LANGUAGE LEARNING AND DEVELOPMENT, *4*(2), 99–121, 2008

ISSN: 1547-5441 print / 1547-3341 online
DOI: 10.1080/15475440801922099

Psychology Press
Taylor & Francis Group

The Development of "Most" Comprehension and Its Potential Dependence on Counting Ability in Preschoolers

Justin Halberda
Johns Hopkins University

Len Taing
Johns Hopkins University

Jeffrey Lidz
University of Maryland

Quantifiers are a test case for an interface between psychological questions, which attempt to specify the numerical content that supports the semantics of quantifiers, and linguistic questions, which uncover the range of possible quantifier meanings allowable within the constraints of the syntax. Here we explore the development of comprehension of *most* in English, of particular interest as it calls on precise numerical content that, in adults, requires an understanding of large exact numerosities (e.g., 23 blue dots and 17 yellow is an instance of "most of the dots are blue"). In a sample of 100 children 2 to 5 years of age we find that (a) successful *most* comprehension in cases with two salient subsets is achieved at 3 years, 7 months of age, and (b) *most* comprehension is independent of knowledge of large exact number words; that is, knowledge of large exact number words is neither necessary, as evidenced by children who understand "most" but not "four," nor sufficient, as evidenced by children who understand "nine" but not "most."

Humans are the only creatures on our planet that naturally exhibit a system of precise number. At the same time, we are the only creatures on the planet that naturally exhibit a recursive linguistic system. The unique co-occurrence of these

---

Correspondence should be addressed to Justin Halberda, Department of Psychological and Brain Sciences, Johns Hopkins University, Ames Hall, 3400 North Charles Street, Baltimore, MD 21218, USA. E-mail: Halberda@jhu.edu

two complex cognitive structures invites the question of whether and how they are related. Is knowledge of precise number concepts dependent on linguistic development, or is it the other way around?

One influential proposal in this domain holds that precise number concepts (at least for large numbers, such as “nine”) are parasitic on the development of the syntax of natural language quantifiers (Carey, 2004). Although the mechanisms by which natural language quantifiers enable the acquisition of precise number have not been fully elaborated, the suggestion is that numerical content for large number words requires prior acquisition of the grammar of quantification. For instance, there is evidence for number marking competence such as singular/plural before children have learned the large exact number words (Guasti, 1993/1994; Kouider, Halberda, Wood, & Carey, 2005; Miller & Schmitt, 2004; Pizzuto & Caselli, 1992; Radford, 1990), and such knowledge may not require an understanding of cardinality (e.g., plural sets might be recognized via mechanisms akin to object tracking). However, there are some quantifiers that clearly express numerical concepts and hence would seem to be dependent on prior acquisition of a representational system for large exact number.[1] For example, understanding a sentence like (1) requires a comparison of the numerosities of two sets.

Most of the crayons are broken. (1)

The sentence in (1) is true just in case the broken crayons outnumber the unbroken crayons. Thus, determining whether the sentence has been truthfully uttered would seem to require knowledge of how many broken crayons there are and how many unbroken crayons there are. In the current paper, we examine the acquisition of *most* comprehension in order to determine whether and how knowledge of number contributes to its acquisition.[2] What we will see, perhaps

[1]Any question that requires an evaluation of a relation of the cardinalities of two sets can be translated into a question that relies on an evaluation of the one-to-one correspondence across two sets (Hume’s Principle; see Boolos, 1998). Thus, when we say that some quantifiers clearly express numerical concepts, this is ambiguous between two formalisms that might capture numerical content (i.e., cardinality and one-to-one). In the present work we will not attempt to decide between these two formalisms. However, because the systems we will discuss (e.g., the Approximate Number System and large exact number concepts) have typically been assumed to engage cardinalities, we will use the language of cardinalities throughout. For experiments in adult subjects designed to directly test whether cardinality or one-to-one correspondence underlies English speakers’ concept MOST, see Pietroski, Halberda, Hunter, and Lidz (under review).

[2]Throughout we will rely on the following conventions: Concepts will be written in all caps (e.g., MOST), words in spoken English will be written in quotation marks (e.g., “most” designates the homophonic English word), and the categories of things in the world that provide the semantic values to both words and concepts will be written in italics (e.g., “most” is the English word that expresses the property of being *most*).

surprisingly, is that acquisition of *most* for cases with two salient subsets proceeds wholly independently of the acquisition of large exact number (e.g., precisely seven). We find children with full counting abilities who lack knowledge of *most*, and, more importantly, we find children with knowledge of *most* who do not display knowledge of exact number concepts. Thus, to the extent that the meaning of *most* requires a comparison of numerosities, this numerical information must be supplied by a cognitive system other than one representing precise number.

ACQUISITION OF PRECISE NUMBER

Learning the meaning of large number words is a difficult challenge that takes preschoolers more than a full year to master. Children pass through five well-defined stages on their way to a full understanding of how counting works (Gelman & Gallistel, 1978; Wynn, 1992; Le Corre & Carey, 2007). In the first stage (≈ ages 2 years, 0 months to 2 years, 9 months), children understand the activity of verbally counting a set via one-to-one mapping as a kind of rehearsal game. At this stage, although children may correctly enumerate sets containing as many as nine items by serially pointing to each item and counting, "One, two, three . . . " and although they may correctly use the counting words in order and not double-count any item, children do not show any evidence of understanding that the last word in the count list designates the numerosity of the set (i.e., the Cardinality Principle; Gelman & Gallistel, 1978). For these children, counting is similar to other ordered memory games such as reciting the ABCs or the days of the week; counting has no numerical content for these children.

During the second stage (≈ ages 2;9–3;3), children begin to appreciate the numerical meaning of the first word in the count list: "one." When asked to count a set with only one item, children will correctly report that the set contains one item; when asked to give someone one item (e.g., "Could you give Kermit one dinosaur?"), children will correctly give only one item. These children are called "one-knowers." At the same time, all other number words in a one-knower's count list remain semantically undifferentiated. When asked to give two or more items (e.g., "Could you give Kermit five dinosaurs?") one-knowers will grab a random handful of dinosaurs, completely failing to differentiate between larger and smaller number words; one-knowers will, on average, grab just as many items when asked for *two* as they will when asked for *eight*, suggesting that they even fail to have approximate meanings for these number words (Le Corre & Carey, 2007).

On average, it takes children 5 more months of counting experience before they advance to the next stage of being "two-knowers" (≈ ages 3;0–3;5; Wynn, 1992; Le Corre & Carey, 2007). During this stage, children exhibit knowledge of the meaning of *one* and *two* by a variety of measures while all other number words remain undifferentiated. After an additional 5 months of counting experience, children move into the fourth stage of counting. The "three-knowers" in this stage (≈ ages 3;2–3;9) know the meanings of *one*, *two*, and *three*, but all other number words remain undifferentiated.

Finally, after approximately 2 more months of counting experience, children come to understand the meaning of *four* and, without any delay, the meanings of all the numbers in their count list as they enter the fifth and final stage of counting ability and become "full-counters" (≈ ages 3;6–). The insight that subsumes the conceptual change that occurs as children become full-counters remains a mystery. Children somehow make the induction that the final word uttered in the counting of any set designates the numerosity of that set, the Cardinality Principle, and every child appears to make this induction upon learning the meaning of *four* (for a few rare exceptions, see Le Corre & Carey, 2007). In the published literature, across multiple labs, counting ability has been assessed in hundreds of children and almost never does one find a child who knows the meanings of *one*, *two*, *three*, and *four* without knowing the meanings of all the other number words in their count list. The above stages appear to progress in a mandatory serial order, as there are also no reports of children knowing the meaning of *two* before *one*, or *three* before *two*, and so forth. It takes children on average more than one full year, once they can count and understand the meaning of *one*, to map large number words (e.g., *nine*) onto large sets.

Prior to mastering counting, however, children do have access to representations of numerosity that are generated by the Approximate Number System. This system is evolutionarily ancient (it is present in nonverbal animals such as chimpanzees, monkeys, and rats), it does not require explicit training with numerosity in order to develop (it is present and active in human infants by at least 6 months of age, the youngest age yet tested), and the brain areas that support this system have been determined (for review, see Feigenson, Dehaene, & Spelke, 2004). The Approximate Number System generates analog representations of approximate number (e.g., *approximately fifteen*) prior to any knowledge of large exact numerosity. In adults, this system is capable of generating numerosity estimates for up to three sets in parallel (Halberda, Sires, & Feigenson, 2006), suggesting its potential relevance for determining the numerical content for quantifiers such as *most* which require computing a relationship across two sets. Although this system does not have the resolution necessary to represent a meaning such as *precisely nine*, it can represent and discriminate two numerosities, so long as they are separated by a discriminable numerical distance, with discriminability being in accord with Weber's Law.

In the absence of an understanding of large exact number words, children have access to only an approximate, prelinguistic numerosity for sets containing large numbers of items. Even adults must maintain access to their verbal count list in order to precisely enumerate large sets (Logie & Baddeley, 1987; Taing, Halberda, & Feigenson, 2006). When access to a verbal count list is blocked via verbal interference (e.g., saying the word “the” repeatedly), adults are able to build only an approximate representation of the number of items in a set (Taing et al., 2006). It is likely that noncounters are unable to build an exact representation of the numerosity of large sets due to their lack of understanding of how the count list works. These children will, however, have access to approximate numerosities for these sets. For instance, though Le Corre’s data suggest that noncounters (i.e., one-, two-, and three-knowers) have yet to map the number words onto approximate numerosities (Le Corre & Carey, 2007), it is clear from studies with preverbal infants that approximate number representations are available outside of language for sets as large as 16 items from as early as 6 months of age (Xu & Spelke, 2000). So, whereas full-counters demonstrably have access to large exact numerosities (e.g., precisely nine), noncounters have access only to approximate numerosities in the large number range (e.g., analog magnitude nine) and these representations have yet to be mapped to the large number words (Le Corre & Carey).

NATURAL LANGUAGE QUANTIFIERS

Most, like all natural language quantifiers, expresses a relation between two sets. What is unique about *most* is that the relation it expresses must contain numerical content.[3] To see why this is the case, consider the relations expressed by three quantifiers: *every*, *some*, and *most*.

a. Every crayon is broken.
b. Some crayons are broken. (2)
c. Most crayons are broken.

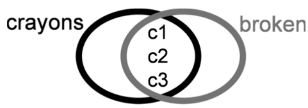
All three of these sentences express a relation between the set of crayons and the set of broken things. In (2a), this relation is inclusion. That is, every crayon is broken just in case the set of crayons is included in the set of broken things. In (2b), the relevant relation is overlap. Some crayons are broken just in case the set of crayons overlaps with the set of broken things. In (2c), the relevant relation involves a comparison of the numerosities of two sets. Most crayons are broken

[3]Other proportional quantifiers requiring such relations include *half* (e.g., *half of the crayons are broken*) and syntactically complex quantifiers like *more than half, less than a third,* and *more A than B*.

just in case the intersection of the set of crayons with the set of broken things has a cardinality larger than the set of crayons that are not in the set of broken things.[4] Let us call the first set (i.e., the intersection: $\{\text{crayons} \cap \text{broken}\}$), the focused set; and, let us call the second set (i.e., $\{\text{crayons} - \text{broken}\}$), the remainder set. The relevant relations are expressed in set-theoretic notation and with corresponding Venn diagrams in (3).

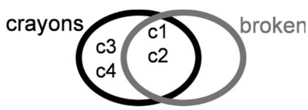
a. *every crayon is broken*

$\{\text{crayons}\} \subseteq \{\text{crayons} \cap \text{broken}\}$



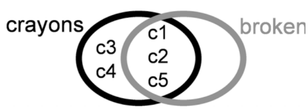
b. *some crayons are broken*

$\{\text{crayons} \cap \text{broken}\} \neq \varnothing$ (3)



c. [5]*most crayons are broken*

$|\text{crayons} \cap \text{broken}| > |\text{crayons} - \text{broken}|$



One thing that should be clear from the meanings provided for these quantifiers is that only *most* is expressed as containing numerical content. Although it is

---

[4]Or, perhaps, the intersection of the set of crayons with the set of broken things has a cardinality *significantly* larger than the set of crayons that are not in the set of broken things. That is, adults might maintain that "most" applies only when the percentage of items in the intersection is well above say 60%. For evidence against this sort of "significantly more" meaning for "most" in adults, see Pietroski, Halberda, Lidz, and Hunter (under review).

[5]The absolute value symbols should be read as defining the cardinality of a set. Thus, (3c) is read as "the cardinality of the intersection of the set of crayons with the set of broken things is greater than the cardinality of the set of crayons that are not in the set of broken things."

possible to express the meanings of *every* and *some* with numerical content, as in (4), this is not necessary, as seen in (3).

$$\begin{aligned}&\text{a. } \textit{every crayon is broken}\\ &\quad |\text{crayon} - \text{broken}| = 0\\ &\text{b. } \textit{some crayons are broken}\\ &\quad |\text{crayon} \cap \text{broken}| > 0\end{aligned} \tag{4}$$

Here, both meanings are expressed as comparing the cardinality of a set with the number 0. We read (4a) as "the cardinality of the set of unbroken crayons is zero" and (4b) as "the cardinality of the set of broken crayons is greater than zero." More generally, "every A is B" is true just in case the remainder set $\{A - B\}$ is empty. And, "some A is B" is true just in case the focused set $\{A \cap B\}$ is non-empty. Although the representations in (4) involve a comparison of cardinalities, such a comparison is not required to represent the meaning of *every* and *some* as seen in (3). However, it is not possible to express the meaning of *most* without numerical content, that is, without a comparison of the cardinality of the focused set with the cardinality of the remainder set (Barwise & Cooper, 1981).[6]

Putting this all together, we can easily see that it should be possible to learn the meanings of *every* and *some* without having acquired numerical concepts, whereas learning the meaning of *most* would seem to require the prior acquisition of numerical concepts. Indeed, although there is no literature determining the exact age of acquisition of *some* or *every*, there are reports of children who are not yet full-counters who correctly interpret *some* (Hurewitz, Papafragou, Gleitman, & Gelman, 2006) and reports of children showing adultlike behavior with *every* at least by 3 years, 5 months (Brooks & Braine, 1996; Gualmini, 2004; Minai, 2006). Given the protracted period of development in the acquisition of number words and the likely inaccessibility of large exact number concepts to non-counters, it is interesting to consider what children understand about words like "most" and other quantifiers across development. Because *most* has a meaning that appears to take advantage of basic numerical concepts, it is important to determine whether children's understanding of *most* emerges as a function of counting ability. Do children understand natural language determiners like *most* before they come to understand large exact numerosities?

Pioneering work by Papafragou and Schwarz (2005/2006) on children's comprehension of *most* may suggest that children have to await the attainment of full-counting ability before coming to understand *most*. Participants in this

[6]For a range of alternative expressions of such a concept, all entailing that the focused set outnumbers the remainder set, see Hackl (2006) and Pietroski, Halberda, Hunter, and Lidz (under review).

study were shown a group of six objects (e.g., birthday candles on a cake). An action was then performed with these objects (e.g., someone lit some number of candles ranging from 0 to 6) and participants were asked whether the action was performed on most of the objects (e.g., Did he light most of the candles?). Although adults overwhelmingly took "most" to mean *more than half*, judging the sentence as true in the 4/6, 5/6, and sometimes 6/6 comparisons, these authors found only 1 in 10 children in the 3- to 5-year-old age range who behaved like adults in treating "most" as meaning *more than half*. Moreover, only 5 out of 9 children in the 6- to 9-year-old age group showed the adult pattern. The other children in these age groups were more promiscuous, assenting to "most" in cases of *more than half* but also sometimes in cases of *less than half*. Barner (in preparation) presents converging evidence for the late acquisition of "most" from an ingenious paradigm requiring children to reason over three distinct subsets, allowing him to tease apart a *more than half* meaning from a *more than everyone else* meaning for "most" (see Hackl, 2006, for additional methods for teasing apart multiple possible meanings for "most" in adults). These data suggest that "most" is a late acquisition, possibly acquired well after knowledge of precise cardinalities.

Understanding *most* may require a sophisticated appreciation of numerosity, and so it is reasonable that children may have to wait until they are full-counters before they can utilize the concept MOST. Prior to becoming full-counters, children are unable to assess and verify the exact numerosity of large sets. However, an exact meaning of *most* requires that such verification take place. To see that this is the case, consider the following scenario. When presented with 17 balls, 9 of which are red, adults will serially count each item in order to ascertain if "most of the balls are red." Because the number of red balls (9) is so close to the number of nonred balls (17 – 9 = 8) in this case, the only route for verification is via counting, making reference to exact numerosities, and anecdotally adults do count in such situations and say that "yes, most of the balls are red." Given that this route of verification is not available to a noncounter, what do they take "most" to mean, if they understand this word at all? Are there any children who appear to understand *most* or have a partial meaning for "most" before they are full-counters? And if so, what mathematical knowledge serves as the basis for this understanding?

There are three possible answers to these questions. First, if comprehension of *most* is dependent on having exact numerical concepts, and if only children who are full-counters have such concepts, then we should not find any children who understand this word before becoming full-counters. Second, children might use approximate numerical concepts to build an initial meaning for "most." If this were the case, then we would expect to find that comprehension of *most* is linked only to verbal experience and is not dependent on counting ability. Third, some interaction of these two might obtain such that both counting ability and verbal experience play a role in determining when a child comprehends *most*.

To our knowledge, research directly addressing the question of the relation between counting ability and knowledge of *most* has yet to be done. Papafragou and Schwarz (2005/2006) included an assessment of *most* comprehension, but this study had no test of the participants' counting abilities.

We assessed counting ability and *most* comprehension in 100 children and looked for correlations between counting ability, age (a proxy for verbal experience), and *most* comprehension.

METHOD

Participants

One-hundred children participated: mean age = 3 years, 7 months; range = 2 years, 5 months to 5 years, 1 month. All were fluent English speakers from middle-class families in the Baltimore area. All children were tested in the Johns Hopkins University Laboratory for Child Development. Families were identified through commercially available lists and were initially recruited by letter. Children were tested in a sound-attenuated testing room, typically with their caregiver present, and received a small gift for participating.

We included in our sample only those children who could count using a consistent and correct number order in one-to-one correspondence and knew the meaning of at least "one." An additional 43 children participated but were excluded for the following reasons: equipment failure (5), parental interference (3), fussiness (15), poor counting order or experimenter inability to determine counting ability (20). Two additional children participated but were excluded due to their performing at greater than 3 SDs below the mean on the Most task. These two children were young full-counters who behaved as if "most" signified the subset with the *fewest* number of items; that is, they chose almost perfectly incorrectly across trials, choosing the smallest subset when asked for "most" on all but 1 or 2 trials. An additional assessment revealed that both children correctly understood the meaning of "more" and their performance appeared to indicate that they genuinely believed that "most" picked out the smallest set. Such children are interesting because this hypothesized meaning (i.e., *least numerous subset*) is not lexicalized as a quantifier in any known language. However, that a small number of English-speaking children will entertain this as a possible meaning for "most" suggests that this meaning may not be blocked by the syntax but rather by the pragmatic constraint to be maximally informative in each utterance (Hunter, Lidz, Pietroski, & Halberda, in preparation).

Materials

Materials for the Counting Assessment, Give a Number, and How Many tasks were small plastic dinosaurs. Stimuli for the Most task were cartoon drawings of crayons of varying colors (Figure 1) presented on a computer monitor (CRT monitor with viewable area measuring 40×30 cm). Stimulus presentation was controlled by a Macintosh G4 computer with Microsoft PowerPoint software.

Procedure

Children entered the testing room and sat at a small table across from the experimenter. A caregiver, if present, sat approximately 3 feet behind the child in a separate chair and was instructed not to interfere with the task. The entirety of the testing session was recorded on videotape, and performance on each trial was scored from video. Thirty children were scored by two scorers, and inter-scorer agreement for the child's response within each task was equal to or above 95% (i.e., number words produced for Counting Assessment, the number of dinosaurs given for Give a Number, a number word for How Many, and a color word for the Most task). The counting ability of each child was assessed by eliciting their count list and then using either Wynn's Give a Number task (n = 61) (Wynn, 1992) or a modified version of Gelman's How Many task (n = 39; Gelman & Gallistel, 1978). For count list elicitation, the experimenter placed 10 small plastic dinosaurs on the table in a row and asked the child to count them. All children included in the final sample correctly counted to at least "seven" using one-to-one correspondence by pointing to the objects as they counted.

For the Give a Number task, the experimenter placed the dinosaurs in a bucket that held many dinosaurs, placed this bucket on the table in front of the child, and asked, "Could you take out *one* dinosaur and place it on the table?" All children

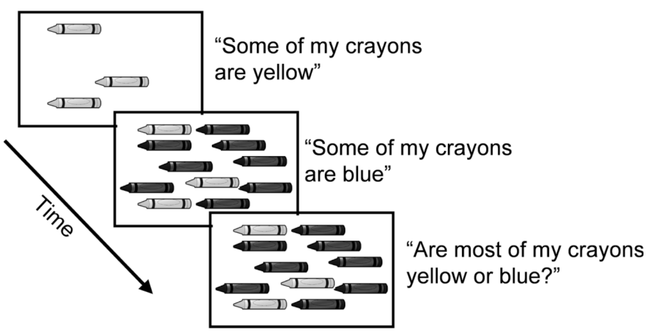


FIGURE 1 An example trial from the Most task.

included in the final sample succeeded on this trial. The experimenter then returned the dinosaur to the bucket, placed the bucket on the table in front of the child, and asked for a higher number (e.g., "Could you take out *two* dinosaurs and place them on the table?"). On each trial, after the child had indicated that he or she was finished placing the dinosaurs on the table, the experimenter asked, "Can you count and make sure this is #?" If the number that the child counted did not match the number that was requested, the experimenter asked, "But I wanted # dinosaurs. Can you fix it so that there are #?" The highest number a child could correctly give was determined using a titration method based on Wynn (1992) and Le Corre and Carey (2007): If a child succeeded at giving N dinosaurs, then the experimenter would ask for $N + 1$ dinosaurs on the next trial. If a child failed to give N dinosaurs and failed to correct it after counting, then the experimenter asked for $N - 1$ dinosaurs on the next trial. This continued until children failed at a particular requested number 2 out of 3 times or until they correctly gave up to 6 dinosaurs. The highest number children could correctly give on at least 2 of 3 trials was recorded as their knower-level (e.g., a "two-knower" is a child who can correctly give *two* dinosaurs but failed to give *three* dinosaurs on 2 out of 3 trials).

While counting ability was assessed using Give a Number for 61 of the children in our sample, the counting ability of 39 children was assessed using a task that combined aspects of Gelman's What's on This Card task (1993) and the How Many task (Gelman & Gallistel, 1978; Hurewitz, Papafragou, Gleitman, & Gelman, 2006; Le Corre, Van de Walle, Brannon, & Carey, 2006). We began the experiment using this How Many task to assess counting ability but changed to Give a Number, as Le Corre and Carey (2007) found that this method took less time and provided an accurate estimate of counting ability. As will be seen in the Results section, there was no difference in performance on the Most task as a function of which procedure, Give a Number or How Many, was used to assess a child's counting ability. For the How Many task, the experimenter placed all dinosaurs in a bucket. On the first trial the experimenter removed one dinosaur, placed it on the table, and asked children, "How many dinosaurs do we have now?" All children included in the final sample responded, "One." The experimenter then modeled the production of a cardinality, saying, "That's right; it's one dinosaur." After this trial the experimenter changed the number of dinosaurs placed on the table, randomly choosing between 2 and 10 dinosaurs on each trial. Each time, the experimenter asked, "How many dinosaurs do we have now?" Most children would count the dinosaurs and then spontaneously produce the final number in the count for numbers that were within their known cardinality vocabulary—for example, "One, two, three . . . three dinosaurs." When a child failed to give a cardinal value and only counted the dinosaurs, the experimenter asked, "So how many dinosaurs is that?" If the child either gave an incorrect cardinal value after counting (e.g., "One, two, three . . . that is two dinosaurs") or refused to give a cardinal value and simply continued counting in response to the experimenter's queries of "So how many dinosaurs is that?" the child was scored as not knowing that cardinal value. Children were tested on the numbers 2 – 10 to assess the highest number they would correctly give a cardinal answer for. For example, a "two-knower" would correctly say "one" for sets of *one* dinosaur and "two" for sets of *two* dinosaurs but would either give a random number larger than "two" for all sets larger than *two* or simply count and recount the set without producing a final definite number word.

Following the assessment of counting ability, the experimenter turned the child to face the computer monitor in the testing room for the Most task. The table was moved out of the way, and the experimenter sat on the floor slightly behind and to the side of the child. The experimenter controlled stimulus presentation via a keyboard. Children sat in a chair approximately 80 cm from the computer screen. Every trial involved two sets of colored crayons displayed on a white background. Crayons were identical in size and shape, were oriented horizontally, and faced the same direction. Crayons were positioned so that the two sets were spatially intermixed, and the crayons themselves never occluded one another (Figure 1). On each trial of the Most task the experimenter pressed the space bar to initiate a trial. The first set of crayons appeared, all of the same color (Figure 1). A friendly female voice on the computer labeled this set of crayons, saying, for example, "Some of my crayons are [red]." Immediately following this, another set of crayons of a different color appeared. The friendly female voice labeled this new set of crayons, saying, for example, "Some of my crayons are [blue]." Immediately following this, the voice asked, for example, "Are most of my crayons [red] or [blue]?" Children were instructed to give a verbal response, saying, for example, either [red] or [blue]. The crayons remained visible until the child responded. If children delayed or requested help, they were told that if they did not know the answer, they should just guess. Every child did give an answer, typically immediately as they came to understand the structure of the game. Children saw 14 trials, 2 trials for each of 7 comparison ratios (actual number of crayons shown = 9:1, 11:3, 8:3, 9:4, 10:6, 7:5, and 7:6). The color of the subset that had more crayons was counterbalanced within a child for each comparison ratio. For instance, one trial involved 9 blue crayons and 1 red crayon, whereas another trial, for this same child, involved 9 red crayons and 1 blue crayon. This controlled for color name knowledge and color preferences (colors used were red, blue, yellow, green, purple, brown, and pink). Lower-frequency colors (e.g., purple, brown, and pink) appeared on trials with higher-frequency colors (e.g., red, blue) to make it more likely that children would know at least one of the color terms on every trial. Trial order was random, and the order of presentation of the subsets within each trial (e.g., whether blue or red crayons were shown first) was counterbalanced across participants.

RESULTS

Table 1 lists the average age and range of ages of children categorized into each of the four counting-ability groups: one-knower, two-knower, three-knower, and full-counter. These ages were comparable to but slightly older than the ages that Wynn (1992) found for these same counting-ability groups (Wynn mean ages: one-knower 2,9; two-knower 2,11; three-knower 3,2; four-knower 3,6).

We first explored whether performance on the Most task differed as a function of which procedure was used to assess a child's counting ability: Wynn's Give a Number ($n = 61$) and our modified version of Gelman's How Many task ($n = 39$). A 2 Counting Assessment × 4 Counting Ability ANOVA on participants' total percent correct in the Most task revealed no significant interaction between Counting Assessment and Counting Ability, $F(3, 92) = .397$, $p = .755$, demonstrating that performance on the Most task did not differ as a function of which procedure was used to assess a child's counting ability. For this reason, all children were combined into a single sample for further analysis ($n = 100$).

Did children, on the whole, succeed at the Most task? Collapsing across all ages and counting abilities, children averaged 65.2% correct ($SE = 2.0\%$), which was significantly above chance as revealed by a t test comparing total percent correct to the chance level of 50%: $t(99) = 7.575$, $p < .001$. This demonstrates that a significant portion of our sample comprehended the word "most" in the context of our task.

It is very likely, however, that some of the children in our task did not demonstrate knowledge of *most* while other children did far better than 65% correct. What are the factors that mediate success in the Most task? If comprehension of *most* requires full counting ability, we would expect a significant effect of counting ability whereby full-counters would succeed on *most* but noncounters would fail. Alternatively, if the acquisition of "most" does not require the prior attainment of exact numerical concepts and instead is mediated solely by linguistic experience, we might expect a significant effect of age (a proxy for linguistic experience) and no effect of counting ability.

TABLE 1
Mean Age and Age Range by Counting Ability for Children in Experiment 1

		Age (years;months)	
Counting ability	*No. of children*	*Mean*	*Range*
1-knowers	15	3;1	2;5, 3;6
2-knowers	24	3;3	2;5, 4;0
3-knowers	18	3;5	2;5, 4;4
Full-counters	43	4;0	3;1, 5;0

We ran a linear regression, with percent correct on the Most task as the dependent measure and counting ability and age as independent variables. This method allows us to ask two questions: (a) when controlling for effects of age, is counting ability a significant predictor of *most* comprehension, and (b) when controlling for effects of counting ability, is age a significant predictor of *most* comprehension? Consistent with the prediction that *most* comprehension is a function solely of verbal experience, this regression revealed age as a significant predictor of performance on the Most task when counting ability was controlled for, $t(97) = 6.285$, $p < .001$ (beta = .595), and no effect of counting ability when age was controlled for, $t(97) = 1.297$, $p = .198$ (beta = .123; $R^2 = .459$). This suggests that the acquisition of *most* does not depend on full counting ability—and hence, exact numerical concepts—but rather requires linguistic experience and some other source of numerical knowledge.

Figure 2 is a plot of the total percent correct on the Most task for all subjects in our sample as a function of age and counting ability. An inspection of this graph first reveals the clear linear trend from failure in younger children (chance = 50%) to success at older ages.[7] Within this trend, and in Table 1, there is the suggestion that age and counting ability are significantly correlated. This was confirmed by a significant linear regression of age by counting ability, $F(1,98) = 59.405$, $p < .001$. This result replicates the developmental trajectory of increasing counting ability as a function of age that has already been described in detail elsewhere (Gelman & Gallistel, 1978; Wynn, 1992).

What is clear in Figure 2 is that there is a continuous improvement on our Most task as a function of age; there is no sudden insight after which children

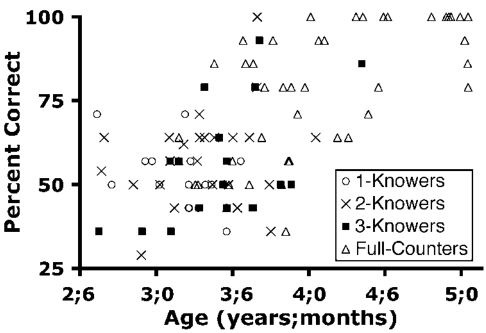


FIGURE 2 Scatter plot of percent correct on the Most task as a function of age and counting ability (chance = 50%).

[7]The linearity of this trend was confirmed in both curve estimation analysis ($R^2 = .449$) and 3-D surface modeling. Three-dimensional models can be viewed at http://www.psy.jhu.edu/~halberda/demos.html.

shift immediately to 100% correct. Nevertheless, it is useful to estimate the age after which most children succeed at the Most task, as it will allow us to combine children, younger or older than this age, into groups. We estimated this age by partitioning our sample into 10 groups of 10 as a function of age. The first group represented the 10 youngest subjects, the second group represented the 10 youngest of the remaining 90, and so forth. For each of these groups, we compared the mean total percent correct to the chance level (50%). As shown in Figure 3, young children performed at chance levels (2 years, 5 months to 3 years, 3 months), and the oldest children were at ceiling (4;6 – 5;0), with a period of transition (3;3 – 4;6) in between.

A conservative estimate for the age of success in our Most task is 3 years, 7 months, and 10 days. This was determined by taking the mean age of the children represented in the sixth group from the left in Figure 3. Although the sixth group is not the first group to be significantly above chance, it is the first group significantly above chance after which all subsequent groups are also above chance.

The discovery that age, rather than counting ability, is the primary factor mediating success in the Most task is further revealed through the identification of older noncounters who succeed at the Most task and younger full-counters who fail. Figure 4 displays percent correct in the Most task as a function of age for all of the full-counters in our sample (N = 43). This figure reveals the clear linear trend of increasing percent correct in the Most task as a function of age and suggests that not all full-counters comprehend *most*. Such children can be identified by simply looking at their individual performance in Figure 4, but they can also be identified as a group of those full-counters who are younger than the above estimated age of success on the Most task (3 years, 7 months, and 10 days). There were 8 full-counters in our sample who were younger than 3 years, 7 months, and 10 days (mean age = 1,199 days; range = 1,134 – 1,260 days). Although these children demonstrated their access to the large exact number representations

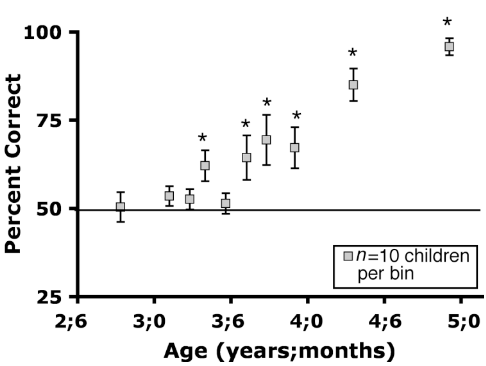


FIGURE 3 Binned comparisons of performance in the Most task as a function of age (N = 10 per bin, ±SE); *indicates p < .05 in a two-tailed t test compared to chance (50%).

FIGURE 4 Scatter plot of percent correct on the Most task as a function of age for children who showed full counting ability in the How Many or Give a Number tasks.

(e.g., exactly nine) in the How Many or Give a Number tasks, they were not significantly above chance at the Most task as measured by a *t* test comparing percent correct to the chance level (50%): mean = 57.13%, *SE* = 4.7%, $t(7) = 1.519$, $p = .173$. This suggests that children in this subgroup of full-counters do not yet know the meaning of *most*. An inspection of Figure 4 reveals that there are other full-counters besides these 8 children who do not succeed at the Most task, demonstrating that there are indeed full-counters who do not comprehend *most*.

We can also identify noncounters in our sample who do comprehend *most*. These children and their individual differences can be seen by inspecting Figure 2, but a group analysis is also possible. There were 14 noncounters (i.e., one-, two-, or three-knowers) in our sample who were older than 3 years, 7 months, and 10 days (mean age = 1,355 days; range = 1,280 – 1,566 days). These children were significantly above chance on the Most task as measured by a *t* test comparing total percent correct to the chance level of 50%, demonstrating that there are indeed noncounters who comprehend *most*: mean 63.9%, *SE* = 5.4%, $t(13) = 2.55$, $p < .05$.

In the How Many or Give a Number tasks, noncounters do not demonstrate access to large exact number concepts (e.g., exactly nine), at least not ones that have been mapped onto number words. One influential view in the literature holds that large exact number concepts are not available preverbally and that they are constructed over the course of learning to count (e.g., Carey, 2004). If noncounters do not have access to large exact number concepts, what are the number concepts that underlie their comprehension of *most*? A reasonable hypothesis is that they rely on the prelinguistic representations of the Approximate Number System, the early developing number sense that is shared broadly throughout the animal kingdom (for review, see Feigenson, Dehaene, & Spelke, 2004). If noncounters are using the analog representations of the Approximate Number System, we should observe two signatures: (a) Noncounters should not verbally count in order to assess the number of items present in either subset because analog magnitude representations are available in parallel without counting (and these children are noncounters at any rate), and (b) performance on the Most task should fall to chance whenever the numerosities of the subsets are close to one another, making discrimination within the Approximate Number System difficult. The closer the numerosities of the two sets, the harder it is for the Approximate Number System to tell the difference between them and thereby to assess *most*.

Consistent with the hypothesis that noncounters relied on approximate number representations, none of the noncounters verbally counted on any trial in order to assess *most*. Also, as can be seen in Figure 5, the 14 noncounters who were older than 3 years, 7 months, and 10 days fell to chance on the difficult comparison of 7:6. This is consistent with the hypothesis that noncounters relied on approximate number representations, though one might have expected even better performance at easy ratios such as 11:3. Although the present data are suggestive, an experiment designed to directly assess the number concepts that noncounters are relying on is still needed.

Is there evidence that the full-counters who succeeded at the Most task also relied on prelinguistic approximate number representations? As a first suggestion, none of the full-counters in our sample (indeed, none of the children irrespective of counting ability) engaged in verbal counting in order to assess *most* on any trial. However, it remains possible that these children counted subvocally. We analyzed the performance of the full-counters in our sample who were older than 3 years, 7 months, and 10 days as a function of the ratio between the two subsets (N = 35; mean age=1,527 days; range = 1,285 – 1,817 days). In Figure 6, although there is a slight trend, there is little evidence that these 35 full-counters

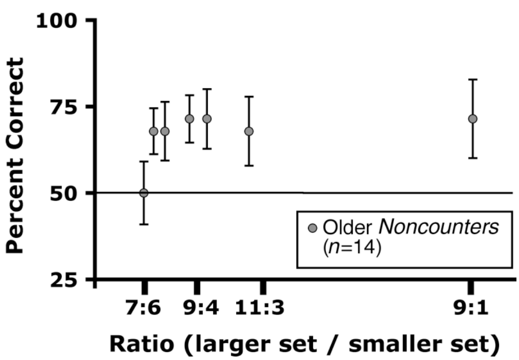


FIGURE 5 Percent correct on the Most task for each of seven comparisons (7:6, 7:5, 10:6, 9:4, 8:3, 11:3, 9:1) plotted as a function of ratio for the noncounters (1-knowers, 2-knowers, and 3-knowers) older than 3 years, 7 months, and 10 days.

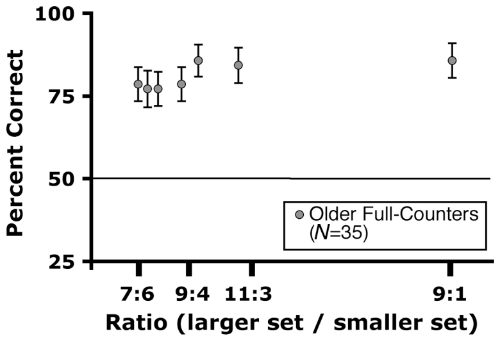


FIGURE 6 Percent correct on the Most task for each of seven comparisons (7:6, 7:5, 10:6, 9:4, 8:3, 11:3, 9:1) plotted as a function of ratio for the full-counters older than 3 years, 7 months, and 10 days.

performed worse on harder ratios. Full-counters are above chance on even the hardest ratio (e.g., 7 pink vs. 6 yellow percent correct mean = 78.6%, *SE* = 5.1%, $t(34) = 5.56$, $p < .001$), suggesting that these children may not be relying on approximate number representations. However, the acuity of the Approximate Number System increases with age throughout the 5th and 6th years of life (Halberda & Feigenson, under review) and is nearing adultlike levels of acuity, which successfully discriminates 8 from 7. The full-counters in our sample were, on average, older than the 14 noncounters analyzed above. Therefore, it remains possible that full-counters were able to discriminate the two relevant sets using approximate number representations on even our hardest trials (i.e., 7 vs. 6), whereas the younger noncounters could not. Further experiments will be needed to directly assess whether full-counters who comprehend *most* rely on large exact number representations or the representations of the Approximate Number System.

GENERAL DISCUSSION

We began by asking whether comprehension of *most* requires prior achievement of full counting ability (and hence the attainment of exact numerical concepts). Our findings reveal that comprehension of *most* is dependent on linguistic experience (age) and crucially not on counting ability. There are noncounters who comprehend *most* in our task and there are full-counters who do not. The full-counters in Figure 4 encompass the full range of performance in the Most task as a function of age, from failure to success. We found no significant effect of counting ability when the effect of age was controlled for. It is also interesting to note in Figure 4 that during the ages of transition into *most* comprehension, when children are above chance at the Most task but not yet at 100% (ages 3;6–4;3), full-counters appear to have no greater insight into the meaning of *most* than do noncounters. We see both full-counters and noncounters (in Figure 2) progressing through gradual improvement on the Most task as a function of age, suggesting that a child with full counting ability does not discover the meaning of *most* any faster than a child lacking this ability does.[8] The correlation between performance on the Most task and age is likely to be the result of linguistic experience. Older children have experienced more instances of "most" uttered in context and have had greater opportunity to refine their understanding of this word.

If exact numerical concepts are not required to understand *most* for cases of two salient subsets, then what kinds of numerical representations do underlie this ability? Our evidence is consistent with the proposal that noncounters rely on approximate number representations to comprehend *most,* though it remains an open question which representations support the meaning of *most* for full-counters.

Given that approximate number representations may support children's earliest understanding of *most* in context, it is important to ask what sort of semantic representations underlie this behavior and how the development of an adultlike understanding of *most* unfolds over development. At what point do children realize that *most* applies even to sets that are not discriminable via the Approximate Number System, and at what point will they bring their full counting ability to bear on determining whether *most* applies?

If approximate number representations provide the foundation for early representations of *most,* then we would expect this word to first be understood to apply only to sets that can be discriminated via the Approximate Number System. If this is so, it would amount to children holding a concept FUZZY-MOST that should be distinguished from EXACT-MOST with respect to the kinds of numerical comparisons it can achieve. Consider again the sentence in (5).

Most of the crayons are broken (5)

For this sentence, EXACT-MOST applies to all possible ratios between broken and unbroken crayons, so long as there is at least one more broken than unbroken crayon (given the semantic analysis noted in the Introduction[9]). In contrast, FUZZY-MOST would apply only when the number of broken crayons

[8]Visit http://www.psy.jhu.edu/~halberda/demos.html to view additional analyses of this trend and a dynamic display showing counting ability, age, and performance on the Most task in a 3-D surface graph. This dynamic graph, not viewable in a paper, gives a more detailed impression of the effect of age, and the null result of counting ability.

[9]Or the number of broken crayons compared to the total number of crayons divided by two, depending on how one cashes out the algorithm for comparing sets to assess *most* (Hackl, 2006).

is sufficiently larger than the number of unbroken crayons so that these quantities are discriminable by the Approximate Number System.[10]

Although children in our Most task clearly demonstrate some appreciation of the meaning of "most," it remains to be specified in detail whether this understanding is consistent with the adult understanding of *most* in English. One aspect of this question concerns whether children hold the concept FUZZY-MOST or EXACT-MOST. Further linguistic possibilities include that children interpret "most" as *more* or as *more-est*. For such a meaning, children might maintain that the situation in (6) is consistent with "most of the dots are blue":[11]

$$\text{12 blue, 9 red, 8 yellow} \tag{6}$$

The present results do not allow us to eliminate this as a possible meaning for the children in our sample because trials contained only two subsets (e.g., red and blue). In such cases the adult meaning of *most* will always agree with this alternative meaning (for some evidence that English-speaking children may maintain this alternative meaning until age 5.5 years, see Barner, in preparation). The present data do not directly address this possible distinction. Lastly, there are issues concerning the possible lower- and upper-bounding of quantifiers such as *most* that the present data do not allow us to address (Papafragou & Schwarz, 2005/2006). Three- to six-year-olds in the procedure of Papafragou and Schwarz were sometimes willing to assent that "most" applied even in cases of *less than half*. These children correctly assented to "most" at rates near 100% for comparisons of 4/6 and 5/6 but were also willing to assent to "most" in comparisons of 1/6 at rates of 60% for 3-year-olds and 37% for 6-year-olds. Thus, the data of Papafragou and Schwarz show some converging evidence that children understand *most* by age 3.5 years (i.e., even the youngest age group was more willing to assent for higher ratios) but highlight that this understanding has not yet attained the adultlike pattern (i.e., 0% assenting to "most" for any ratio at or below 3/6). Our task, which forces children to make a choice between the smaller or the larger set of items, reveals that children who are

[10]Elsewhere we discuss this distinction in terms of the functions that these two concepts would instantiate (Pietroski et al., under review). EXACT-MOST would pick out the total function for *most*, giving an answer for every numerical comparison, and FUZZY-MOST would pick out a partial function for *most*, agreeing with EXACT-MOST when ratio differences are large and failing to give an answer (or failing to apply) when ratio differences are small.

[11]In English, such a situation could be described with an adjectival use of *most*, as in *Blue has the most crayons*. Indeed, such a meaning is the only one possible for the word corresponding to *most* in some languages (e.g., Kannada, Hindi).

beginning to comprehend *most* will correctly identify the larger set as *most*. But this ability is likely only the beginning stage of adultlike *most* comprehension, and this development appears to be a gradual process (Papafragou & Schwarz; Barner).

We see multiple interesting open questions for research on children's understanding of *most*: (a) Do noncounters rely solely on the Approximate Number System to evaluate *most*? (b) Do newly attained full-counters persist in relying solely on the Approximate Number System to evaluate *most*, even though they now have access to the more powerful verification procedure of exact counting and, according to many authors, they have only recently acquired the concepts of large exact numbers? (c) At what point do full-counters attain the adult concept of EXACT-MOST? (d) Will adults rely on the Approximate Number System to verify instances of *most*? (e) If yes, how does the conceptual translation between approximate numbers and EXACT-MOST take place? (f) Do adults have access to two separate concepts EXACT-MOST and FUZZY-MOST? Finally, (g) how are the focused set and the remainder set selected for evaluation, and what is the underlying computation by which they are compared?

What we find most interesting in the present results is the lack of an effect of counting ability on *most* comprehension. Specifying the numerical representations that provide numerical content for terms such as *most*, *many*, and *more* remains an important open question at the interface of psychology, linguistics, and philosophy. And facing these challenges brings new data to bear on the broader question of how language and nonlinguistic numerical cognition shape and constrain one another.

RIGHTS OF PARTICIPANTS

Guidelines for testing human research subjects were followed as certified by the Johns Hopkins University and the University of Maryland Institutional Review Boards. Participants' rights were protected throughout.

ACKNOWLEDGMENTS

J.H. and J.L. devised the task; J.H., L.T., and J.L. defined the trial types of interest; L.T. implemented and ran the experiment; J.H. and L.T. analyzed the data; J.H. and J.L. wrote the manuscript with input from L.T. We thank Paul Pietroski, Tim Hunter, and Lisa Feigenson for helpful discussion and feedback.

REFERENCES

Barner, D. (in preparation). Assembling quantifiers in language acquisition: Getting "the mostest" from degree morphology.

Barwise, J., & Cooper, R. (1981). Generalized quantifiers and natural language. *Linguistics and Philosophy, 4*, 159–219.

Boolos, G. (1998). *Logic, logic, and logic*. Cambridge, MA: Harvard University Press.

Brooks, P., & Braine, M. (1996). What do children know about the universal quantifiers all and each? *Cognition, 60*, 235–268.

Carey, S. (2004). Bootstrapping & the origin of concepts. *Daedalus*, 59–68.

Feigenson, L., Dehaene, S., & Spelke, E. (2004). Core systems of number. *Trends in Cognitive Sciences, 8*(7), 307–314.

Gelman, R. (1993). A rational-constructivist account of early learning about numbers and objects. In D. L. Medin (Ed.), *The psychology of learning and motivation. Advances in research theory* (Vol. 30, pp. 61–96). San Diego, CA: Academic Press.

Gelman, R., & Gallistel, C. R. (1978). *The child's understanding of number*. Cambridge, MA: Harvard University Press.

Gualmini, A. (2004). *The ups and downs of child language*. New York: Garland.

Guasti, M. T. (1993/1994). Verb syntax in Italian child grammar: Finite and nonfinite verbs. *Language Acquisition, 3*, 1–40.

Hackl, M. (2006). *On the grammar and processing of proportional quantifiers:* Most *versus* more than half. Unpublished manuscript, Pomona College, Claremont, CA.

Halberda, J., & Feigenson, L. (under review). Developmental change in the acuity of the "Number Sense": The approximate number system in 3-, 4-, 5-, 6-year-olds and adults.

Halberda, J., Sires, S. F., & Feigenson, L. (2006). Multiple spatially overlapping sets can be enumerated in parallel. *Psychological Science, 17*(7), 572–576.

Hunter, T., Lidz, J., Pietroski, P., & Halberda, J. (in preparation). On the non-existence of "most."

Hurewitz, F., Papafragou, A., Gleitman, L., & Gelman, R. (2006). Asymmetries in the acquisition of numbers and quantifiers. *Language Learning and Development, 2*(2), 77–96.

Kouider, S., Halberda, J., Wood, J., & Carey, S. (2006). Acquisition of English number marking: The singular-plural distinction. *Language Learning and Development, 2*(1), 1–25.

Le Corre, M., & Carey, S. (2007). One, two, three, four, nothing more: An investigation of the conceptual sources of the verbal counting principles. *Cognition, 5*(2), 395–438.

Le Corre, M., Van de Walle, G. A., Brannon, E., & Carey, S. (2006). Re-visiting the performance/competence debate in the acquisition of counting as a representation of the positive integers. *Cognitive Psychology, 52*(2), 130–169.

Logie, R. H., & Baddeley, A. D. (1987). Cognitive processes in counting. *Journal of Experimental Psychology: Memory and Cognition, 20*, 1396–1408.

Miller, K., & Schmitt, C. (2004). *Ambiguous input and the acquisition of plural marking in Spanish*. Generative Approach to Language Acquisition North America 2004, University of Hawaii at Manoa.

Minai, U. (2006). *Everyone knows, therefore every child knows: An investigation into logico-semantic competence in child language*. Ph.D. dissertation, University of Maryland.

Papafragou, A., & Schwarz, N. (2005/2006). Most wanted. *Language Acquisition: A Journal of Developmental Linguistics* [Special issue: On the Acquisition of Quantification], *13*(3), 207–251.

Pietroski, P., Halberda, J., Lidz, J., & Hunter, T. (under review). Beyond truth conditions: An investigation into the semantics of "most."

Pizzuto, E., & Caselli, M. C. (1992). The acquisition of Italian morphology: Implications for models of language development. *Journal of Child Language, 19*, 491–557.

Radford, A. (1990). *Syntactic theory and the acquisition of English syntax*. Oxford, UK: Blackwell.

Taing, L., Halberda, J., & Feigenson, L. (2006). *Beyond pre-linguistic concepts: Exact number concepts*. Talk presented at the annual meeting of the Eastern Psychological Association, Baltimore, MD.

Wynn, K. (1992). Children’s acquisition of number words and the counting system. *Cognitive Psychology, 24*, 220–251.

Xu, F., & Spelke, E. (2000). Large number discrimination in 6-month-old infants. *Cognition, 74*, B1–B11.