ends up serving as the restriction on the universal quantifier. In the case of sentences like *Three boys are holding each balloon*, this would predict that making the balloons more salient than the boys should have the desired effect.

### 5.4. Implication for development and developmental accounts

In addition to experimentally verifying the intuitions of linguists regarding the logical syntax of NQE, highlighting the explanatory power of linguistically-based models, and tying the present results to recent developments on the acquisition of quantification and the development of sentence processing abilities in young children, these findings also raise serious developmental questions. What I hope to have shown here is that a grasp of the complexity associated with the logico-syntactic properties of NQE is not the exclusive privilege of individuals holding advanced degrees in logic or linguistics. College undergraduates, and more importantly preschool children, who have had little to no formal education, possess the intricate knowledge described by linguists. Consequently, developmental accounts are now faced with the new challenge of having to explain how this knowledge is acquired.

To put this challenge in perspective, recall that the main puzzle that developmental psychologists have been trying to solve over the past three decades is how children learn that expressions like *two dogs* are used to describe sets of two dogs. As the work of linguists makes it clear however, mastery of the number vocabulary goes far beyond the recognition that *two* is used in the presence of two-membered sets. NQE also give rise to a range of interpretations depending on the context in which they are used (Musolino, 2004), a rich set of pragmatic inferences and scalar effects (Papafragou & Musolino, 2003), and when combined, they interact with each other and other logical expressions in intricate ways. Thus, mastery of the number vocabulary, just like any other aspect of language, involves knowledge of complex semantic, pragmatic and syntactic properties.

Although a detailed account of how these complex linguistic properties are acquired by young children is a task that lies far beyond the scope of the present article, I would nevertheless like to consider, if only briefly and in a speculative and abstract manner, how this might be accomplished, focusing on the properties of NQE discussed in this article. What I would like to consider are two options at opposite ends of the nativist/empiricist continuum, without necessarily ascribing these views to any particular account or investigator. Specifically, I would like to consider the idea that the complex logico-syntactic properties discussed in this article are directly learned from an analysis of the input, and the idea that these properties are not learned – and in fact that they do not even need to be learned – but rather that they are (implicitly) deduced from knowledge of the lexical meaning of NQE combined with knowledge of the general rules of syntax for one's language, as discussed in Section 2.2.

According to the first approach, children would come to know that NQE can give rise to scope-dependent/independent readings, *inter alia*, because they have heard NQE being used by the people around them in the relevant situations. First, notice that this scenario would require that mothers and caretakers routinely use sentences containing multiple quantificational expressions (NQE combining with NQE and other quantifiers) in highly constrained situations which correspond to the configurations verifying the truth conditions of the readings that we have been discussing throughout this paper. However remote this may sound, this is of course not impossible, and only a detailed analysis of the input will settle the issue one way or the other. A second, perhaps more serious, problem is that the inferences and conclusions that children would draw about the behavior of NQE on the basis of examples provided by caretakers would have to be highly constrained. Imagine for example that a child were to hear a sentence like *Three boys are holding two balloons* in configurations corresponding to SU, OBJ and CU. One logically possible conclusion that the child may reach on the basis of such evidence is that sentences like *Three boys are holding two balloons* are true when (a) the number of boys is either 3 (SU) or 6 (OBJ), and (b) the number of balloons is either 6 (SU) or 2 (CU). The problem here is that such a conclusion, perfectly reasonable as it may be given the nature of the evidence, would nevertheless lead to massive overgeneralization. For example, the child would now erroneously assume that a sentence like *Three boys are holding two balloons* is true when six different boys are each holding one balloon (number of boys = 6 and number of balloons = 6) or when three boys are such that two are holding one balloon each and the third is holding four balloons (number of boys = 3 and number of balloons = 6). Examples of this sort are just a small fraction of the set of logically possible conclusions that a child might reach on the basis of the positive evidence that would seem to be required for the appropriate learning to take place. And so unless the child receives explicit instruction regarding possible and impossible configurations, it is hard to see how learning could be successful. This, of course, is nothing more than the familiar problem of unconstrained induction applied to language (Chomsky, 1975).

As mentioned earlier, another possibility is that the properties under consideration are not learned but rather that they are (implicitly) deduced from knowledge of the meaning of the individual words in a given sentence along with knowledge of the basic rules of syntax for one's language. This would not be unreasonable since it is unthinkable that children learn the meaning of every single sentence they hear on the basis of a pairing of each sentence with a situation that would verify its truth conditions. Fortunately for children, semantics is compositional. On this view, the problem would boil down to having a rich enough theory of the lexical semantics of NQE, which, when engaged by independently motivated, general syntactic principles would yield, without any further stipulation, the desired set of logico-syntactic properties. The main developmental issue on this view would be to explain how children solve the mapping problem for NQE – namely, how they learn to pair the relevant pieces of phonology with the right pieces of lexical semantics. Needless to say, this problem needs to be solved regardless of one's theoretical inclination.

In this regard, some linguists working on natural language quantification seem to have opted for an approach of the kind just described in order to account for the principled – and yet highly idiosyncratic - behavior of different quantifiers. For example, Beghelli and Stowel (1997), based on their own work and that of others, have partitioned the class of natural language quantifiers into a number of separate categories such as, to give a few examples, interrogative, negative, distributive-universal, counting and group denoting quantifiers (with further subclassifications in certain cases). Moreover, on this view, the lexical entries for quantifiers include specific features such as [+interrogative], [+negative], [+distributive], [+universal], etc. All this structure is in part motivated by the need to account for the intricate logico-syntactic behavior displayed by different types of quantifiers, including NQE, without having to massively complicate the rules of logical syntax. On this view, the child's main problem would not be to have to learn the complex logico-syntactic properties of different quantifiers, but rather to recognize what kind of quantifier she is dealing with. Once phonological sequences have been appropriately mapped onto the correct lexical concepts, the rest would come for free and follow from the compositional nature of semantics and the relationship between syntax and semantics. I take the results presented here to be compatible with this hypothesis, but it should be recognized that they are also compatible, at least in principle, with the 'learning' hypothesis discussed above.

The facts discussed throughout this article, namely that NQE, while displaying some of the properties of other quantified expressions, are nevertheless associated with a very specific logico-syntactic profile has further consequences for developmental accounts of the number vocabulary. In order to illustrate this point, I will focus on a recent proposal by Susan Carey (2004). In doing so, my aim is not to argue against this particular proposal, or even to review it in full detail, but simply to show that the facts and results presented in this article impose severe constraints on accounts involving general claims of the kind made by Carey (2004) (for related discussion and similar conclusions, see Hurewitz et al., 2006).

An intriguing aspect of the acquisition of the number vocabulary is its unusually protracted nature. A number of studies on the acquisition of number words have shown that English-speaking children first seem to learn the meaning of the word *one* and take all the other number words to contrast with *one* and mean something like 'more than one'. About half a year to nine months later, children learn the meaning of *two* but they still do not seem to know the exact meaning of numbers words greater than *two*. Some time later, children come to be known as 'three-knowers' which means that they know the meaning of *one*, *two* and *three* but take all the other number words to mean something like 'more than three'. Eventually, after a few more months, children finally understand the correct relationship between the count list and the integers (Wynn, 1990; Wynn, 1992).

On the basis of these observations, Carey (2004) proposes that preverbal number representations are not representations of integers and, more importantly for our present purposes, that children initially represent number words as quantifiers (to use Carey's terminology). Since NQE share some of their properties with other quantifiers, this much does not seem particularly controversial. Let's take a closer look at what exactly is being proposed though. Carey's second conclusion seems to hold of the number words whose meanings children know "As described above, the child learns the meanings of the first number words as natural language quantifiers. Children learn the meaning of 'one' just as they learn the meaning of the singular determiner 'a' ..." (p. 66). This conclusion also applies to those number words whose exact meaning children do not yet appear to know "In the early stages of being a one-, two- or three-knower, the child represents other number words as quantifiers, meaning 'many', where 'many' is more than any known number words." (p. 66). So the claim seems to be that children initially 'mismap' NQE – if one takes Carey's proposal literally – for example initially assigning *two N* or *three N* the semantics of *many*, because the child does not yet have the appropriate conceptual wherewithal to do the correct mapping (namely the concept of integer and cardinality).

The problem here is that even though *a* and *one*, *some* and *two*, *three* and *many* may seem conveniently interchangeable when their intuitive meaning is concerned, as soon as their more complex linguistic properties are taken into consideration it is clear that NQE are quite different from other quantifiers. Consequently, a child who has initially identified *two* as meaning *some* or *three* are meaning *many*, will have a lot of unlearning and fine tuning to do in the course of development if s/he ever hopes to arrive at the correct conclusions regarding the set of semantic, pragmatic and logico-syntactic properties associated with NQE. To be sure, as we have seen here, NQE are associated with specific logico-syntactic properties that sets them apart from other quantifiers. Moreover, this conclusion also applies to the semantic and pragmatic properties of NQE which are different from those of other quantifiers, like *some*, for example (see Papafragou and Musolino (2003), Musolino (2004), Hurewitz et al. (2006), and Huang et al. (submitted for publication) for relevant theoretical and experimental evidence).

Moving beyond particular developmental accounts of the number vocabulary, the general point that I would like to emphasize here is that by providing a richer specification of the end point of development, the integrative approach advocated in this article imposes constraints on developmental explanations. Moreover, these constraints may ultimately serve as a basis to tease apart competing developmental accounts just as previously obtained developmental data can be – and have indeed been – used to tease apart competing theoretical analysis of the semantics and pragmatics of number words (Huang et al., submitted for publication; Hurewitz et al., 2006; Musolino, 2004; Papafragou & Musolino, 2003).

## 6. Concluding remarks

The main goal of this paper has been try to bridge the gap between theoretical linguistics and developmental psychology and in doing so to extend the integrative approach developed in Musolino (2004). In principle, these two disciplines share, as a common goal, the task of explaining how children acquire language. In reality, each side approaches this task rather differently and too often without much influence from the other. A review of the work on number words that linguists and psychologists have carried out over the past few decades provides a good illustration of this observation. The complex structure postulated by linguists raises important developmental questions which, unfortunately, are rarely addressed within linguistics. On the other hand, the experiments and theorizing of developmental psychologists are based on assumptions about linguistic structure that often do not match the level of complexity advocated by linguists.

In this paper, I have tried to show that it is not only possible, but also desirable, to approach questions pertaining to the acquisition of the number vocabulary from a perspective which combines the concerns of both linguists and psychologists. Specifically, I have shown that the tools of developmental psychology can be used to experimentally verify the complex structure postulated by linguists and that the models proposed by linguists, in turn, can be used to account for developmental patterns emerging from the results of such experimentation. Finally, I have shown that the results presented here have important implications for developmental accounts of the number vocabulary.

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## Appendix A

Target sentences for both quantifier type conditions (*two N* and *each N*)

| Condition | Target sentences | Configurations |
|---|---|---|
| *Two N* | Three boys are holding two balloons (×4) | SU, OBJ, EA, CU |
| | Three girls are holding two kites (×4) | SU, OBJ, EA, CU |
| | Three men are walking two dogs (×4) | SU, OBJ, EA, CU |
| | Three clowns are holding two flowers (×4) | SU, OBJ, EA, CU |
| *Each N* | Three boys are holding each balloon (×4) | SU, OBJ, EA, CU |
| | Three girls are holding each kite (×4) | SU, OBJ, EA, CU |
| | Three men are walking each dog (×4) | SU, OBJ, EA, CU |
| | Three clowns are holding each flower (×4) | SU, OBJ, EA, CU |

Control sentences used to test knowledge of the meaning of individual quantifiers (*two N, three N, each N*) in both quantifier type conditions (*two N* and *each N*)

| Control sentences | True/false |
|---|---|
| Three bunnies are eating carrots | False |
| The clown is holding three flowers | False |
| The boy is holding three balloons | True |
| There are three monkeys in the tree | True |
| Each boy is holding a balloon | False |
| The woman gave each boy candy | False |
| Each boy has an ice-cream cone | True |
| The man gave each dog a bone | True |
| Two cows are eating grass | False |
| The man is walking two dogs | False |
| The girl is holding two kites | True |
| Two cats are playing with the mouse | True |

Control sentences used to create configurations that falsify target sentences in the *two N* condition. The same sentences in the same configurations were used in the *each N* condition except that *two N* was replaced by *each N*.

| Condition | Other control sentences | Configurations |
|---|---|---|
| *Two N* | Three boys are holding two balloons (×2) | A, B |
| | Three girls are holding two kites (×2) | A, B |
| | Three men are walking two dogs (×2) | A, B |
| | Three clowns are holding two flowers (×2) | A, B |
| *Each N* | Three boys are holding each balloon (×2) | A, B |
| | Three girls are holding each kite (×2) | A, B |
| | Three men are walking each dog (×2) | A, B |
| | Three clowns are holding each flower (×2) | A, B |

'A' configurations correspond to situations in which all three characters are each Ving one N. 'B' configurations correspond to situations in which two of the three characters are each Ving two Ns and the third character is only Ving one N.

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