Journal of Experimental Psychology:
Learning, Memory, and Cognition
2013, Vol. 39, No. 2, 451–461

0278-7393/13/$12.00 DOI: 10.1037/a0028874

Young Children's Understanding of "More" and Discrimination of Number and Surface Area

Darko Odic
Johns Hopkins University

Paul Pietroski, Tim Hunter, and Jeffrey Lidz
University of Maryland College Park

Justin Halberda
Johns Hopkins University

The psychology supporting the use of quantifier words (e.g., "some," "most," "more") is of interest to both scientists studying quantity representation (e.g., number, area) and to scientists and linguists studying the syntax and semantics of these terms. Understanding quantifiers requires both a mastery of the linguistic representations and a connection with cognitive representations of quantity. Some words (e.g., "many") refer to only a single dimension, whereas others, like the comparative "more," refer to comparison by numeric ("more dots") or nonnumeric dimensions ("more goo"). In the present work, we ask 2 questions. First, when do children begin to understand the word "more" as used to compare nonnumeric substances and collections of discrete objects? Second, what is the underlying psychophysical character of the cognitive representations children utilize to verify such sentences? We find that children can understand and verify sentences including "more goo" and "more dots" at around 3.3 years—younger than some previous studies have suggested—and that children employ the Approximate Number System and an Approximate Area System in verification. These systems share a common underlying format (i.e., Gaussian representations with scalar variability). The similarity in the age of onset we find for understanding "more" in number and area contexts, along with the similar psychophysical character we demonstrate for these underlying cognitive representations, suggests that children may learn "more" as a domain-neutral comparative term.

Keywords: comparatives, quantifier acquisition, quantity representation, count/mass-nouns

As children acquire language, they come to understand sentences in a way that lets them verify whether these sentences are true or false. The verification of a sentence relies not only on the child's ability to linguistically understand the sentence, but also on successfully navigating an interface between language and nonlinguistic cognitive systems. For instance, verifying the sentence "More of the dots are blue than yellow" might involve engaging both visual attention (to select just the blue and yellow dots) and a representation of number (to enumerate and compare them) as well as a linguistic system that composes an understanding of the meaning of the sentence from its individual words. Given appropriate experimental conditions, studying this language/cognition interface may inform both theories of lexical acquisition and lexical meaning, and theories of basic cognition (Booth & Waxman, 2003; Lidz, Halberda, Pietroski, & Hunter, 2011; Soja, Carey, & Spelke, 1991).

Here, we ask at what age children begin to understand comparative expressions involving the comparative word "more" as applied to continuous extents (e.g., "there is more yellow goo than blue goo") and to collections of countable items (e.g., "there are more yellow dots than blue dots"), and we make use of psychophysical methods to characterize the cognitive systems children engage to verify such expressions. In studying the learning of the interface between the lexical meaning of "more" and the cognitive systems that represent quantity, we hope to inform debates in both language acquisition and the nonlinguistic representations of quantity.

Quantifier words, such as "some," "many," and "most," play a critical role in our communication and reasoning about amounts. A classic case study, and one that has drawn both fruitful research and controversy, has been the acquisition of the comparative "more" (e.g., "There are more apples than oranges"; Bloom, 1970; Donaldson & Wales, 1970; Hohaus & Tiemann, 2009; Townsend, 1974). One point of contention has been whether children *immediately* understand comparative "more" as having the adult meaning—a comparative operation that can be applied to any dimension—or whether they might initially have a more general (H. H. Clark, 1970) or less general meaning for "more" that is *incremen-*

This article was published Online First June 11, 2012.

Darko Odic, Department of Psychological and Brain Sciences, Johns Hopkins University; Paul Pietroski, Tim Hunter, and Jeffrey Lidz, Department of Linguistics, University of Maryland College Park; Justin Halberda, Department of Psychological and Brain Sciences, Johns Hopkins University.

This research was funded by NIH RO1 HD057258 awarded to Justin Halberda and NSERC PGS-D awarded to Darko Odic. We thank Michael Alfieri, Bhaavana Venkatesh, and Cicek Erdem for help in gathering data.

Correspondence concerning this article should be sent to Darko Odic, Psychological and Brain Sciences, Johns Hopkins University, Ames Hall, 3400 N. Charles Street, Baltimore, MD 21218. E-mail: darko.odic@jhu.edu

tally changed throughout development (Gathercole, 1985, 2008). The debate about incremental versus immediate learning has featured prominently in theories of lexical acquisition and has usually been thought to reveal both what the initial meanings available to children are (e.g., are domain-neutral logical operations accessible to young children), and what learning strategies they apply to acquiring new words (e.g., if they must go from overly specific or general meanings to correct ones; Bowerman, 1978; H. H. Clark, 1970; Gathercole, 1985, 2008).

Evidence for the incremental learning account of "more" has come from three sources. First, although children produce "more" by 2 years of age (e.g., "More juice"; Bloom, 1970; Carter, 1975; Harris, Barrett, Jones, & Brookes, 1988; Mehler & Bever, 1967), many researchers have argued that this early meaning is that of an additive, not the comparative "more" (e.g., "Some books are on this desk, and more are over there"; Beilin, 1968; Gathercole, 2008; Thomas, 2010; Weiner, 1974). In turn, some incremental learning theories have suggested that children first learn "more" as having an additive meaning and later on supplement it with the comparative form (H. H. Clark, 1970). This evidence has been controversial, however, because the two forms of "more" may not be related (Beilin, 1968; Weiner, 1974). Indeed, some languages use different words for the additive versus comparative "more" (e.g., "još" vs. "više" in Serbo-Croatian; Odic, Pietroski, Hunter, Lidz, & Halberda, 2012). As such, evidence for the acquisition of additive "more" may not be informative about the development of the comparative form. Here, we focus only on comparative uses of "more" in children learning English.

The second source of evidence for the incremental learning account has been the contrast of how children learn "less" from "more." Donaldson and Balfour (1968), for example, demonstrated that young 3-year-olds understand the word "less" to mean "more" and argued that it takes an additional stage of development for the adult-like meaning of "less" to emerge (see also Palermo, 1973). Other work has suggested that this "less-is-more" effect stems from experiment demands and not from children's use of lexical knowledge (Carey, 1978). Nevertheless, many theories of "more" development have argued for a stage-like development of comparative "more" understanding that only resembles the adult meaning after about 4 or 5 years of age (H. H. Clark, 1970; Gathercole, 1985, 2008).

The final source of inquiry for the incremental view, one that has deep connections to the psychological literature on magnitude representations, comes from how children understand comparative "more" in numeric versus nonnumeric contexts. For example, although some words in English, like "many" and "much," are restricted with regard to what they can modify ("I have too *many* rocks" means that my individual hunks of rock are too numerous, whereas "I have too *much* rock" means that my volume of rock stuff is too great), other words, including "most," "some," and "more," are dimension neutral. For example, "more" can refer to quantification by number ("I have more apples than you"), by area ("I have more land than you"), by normative quantity ("I have more charm than you"), and so on.

Because "more" can be used to modify various dimensions in grammatical sentences (e.g., number or area), the meaning of "more" remains equivocal as to the specified dimension, and other indicators in the phrase or the context must specify the intended dimension. The problem of determining the correct quantity dimension might be made easier by the presence of a mass/count-noun distinction, as in English (Barner & Snedeker, 2005; Gathercole, 1985). Roughly, this distinction is between words that typically refer to individuals—count-nouns like "dot" and "cow"—and those that typically do not refer to individuals—mass-nouns like "goo" and "beef"[1] (Bale & Barner, 2009; Gillon, 1992). The mass/count distinction is grammatical. Only count-nouns can be pluralized ("cow"/"cows," "pebble" /"pebbles"; "beef"/*"beefs," "gravel"/*"gravels"), and only count-nouns can co-occur with numerical determiners ("three cows"/*"three beef"; for evidence that children learn the distinction as a syntactic one, see Gordon, 1985). Thus, given that children know the syntactic difference between mass- and count-nouns, they could use this knowledge to interpret "more" as indicating a numerical dimension when used with count-nouns (e.g., "you have more cows than me") and indicating a nonnumerical dimension when used with mass-nouns (e.g., "you have more beef than me").

Even with a mass/count distinction in place, the development of "more" may be incremental. Gathercole (1985, 2008), for example, suggested that children may initially understand "more" to apply only to count nouns (thus resembling "many") and only later revise the meaning of "more" to be dimension-neutral and include quantification by nonnumeric dimensions (e.g., area). The alternative is that children might learn the meaning of "more" immediately as a domain-general comparative that can apply equally well to multiple dimensions (e.g., number or area). This issue of incremental versus immediate acquisition of the meaning of "more" remains contentious in the literature (see Barner & Snedeker, 2005).

Early theories of "more" acquisition were relatively unconcerned about the contrast between numeric and continuous stimuli, and almost exclusively tested children with discrete objects and count nouns (Beilin, 1968; Donaldson & Wales, 1970; Mehler & Bever, 1967; Weiner, 1974). The few studies that did use nonnumeric stimuli tested children older than 4 years (Hudson, Guthrie, & Santilli, 1982; Palermo, 1973), by which point the dimension-neutral form of comparative "more" may have been acquired. This has, at least in part, been the inheritance of a literature that focused on children's understanding of "more" in the context of understanding conservation of volume and conservation of number, which tended to target children older than age 3 (Piaget, 1965; but see Mehler & Bever, 1967).

An important methodological innovation came in a series of studies that directly pitted numerical and continuous dimensions against one another (Barner & Snedeker, 2005, 2006; Gathercole, 1985; Huntley-Fenner, 2001). In these studies, children saw displays of items that might either typically be described with count-nouns (e.g., candles, feet) or typically be described with mass-nouns (e.g., ribbon, candy), and children had to judge which of two displays had more of that noun (e.g., "Which piece of paper has more ribbon?" or "Which piece of paper has more bows"). Criti-

[1] Importantly, not all mass-nouns refer to nonobjects (e.g., "furniture," "mail"), and children are aware of this from early on (Barner & Snedeker, 2005). Thus, while count-nouns surely suggest individuals and a comparison by number, mass-nouns are neutral and may depend on world knowledge or context for the selection of the appropriate dimension (Bale & Barner, 2009).

cally, while one option always had more by number, the other option always had more by area (e.g., one giant candle versus three small candles). This allowed trials to serve as their own controls, as children could demonstrate flexibility in quantifying either by mass (e.g., "ribbon") or by count (e.g., "bows"; Barner & Snedeker, 2005). Results with this method have sometimes supported an incremental acquisition of "more" (Gathercole, 1985) and sometimes supported an immediate acquisition of both number and area "more" (Barner & Snedeker, 2005, 2006; Huntley-Fenner, 2001). For example, Gathercole (1985) found that children can verify "more" for numerical quantities relatively early—by around 3.5—but that they also inappropriately verify all mass-nouns by number up until at least age 5 years. And although children can successfully quantify via mass for familiar substance-like mass-nouns such as "toothpaste" (Barner & Snedeker, 2005, 2006), Barner and Snedeker (2006) have argued convincingly that 3-year-olds are willing to quantify using number for both familiar and novel mass-nouns (e.g., counting the pieces of a novel mass-noun "fem" rather than its mass). Thus, evidence from this method remains equivocal between immediate and incremental acquisition.

Evidence that may resolve this issue includes investigating the interface between children's first understanding of "more" and the psychological systems that represent area and number information. If children are to learn the meaning of "more" immediately as a domain general comparative, they must also immediately learn how the meaning of this word interfaces with the cognitive systems that code area and number information. In the present work, we focus on how the interface between linguistic meaning and the cognitive systems that represent number and area may provide evidence for or against the incremental "more" account. As reviewed above, on at least one version of the incremental account (Gathercole, 1985, 2008), "more" is initially understood as applying only to count-nouns. At this stage, "more" would have the restricted *greater-in-number* meaning while lacking the adult-like *greater-in-amount* meaning (see Figure 1). This would imply that when children acquire "more," they first learn an interface between the linguistic meaning and the cognitive systems that represent number. Only later in development, as incremental learning lets children generalize "more" to other dimensions, would the interface be extended to other cognitive representations of quantity.

On the alternative immediate account, children's meaning of "more" is the dimension-neutral meaning greater-in-amount (see Figure 1). So they must also be capable of immediately learning an interface with each of the relevant cognitive representations of quantity (e.g., area and number) and eventually rely on a count/mass distinction or contextual cues to identify which dimension is intended for any given utterance. One challenge for the immediate account is that it makes the problem of learning the interface between "more" and cognition potentially difficult: If there is very minimal similarity between the cognitive systems that represent, for example, area and number, the children would have to somehow immediately form an interface between a domain-neutral meaning of more and very disparate quantity representations in cognition. The interface problem is simpler, however, if these cognitive systems share some underlying formal character that can support a single interface between a domain-neutral meaning of "more" and the cognitive representations of, for example, area and number. That is, immediately learning a domain-neutral meaning of "more" might be aided if the cognitive representations of area and number are related by sharing some underlying character.

Thus, understanding the cognitive representations of area and number becomes a relevant source of evidence for understanding the immediate or incremental acquisition of "more." Here, we sought to determine (a) whether there are underlying similarities in the cognitive representations of area and number that could support the immediate acquisition of a domain-neutral meaning of greater-in-amount, and (b) whether there is developmental evidence that children can successfully verify sentences with area and number "more" at approximately the same ages. Positive evidence for each of these would serve as evidence in favor of an immediate acquisition of a domain-neutral "more."

Evidence for (a) has been mounting. Recent work has suggested that from very early on, infants have access to noisy, approximate representations of various dimensions including number (Dehaene, 1997; Feigenson, Dehaene, & Spelke, 2004; Izard, Sann, Spelke, & Streri, 2009), volume (Huttenlocher, Duffy, & Levine, 2002),

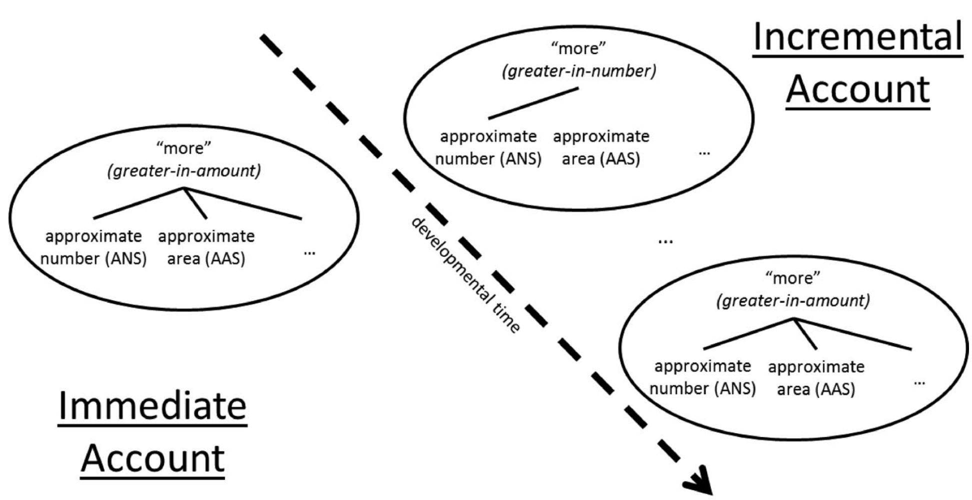

Figure 1. Two prominent theories of "more" acquisition.

and area (Brannon, Lutz, & Cordes, 2006; for reviews, see Cantlon, Platt, & Brannon, 2009, and Feigenson, 2007). A key aspect of these representations is that they are noisy in that they do not represent these continua precisely (i.e., there is always some error surrounding the estimates they generate). These representations are hypothesized to be normal (or Gaussian) distributions over a mental quantity scale, with the noise, or variability, of the representation increasing with larger numbers (i.e., showing scalar variability; Dehaene, 1997; Feigenson et al., 2004). The underlying cognitive system purported to support numerical discriminations, the Approximate Number System (ANS), demonstrates several key behavioral signatures, chief among which is Weber's law—discrimination of numerosity depends not on the absolute difference between the cardinalities of the two sets but on their ratio (Feigenson et al., 2004). Thus, discriminating 20 from 10 items (a ratio of 2.0) is relatively easy, whereas discriminating 20 from 18 items (a ratio of 1.11) is relatively difficult. This ratio dependence and dependency on Weber's law occur as a natural consequence of Gaussian representations with scalar variability—the distance between two activations is greater for larger ratios and makes discriminating between two numbers easier. Recent work has also demonstrated that the most difficult numerical ratio children can successfully discriminate improves with age (Halberda & Feigenson, 2008).

This dependency on Weber's law seems to characterize infants' judgments of surface area. For example, Brannon et al. (2006) habituated infants to a face of a particular size and then presented them with the same face in a different size. Infants could discriminate the change if the area ratio between the original and new face was around 3.0 (3:1) or 2.0 (2:1) but not if it was more difficult. Furthermore, Huntley-Fenner (2001) demonstrated that children around age 4 years could discriminate two piles of sand that differed by a ratio of 1.5 (3:2). These findings suggest that area, like number, relies on an approximate representation system and that the representational precision of this system, much like in the case of number, may improve with age (Cantlon et al., 2009).

However, although the evidence from infancy suggests that both number and area share a common representational format (i.e., Gaussian activations with scalar variability), there has been no direct evidence showing that young children approximate area, more generally, in accordance with Weber's law. Psychophysicists have long debated whether representations of all quantity dimensions obey Weber's law (Bizo, Chu, Sanabria, & Killeen, 2006; Getty, 1975), and work with adults has led some authors to suggest that area approximation does not occur via a dedicated mechanism, but rather that, when presented with geometrical figures, adults fail to estimate area and rely on diameter or aspect-ratio as a proxy for area (Chong & Treisman, 2003; Morgan, 2005; Nachmias, 2008; Teghtsoonian, 1965). A similar issue exists in the infancy literature, where area discrimination tasks could, in principle, be done through many other dimensions, such as perimeter, radius, and so on. Before we can conclusively state that there are similarities in the underlying representations of number and area we need a direct test of children's abilities to approximate area with stimuli that can disrupt attempts to use alternative dimensions like diameter or aspect-ratio as a proxy for area.

Evidence for (b)—that children verify sentences with area or number "more" at approximately the same age—is controversial. As reviewed above, Gathercole (1985) found that children do not verify via area until age 5 years, whereas Barner and Snedeker (2005) also found a number bias in their novel mass-noun conditions, thus suggesting that an interface between "more" and number may emerge prior to the interface with area representations. However, the methods used in paradigms such as Gathercole (1985) and Barner and Snedeker (2005, 2006) are not conclusive, as they require children to resolve a conflict between two number and area. If, independent of language, a child's underlying representations of number and area are biased in favor of number (perhaps because number processing is easier or more salient, independent of language; see Cordes & Brannon, 2008, 2009), then children's competence at understanding "more" as applied to nonnumeric stimuli may be overshadowed by their inability to ignore the numbers of items in the scenes. In fact, several studies have demonstrated that 6- and 7-month-olds, when habituated to a display of several boxes or circles, will dishabituate when the number of boxes changes but not when their total area changes, leading authors to suggest that numerical changes are more salient than changes in cumulative area (Cordes & Brannon, 2008, 2009, 2011).[2] Three-year-old children also find quantifying via number easier than area in nonlinguistic contexts. Cantlon, Safford, and Brannon (2010) played a match-to-sample game and showed children a card with a standard object, and then two cards as choices for the match. Critically, neither of the two cards were identical to the standard—one had the same number of objects as the standard but was vastly off in area, and the other had the same area as the standard but a different number of objects. Preschoolers consistently chose to match by number in this language-neutral context, once again demonstrating a preference for processing number rather than area in the presence of discrete stimuli (and for evidence that even 6-, 8-, and 10-year-old children are swayed by number over cumulative area, see Jeong, Levine, & Huttenlocher, 2007). The existence of a nonlinguistic bias toward number over area may make a linguistic task that pits number against area particularly difficult for young children.

In the present experiment, we asked children to verify sentences with "more" applied to either area or number in nonconflicting stimuli. In the area condition (e.g., "is more of the goo blue or yellow"), the stimuli clearly resembled a continuous mass of stuff with two colors that did not create a conflict between number and area (see Figure 2). In the number condition (e.g., "are more of these dots blue or yellow"), the stimuli clearly resembled two groups of discrete objects where total surface area was always equated, thereby removing any conflict between number and total surface area (see Figure 2). Additionally, the stimuli used in the area condition were not geometric figures, thereby promoting surface area as the only reliable cue to area. We tested a large group of children ranging from 2 to 4 years of age. By alleviating the potential conflicts between number and area representations, we sought to determine whether young children successfully verify sentences with both number and area "more" at approximately the same age. In addition, we relied on psychophysical modeling to

[2] This may not always be the case, however, as both Clearfield and Mix (2001) and Feigenson and colleagues (Feigenson, Carey, & Spelke, 2002) found that when the number of objects is fewer than three and the objects are identical in appearance infants may prefer to quantify by area rather than by number (see also Feigenson, 2005).

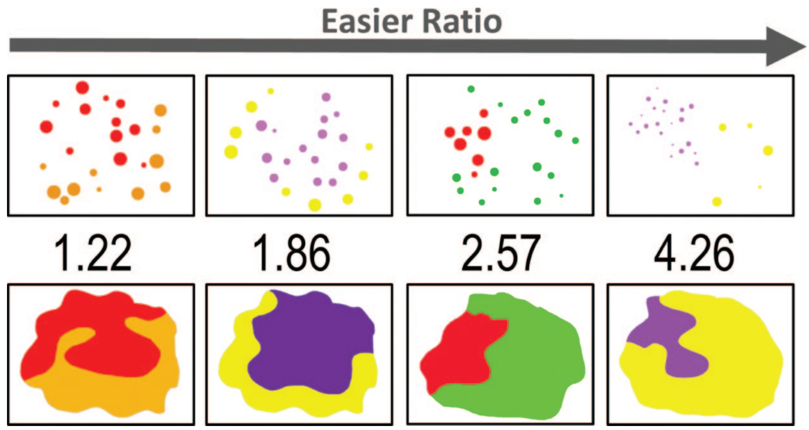

Figure 2. On the top are four examples of the "dots" cards, and on the bottom are four examples of the "goo" cards.

determine if the cognitive representations of number and area had a similar underlying psychophysical character (i.e., Gaussian with scalar variability) that could support a single interface between a domain-neutral understanding of "more" and the cognitive representations of number and area. Answering this question is absolutely necessary for understanding the interface between the linguistic meaning of "more" and the cognitive systems that represent number and area information, and it has yet to be answered for nongeometric figures in any age group.

We expect that if children understand "more" as a domain-neutral greater-in-amount, they will approximate the relevant quantity that the noun is indicating (number for count-nouns and area for mass-nouns in our contexts), and their discrimination performance will adhere to the behavioral signatures of the extra-linguistic cognitive systems that represent quantity. Unlike previous work, we use psychophysical modeling to test whether each *individual* child understands "more." If we find that children, at roughly the same age, demonstrate an understanding of "more" in both mass-noun (area) and count-noun (number) contexts, and that performance in both contexts is consistent with children relying on Gaussian representations with scalar variability, this would support the proposal that "more" is learned as a domain-neutral comparative term from the earliest ages of comprehension and that this understanding is empowered by a single domain-neutral interface between the linguistic meaning of "more" and the Gaussian representations of approximate area and approximate number.

Method

Subjects

Ninety-six children from age 2.0 to age 4.0 (mean age = 3.2) were tested. Of these, 16 had to be removed from data analysis for the following reasons: nonnative English speaker (1), parental interference (2), refusal to participate (12),[3] or technical problems with sound recording (1). Of the remaining children, 40 participated in the area task (i.e., testing mass-noun "more") and 40 in the number task (i.e., testing count-noun "more"). All children were learning English as their first language and were recruited from the greater Baltimore community and were tested with methods certified by the Johns Hopkins University Internal Review Boards. Children received a small gift for participating.

Materials

For the area task, the materials consisted of 16 color "goo" images each printed on a 8.5 × 11″ sheet of paper that was subsequently laminated (see Figure 2). The images were selected from a larger databank of two-colored, circular blob-like images that had been drawn by hand to instantiate a wide range of ratios. To calculate the ratio (i.e., difficulty) between the two colored areas in each image we created a program that counted the number of pixels of each color in each image; ratios were calculated by dividing the larger area by the smaller (e.g., a ratio of 2.0 had twice as many pixels in the larger color area). We chose 16 images from the larger databank that were grouped into four approximate ratio bins with four images in each bin: 1.22, 1.85, 2.5, and 4.2. To make the "goo" images more interesting, we varied the colors used on each trial. Children needed only to point during the task and were not required to know the names of the colors. Yellow, blue, red, orange, purple, and green were used randomly throughout, and all colors occurred equally often.

For the number task, we took the same goo images and used a custom-made program to extract individual dots from them (see Figure 2). This guaranteed that the relative spread of the two collections was matched to the spread in the goo images. Additionally, we made the ratio of the dots exactly the same as the ratio of the goo images (e.g., a 2.5 ratio on a blue and yellow goo card was converted into, for example, a card with 25 blue dots and 10 yellow dots). For all dots cards, the cumulative area of the two sets was identical. For half of the cards, the larger set of dots appeared in the smaller area of the blob, thereby ensuring that neither cumulative area, nor the area envelope surrounding the dots, nor density of dots could serve as a stable correlate to number.

[3] In all but two cases, these children were younger than 2.5 and did not appear to understand the game—in most cases the child simply did not respond to our requests. We take this as evidence that these children did not understand the meaning of the comparative "more."

Procedure

Before the experiment, parents signed a consent form and filled out a version of the McArthur-Bates III vocabulary inventory (Fenson et al., 2007).

Children were brought into the room and played a short number titration warm-up game ("What's on This Card"; see Le Corre & Carey, 2007; Halberda, Taing, & Lidz, 2008) with the experimenter, which involved counting pictures of animals on cards. After number titration, the experimenter said that she had some pictures of "goo" to show the child or some pictures of "dots" to show the child. The parents remained with the child at all times but were seated so that they could not see the cards presented.

In the area task, each trial began with the experimenter putting a single "goo" card on the table and saying, "Look at *this* goo. Some of the goo is *blue*, and some of the goo is *green*. Is *more* of the goo *blue* or *green*?" (Italics indicate increased prosodic stress on those words.) While naming the color, the experimenter ran her fingers over the color in a smudging motion in case the child did not know the color name. Children were allowed to respond by either pointing or saying the name of the color.

In the number task, each trial began with the experimenter putting a single dots card on the table and saying, "Look at *these* dots. Some of the dots are *blue*, and some of the dots are *green*. Are *more* of the dots *blue* or *green*?" While naming the colors, the experimenter would touch individual dots to make sure children knew which color was being referred to. Children were not allowed to count the dots and, if they attempted to, the experimenter removed the card and reminded the child that he or she should simply give the best guess without counting; all children complied with the instruction not to count.

Cards were presented in one of two possible orders with the ratio presented varying pseudorandomly from trial to trial. Because the dots cards were made from the goo cards, the order of the cards was identical across the two conditions. Whether the larger color was said first or second in the sentence was counterbalanced across trials. Every trial ended with neutral-positive feedback from the experimenter. The entire experiment was digitally audio–video recorded and was later coded for whether the child indicated the correct or incorrect color.

Results

We first analyzed the data by averaging performance across all 16 trials (i.e., ignoring ratio). Across all children, the average accuracy on the area task was 63% (SE = 3.17%), which was significantly above chance, $t(39) = 4.01$, $p < .01$, indicating that the children, as a group, succeeded on the task. Across all children, the accuracy on the number task was 60% (SE = 2.98%), which was also significantly above chance, $t(39) = 3.352$, $p < .01$. There was no significant difference in accuracy between the two tasks, $t(78) = -0.618$, $p = .54$.

We computed a stepwise linear regression with accuracy as the dependent variable and age, task, vocabulary, what's-on-this-card performance, and order as the independent variables (IVs). Age was the only IV that significantly predicted the dependent variable ($\beta = 0.450$, $p < .01$, $r^2 = 0.20$; see Figure 3), that is, once age was entered as an IV, none of the other IVs were significant predictors of average performance. Examining the scatter plot, it appears that

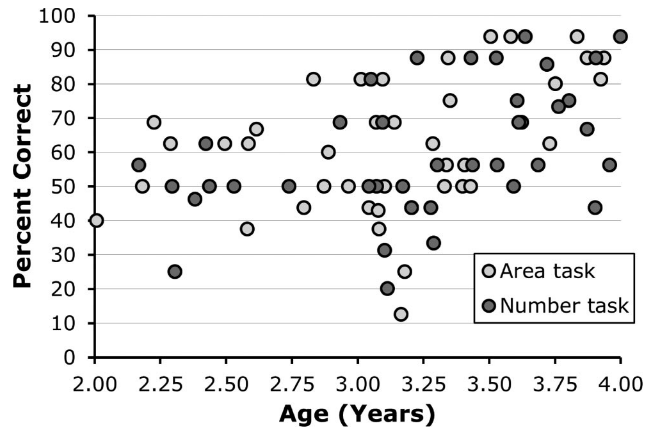

Figure 3. The average performance across all 16 cards over age for both the dots and area task. The pattern shows a clear linear increase in performance with age and a high degree of overlap between the two tasks.

children can perform above chance on the area and the number task starting between the ages of 3.3 and 3.5.

This method of analysis—relying on overall percentage correct—is standard in the word-learning literature (e.g., Barner & Snedeker, 2006). However, a more sensitive measure of children's word knowledge is possible when we consider the psychophysics of the underlying area and number representations. We next used psychophysical modeling to determine which individual children succeeded at the task and whether their performance was consistent with Weber's law.

We predicted that if children understand "more" as greater-in-amount, children would rely on a cognitive system that encodes the approximate area or approximate number on each trial (depending on the syntax and stimulus context), and that discrimination performance would be consistent with Weber's law in the following sense: Performance should be ratio dependent and well modeled by a Gaussian cumulative density function (see modeling details below; Halberda & Feigenson, 2008; Lidz et al., 2011; Pica, Lemer, Izard, & Dehaene, 2004).

For each child, performance was grouped into four ratio bins, with four trials falling into each of these bins ranging from harder trials (ratio bin = 1.22) to easier trials (ratio bin = 4.2).[4] Performance was fit by a standard psychophysical model of Weber's law (Barth et al., 2006; Green & Swets, 1988; Halberda & Feigenson, 2008; Pica et al., 2004; Pietroski, Lidz, Hunter, & Halberda, 2009). We have previously applied this model to adult area and number perception with good results (Odic et al., 2012):

$$percent\ correct = \frac{1}{2} erfc\left(\frac{n_1 - n_2}{\sqrt{2w}\sqrt{n_1^2 + n_1^2}}\right) * 100$$

The model assumes that the underlying representations of area or number are distributed along a continuum of Gaussian random variables (with one value for the trial having a mean of n_1 and the

[4] The data were grouped because each ratio was presented only once, but the model expects accuracy for each ratio to range between 50% and 100%. The results are identical without binning, although the r^2 values are much lower.

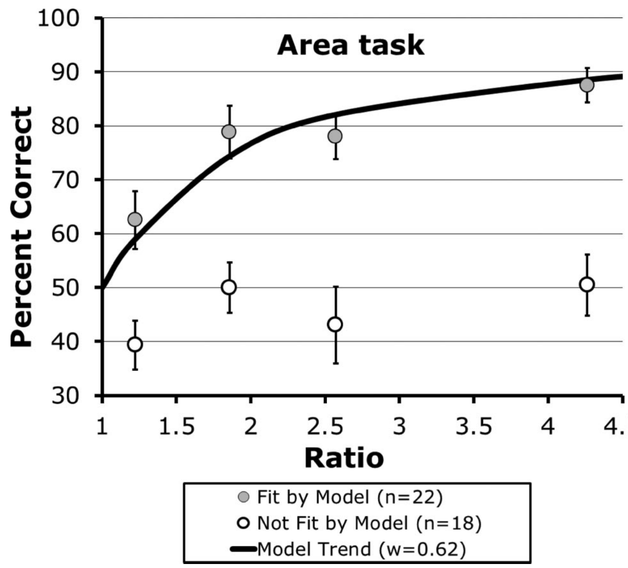

Figure 4. The average performance across the four ratios for children in the area task whose data could be fit by the Weber's law model and those who could not. Error bars are standard error of the mean.

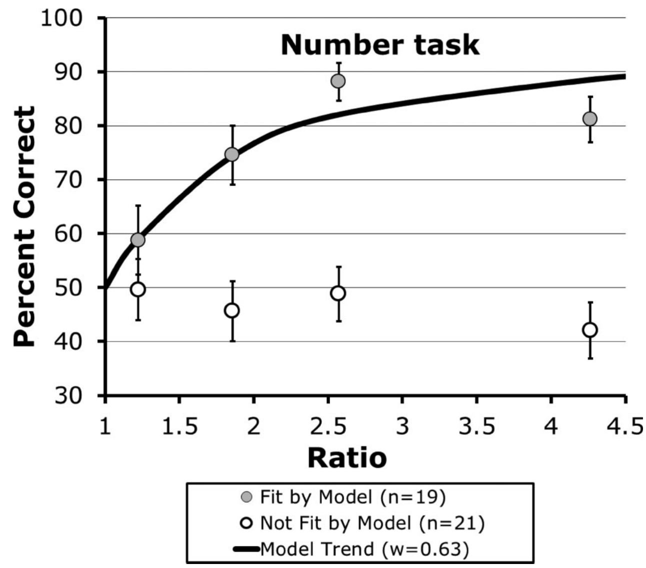

Figure 5. The average performance across the four ratios for children in the number task whose data could be fit by the Weber's law model and those who could not. Error bars are standard error of the mean.

other having a mean of n_2). An important implication of this model is that the two different numbers (or areas) on each trial will often have overlapping representations. In other words, as the means of the two distributions become increasingly similar (i.e., as the numbers become closer and the ratio moves closer to a ratio of 1.0), their Gaussian representations should overlap more and participants should have a more difficult time determining which is larger, thus resulting in decreasing accuracy at the task as a function of ratio—in accordance with Weber's law.

This model has only a single free parameter—the Weber fraction (w)—which indicates the amount of noise in the underlying Gaussian representations (i.e., the standard deviation of the n_1 and n_2 Gaussian representations where $SD_n = w \times n$). Larger w values indicate higher representational noise and, thus, poorer discrimination across ratios (i.e., lower Weber fractions indicate better discrimination performance). If a child is successfully discriminating in a manner consistent with Weber's law, the model will determine the most plausible w for the child. If a child is not successfully discriminating in a manner consistent with Weber's law, the model will fail to find a value for w.

In the area task, the model returned a w value for 22/40 children with an average w of 0.62 ($SE = 0.11$; approx. 3:2 ratio), and in the number task the model returned a w value for 19/40 children with an average w of 0.63 ($SE = 0.12$; approx. 3:2 ratio). For the remaining "nonfit" children, the model could not settle on a minimum least-squares value and, thus, could not provide a w value that correctly fit the data. Figures 4 and 5 display the average percentage correct in each ratio bin for the children who were successfully fit by the model and for those who were not. It is clear that children who could not be fit simply guessed at every ratio: Not only was there no improvement with ratio, but also the highest percentage correct amongst the nonfit children was at chance levels given a binomial test with 16 trials (best nonfitter in area was at 63%, and best nonfitter in number was at 57%; above-chance is around 69%). For the children who could be fit, the smooth curve is the least squares value for the cumulative density function for the group. Agreement between the psychophysical model and children's performance was quite good for both area ($r^2 = .92$) and for number ($r^2 = .82$), suggesting that children did rely on the ANS and on approximate representations of area that are consistent with Weber's law (i.e., an Approximate Area System, or AAS). The good fit also confirms that these systems share an underlying Gaussian scalar variability format (cf. Cantlon et al., 2009). Further validating the performance on the number task, the least-squares value for w for the group ($w = .63$) is in agreement with previously documented developmental trends for this age group (Halberda & Feigenson, 2008; Piazza et al., 2010) where no understanding of the word "more" was required. There are no previously documented developmental trends for area discrimination for these ages as our study is the first to test children's abilities with blob-like stimuli.

Even more remarkably, the distributions of w scores for area and number are extremely similar (see Figure 6). In the quantity representation literature, some have argued that similarity in observed w scores in two tasks suggests quite strongly that a shared representational system is responsible for the similar performance (Cantlon et al., 2009; Meck & Church, 1983). Weber fractions (w) have been found for many discrimination tasks and can range from very poor performance (e.g., $w = 1$ in 6-month-olds for number and area; Brannon et al., 2006) to very accurate performance ($w = .03$ in adults for line length; Coren, Ward, & Enns, 1994)—a difference of nearly two orders of magnitude. With this in mind, it is particularly noteworthy that the observed w scores in our area and number tasks were so similar. This is consistent with the proposal that children initially learn "more" as a domain-neutral comparative term that, in the case of area and number, maps to a

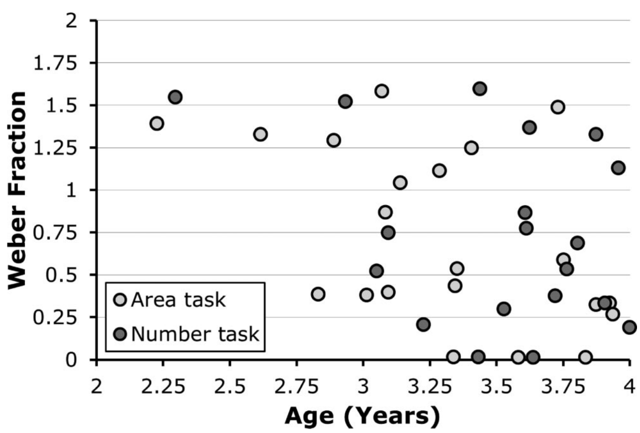

Figure 6. The fit Weber fraction of each fitted child over age for the area and number task. As can be seen, there is a clear downward trend for lower Weber fractions (i.e., better area discrimination) with age.

single shared approximation system or to a system that shares a common psychophysical character for area and number.[5]

Next, we turn to the question of the immediate acquisition of a domain-neutral "more." The average age of children who were fit in the area task was 3.4 ($SE = 0.09$) and in the number task was 3.5 ($SE = 0.10$) suggesting that, by at least age 3.5 years, children understand "more" in both count- and mass-noun contexts. Additionally, the average age of children who were successfully fit was significantly higher than those who could not be fit for both area, $t(38) = -3.35$, $p < .01$, and number, $t(38) = -3.27$, $p < .01$. The similar age of success in area and number contexts presents difficulty for the incremental acquisition of "more" (cf. Gathercole, 1985).

The presence of children who could not be fit by the model provides a convenient control for methodological concerns about our tasks. For example, it could be argued that, because even infants can make discriminations of area (Brannon et al., 2006) and number of items (Izard et al., 2009) in visual displays—without language—it is possible that our stimuli were such that children of any age would simply settle into choosing the greater area or number without having to understand the word "more" at all. In fact, young children in the area and number tasks performed at chance and failed to choose the greater area or number. If it were solely a default behavior or a bias to choose the greater quantity—observable in young infants—it would be mysterious why younger children in our task would perform at chance and why the estimated age of acquisition of understanding "more" would be so similar in our tasks and other reported studies (e.g., Barner & Snedeker, 2006; Beilin, 1968; Weiner, 1974).

Our final question concerns developmental changes in the acuity of the two approximate systems. Our age range afforded us the opportunity to ask whether the precision of area and number representations improves during the late preschool years. In fact, area w for children who were successfully fit by the model improved (i.e., went down) with age as revealed by a linear regression, $r(21) = -0.53$, $p < .05$; see Figure 6), but a linear regression with age and number w did not reach significance, $r(18) = -0.34$, $p = .16$; see Figure 6). The improvements in area w are most likely a result of developmental improvements in the acuity of the AAS rather than any change in children's understanding of the word "more," and the nonsignificant result for number w is likely a function of power ($n = 19$) as other studies that did not involve linguistic contrasts have demonstrated developmental improvements in w for number across these same ages (Halberda & Feigenson, 2008; Piazza et al., 2010).

Discussion

Theories on the acquisition of comparative "more" fall into two categories: some, like Gathercole (1985), advocate the incremental learning account, where the child's earliest understanding of "more" is consistent with meaning greater-in-number and only later enriched to include an understanding of other dimensions (e.g., area) that generalizes to greater-in-amount; others, like Barner and Snedeker (2005) and Mehler and Bever (1967), have argued that children immediately understand "more" to mean greater-in-amount. We have highlighted an important challenge for the latter (immediate, domain-neutral) account that has not been the focus of previous investigation: namely, in order to use and understand "more" across various contexts (e.g., area and number), children must also master an interface between the meaning of "more" and the various cognitive representations of quantity. We noted that if each quantity representation had a different underlying format, learning each of these interfaces immediately would be unlikely. Here, we sought to determine (a) whether there are underlying similarities in the cognitive representations of area and number that could support the immediate acquisition of a domain-neutral meaning of greater-in-amount, and (b) whether there is developmental evidence that children can successfully verify sentences with area and number "more" at approximately the same ages. Positive evidence for each of these would serve as evidence in favor of an immediate acquisition of a domain-neutral "more."

The present experiment provides support for the immediate acquisition of a domain-neutral "more." First, we found a close relationship between representations of number and area: We found that both representations obey Weber's law and are, thus, represented as mental magnitudes with Gaussian tuning and scalar variability. This was known for representations of approximate number (Halberda & Feigenson, 2008) and not entirely surprising given suggestions about area (e.g., Brannon et al., 2009), though it

[5] For our purposes here—arguing that children learn the comparative "more" as a domain-neutral comparative that can interface with either number or area—it is enough that successful performance in both the number and area tasks was well fit by the psychophysical model of Weber's law. But taking a broader view, there are other dimensions besides number and area that will be of interest for investigating the acquisition of "more," and not all of these will share the same Weber fraction. Just so long as these other systems share a common abstract format with number and area (e.g., Gaussian scalar variability; see Discussion) the interface between "more" and these dimensions will remain transparent. We note the similarity in Weber fractions for area and number in the present article because many authors are currently interested in the possibility that dimensions like time, space, and number may rely on a single, more general Analog Magnitude System that may have a single common Weber fraction (Bueti & Walsh, 2009; Dehaene & Brannon, 2011). Our results are consistent with this possibility, though we caution that any such shared system would still require representations that allow one to distinguish, for example, number thoughts from area thoughts.

had yet to be demonstrated for amorphous stimuli in children. We also found that area representations, like number representations (Halberda & Feigenson, 2008; Piazza et al., 2010), improve in acuity over the preschool years. Perhaps of even greater note, we found that children had very similar Weber fractions (*w*) for number and area, suggesting the possibility of a shared underlying system. This similarity between number and area representations supports the possibility that children might immediately learn a domain-neutral "more" meaning greater-in-amount as it may support a single interface between the meaning of "more" and the cognitive systems that represent number and area.

Next, we showed that children begin to understand "more" as applied to both count- and mass-nouns (and, in the context of our experiments, number and area) at the same ages (3.3 years). Thus, not only do children have the kind of representations that would support the learning of a dimension-neutral "more," but we also found evidence that they immediately understand "more" as applying to either number or area. Our estimate of 3.3 years as the age of first understanding number and area "more" is consistent with the findings of Barner and Snedeker (2006) and contrasts with those of Gathercole (1985), and suggests that children of this age know that "more" can be applied to both numeric and nonnumeric stimuli. Children's success with our stimuli that remove any conflict between number and area also suggests that some of the number bias in the Gathercole (1985) study and in the Barner and Snedeker (2006) novel-noun condition may have been due to a general cognitive bias toward number over area whenever these dimensions are placed in conflict (i.e., this number bias may be independent of children's language understanding). This too is consistent with an immediate acquisition of a domain-neutral "more" meaning greater-in-amount.

Our data also have implications for word learning accounts more generally. First, incremental and immediate learning accounts of word learning have been prevalent in the acquisition of nouns (Bowerman, 1978; E. V. Clark, 1973), number words (Carey, 2009; Wynn, 1992), and quantifiers (H. H. Clark, 1970). This debate has often focused on learning strategies used by children and on identifying the basic components of lexical meaning available to children early on (Gathercole, 2008). In the context of our findings, evidence suggests that children are capable of learning the comparative "more" without having to first understand it as having a more general (e.g., H. H. Clark, 1970) or a more specific meaning (cf. Gathercole, 1985). Furthermore, our findings suggest that the comparative operation necessary for the domain-neutral lexical meaning of "more" is available to children early on and that the interface between this lexical meaning and cognition may be simple for children to resolve.

Although our work focused on the relationship between the lexical meaning of "more" and representations of area and number, it is clear that the comparative "more" can refer to many other dimensions (e.g., time, happiness). Work in psychophysics has demonstrated that not all dimensions obey scalar variability (e.g., Bizo, Chu, Sanabria, & Killeen, 2006; Grondin, 2012) and, given this difference, we should not expect the interface to be as easily generalizable to these dimensions as to those that do share a common representational format. Future work should, therefore, compare how children learn the interface between the comparative "more" and these dimensions. At the same time, some work has shown that some dimensions are, perhaps surprisingly, represented as Gaussian estimations with scalar variability (e.g., happiness, gender, and facial expression; de Fockert & Wolfenstein, 2009; Haberman & Whitney, 2007). One possibility is that we come to understand most scales and dimensions through the use of the magnitude systems, which themselves obey scalar variability (Bueti & Walsh, 2009; Lourenco & Longo, 2010).

Finally, although we identified early- to mid-3s as the age of acquisition for the comparative "more," many corpus studies have shown that children begin producing the word "more" much earlier (Carter, 1975; Harris et al., 1988). As discussed in the introduction, these studies have shown that children produce the *additive* form of "more" (e.g., "More juice!"), and not the comparative form. Nevertheless, this raises the possibility that the two forms may be related and that children first learn "more" in some limited contexts, and only extend it to the context we tested much later on. We doubt this possibility for two reasons. First, as discussed earlier, the two forms of "more" are unlikely to be tightly related given both semantic (Thomas, 2010) and cross-linguistic evidence (Odic et al., 2012). Second, our age of acquisition for the count-noun comparative "more" agrees with previous findings in the literature that have used different sentence frames and different contexts (Barner & Snedeker, 2006; Beilin, 1968; Gathercole, 1985, 2008; Weiner, 1974). Thus, it is likely that the two forms of "more" are largely unrelated and that children could not perform our task because they simply had no meaning for the "more" in the comparative position.

One important future direction is to determine the relationship between approximate representations of area, number, and other quantities. For example, does the similarity between number and area discrimination performance reflect two distinct cognitive systems that are similar in format or a single unified magnitude system (cf. Bueti & Walsh, 2009; Cantlon et al., 2009)? At present, our data are consistent with either account, although the highly similar Weber fraction has, in the past, been used as evidence for a single system (e.g., Meck & Church, 1983). Likewise, the similar growth pattern in the acuity of these systems may be used as evidence for their identity, although we stress that changes in acuity may be either due to changes of the representation of number and area or due to more peripheral factors, like changes in attention, working memory span, and so on (see Halberda & Feigenson, 2008).

More generally, our findings highlight the potential value of studying the interface between linguistic meanings and the extralinguistic cognitive representations used during verifications of these meanings. The study of such an interface can shed important light on our interpretations of both psycholinguistic data (e.g., the meaning and acquisition of quantifiers, comparatives, gradable adjectives) and on cognitive theories of quantity representation and selection (e.g., developmental changes in the precision of quantity representations). Although linguistics and psychology remain independent disciplines, new questions may arise and become answerable in light of evidence for how language and psychology interface with each other.

References

Bale, A. C., & Barner, D. (2009). The interpretation of functional heads: Using comparatives to explore the mass/count distinction. *Journal of Semantics, 26*(3), 217–252. doi:10.1093/jos/ffp003

Barner, D., & Snedeker, J. (2005). Quantity judgments and individuation: Evidence that mass nouns count. *Cognition, 97*(1), 41–66. doi:10.1016/j.cognition.2004.06.009

Barner, D., & Snedeker, J. (2006). Children's early understanding of mass-count syntax: Individuation, lexical content, and the number asymmetry hypothesis. *Language Learning and Development, 2*(3), 163–194. doi:10.1207/s15473341lld0203_2

Barth, H., La Mont, K., Lipton, J., Dehaene, S., Kanwisher, N., & Spelke, E. S. (2006). Non-symbolic arithmetic in adults and young children. *Cognition, 98*(3), 199–222. doi:10.1016/j.cognition.2004.09.011

Beilin, H. (1968). Cognitive capacities of young children: A replication. *Science, 162*(3856), 920–921. doi:10.1126/science.162.3856.920

Bizo, L. A., Chu, J. Y. M., Sanabria, F., & Killeen, P. R. (2006). The failure of Weber's law in time perception and production. *Behavioural Processes, 71,* 201–210. doi:10.1016/j.beproc.2005.11.006

Bloom, L. (1970). *Form and function in emerging grammars.* Cambridge, MA: MIT Press.

Booth, A. E., & Waxman, S. R. (2003). Mapping words to the world in infancy: Infants' expectations for count nouns and adjectives. *Journal of Cognition and Development, 4*(3), 357–381. doi:10.1207/S15327647JCD0403_06

Bowerman, M. (1978). Systematizing semantic knowledge: Changes over time in the child's organization of word meaning. *Child Development, 49*(4), 977–987. doi:10.2307/1128737

Brannon, E. M., Lutz, D., & Cordes, S. (2006). The development of area discrimination and its implications for number representation in infancy. *Developmental Science, 9*(6), F59–F64. doi:10.1111/j.1467-7687.2006.00530.x

Bueti, D., & Walsh, V. (2009). The parietal cortex and the representation of time, space, number and other magnitudes. *Philosophical Transactions of the Royal Society B: Biological Sciences, 364*(1525), 1831–1840. doi:10.1098/rstb.2009.0028

Cantlon, J. F., Platt, M., & Brannon, E. M. (2009). Beyond the number domain. *Trends in Cognitive Sciences, 13*(2), 83–91. doi:10.1016/j.tics.2008.11.007

Cantlon, J. F., Safford, K. E., & Brannon, E. M. (2010). Spontaneous analog number representations in 3-year-old children. *Developmental Science, 13*(2), 289–297. doi:10.1111/j.1467-7687.2009.00887.x

Carey, S. (1978). Less may never mean more. In R. Campbell & P. Smith (Eds.), *Recent advances in the psychology of language* (pp. 109–132). New York, NY: Plenum Press.

Carey, S. (2009). *The origin of concepts.* New York, NY: Oxford University Press. doi:10.1093/acprof:oso/9780195367638.001.0001

Carter, A. L. (1975). The transformation of sensorimotor morphemes into words: A case study of the development of "more" and "mine." *Journal of Child Language, 2*(2), 233–250. doi:10.1017/S0305000900001069

Chong, S., & Treisman, A. (2003). Representation of statistical properties. *Vision Research, 43*(4), 393–404. doi:10.1016/S0042-6989(02)00596-5

Clark, E. V. (1973). What's in a word? On the child's acquisition of semantics in his first language. In T. E. Moore (Ed.), *Cognitive development and the acquisition of language* (p. xii, 308). Oxford, England: Academic Press.

Clark, H. H. (1970). The primitive nature of children's relational concepts. In J. R. Hayes (Ed.), *Cognition and the development of language* (pp. 269–278). New York, NY: Wiley.

Clearfield, M. W., & Mix, K. S. (2001). Amount versus number: Infants' use of area and contour length to discriminate small sets. *Journal of Cognition and Development, 2*(3), 243–260. doi:10.1207/S15327647JCD0203_1

Cordes, S., & Brannon, E. M. (2008). The difficulties of representing continuous extent in infancy: Using number is just easier. *Child Development, 79*(2), 476–489. doi:10.1111/j.1467-8624.2007.01137.x

Cordes, S., & Brannon, E. M. (2009). The relative salience of discrete and continuous quantity in young infants. *Developmental Science, 12*(3), 453–463. doi:10.1111/j.1467-7687.2008.00781.x

Cordes, S., & Brannon, E. M. (2011). Attending to one of many: When infants are surprisingly poor at discriminating an item's size. *Frontiers in Developmental Psychology, 2,* 65. doi:10.3389/fpsyg.2011.00065

Coren, S., Ward, L. M., & Enns, J. T. (1994). *Sensation and perception* (4th ed.). Fort Worth, TX: Harcourt Brace.

de Fockert, J., & Wolfenstein, C. (2009). Rapid extraction of mean identity from sets of faces. *The Quarterly Journal of Experimental Psychology, 62*(9), 1716–1722. doi:10.1080/17470210902811249

Dehaene, S. (1997). *The number sense.* New York, NY: Oxford University Press.

Dehaene, S., & Brannon, E. (Eds.). (2011). *Space, time and number in the brain: Searching for the foundations of mathematical thought* (1st ed.). New York, NY: Academic Press.

Donaldson, M., & Balfour, G. (1968). Less is more: A study of language comprehension in children. *British Journal of Psychology, 59*(4), 461–471. doi:10.1111/j.2044-8295.1968.tb01163.x

Donaldson, M., & Wales, R. J. (1970). On the acquisition of some relational terms. In J. R. Hayes (Ed.), *Cognition and the development of language* (pp. 235–268). New York, NY: Wiley.

Feigenson, L. (2005). A double-dissociation in infants' representations of object arrays. *Cognition, 95,* B37–B48. doi:10.1016/j.cognition.2004.07.006

Feigenson, L. (2007). The equality of quantity. *Trends in Cognitive Sciences, 11*(5), 185–187. doi:10.1016/j.tics.2007.01.006

Feigenson, L., Carey, S., & Spelke, E. (2002). Infants' discrimination of number vs. continuous extent. *Cognitive Psychology, 44*(1), 33–66. doi:10.1006/cogp.2001.0760

Feigenson, L., Dehaene, S., & Spelke, E. S. (2004). Core systems of number. *Trends in Cognitive Sciences, 8*(7), 307–314. doi:10.1016/j.tics.2004.05.002

Fenson, L., Marchman, V. A., Thal, D. J., Dale, P. S., Reznick, J. S., & Bates, E. (2007). *MacArthur-Bates Communicative Development Inventories, User's guide and technical manual* (2nd ed.). Baltimore, MD: Brookes.

Gathercole, V. C. (1985). More and more and more about "more." *Journal of Experimental Child Psychology, 40,* 73–104. doi:10.1016/0022-0965(85)90066-9

Gathercole, V. C. (2008). It was so much fun. It was 20 fun!: Cognitive and linguistic invitations to the development of scalar predicates. In V. C. Gathercole (Ed.), *Routes to language: Studies in honor of Melissa Bowerman* (pp. 319–443). New York, NY: Psychology Press.

Getty, D. J. (1975). Discriminations of short temporal intervals: A comparison of two models. *Perception & Psychophysics, 18,* 1–8. doi:10.3758/BF03199358

Gillon, B. S. (1992). Towards a common semantics for English count and mass nouns. *Linguistics and Philosophy, 15*(6), 597–639. doi:10.1007/BF00628112

Gordon, P. (1985). Evaluating the semantic categories hypothesis: The case of the count/mass distinction. *Cognition, 20*(3), 209–242. doi:10.1016/0010-0277(85)90009-5

Green, D. M., & Swets, J. A. (1988). *Signal Detection Theory and psychophysics.* Los Altos, CA: Peninsula Publishing.

Grondin, S. (2012). Violation of the scalar property for time perception between 1 and 2 seconds: Evidence from interval discrimination, reproduction, and categorization. *Journal of Experimental Psychology: Human Perception and Performance.* Advance online publication. doi:10.1037/a0027188

Haberman, J., & Whitney, D. (2007). Rapid extraction of mean emotion and gender from sets of faces. *Current Biology, 17*(17), R751–R753. doi:10.1016/j.cub.2007.06.039

Halberda, J., & Feigenson, L. (2008). Developmental change in the acuity of the "number sense": The approximate number system in 3-, 4-, 5-, and

6-year-olds and adults. *Developmental Psychology, 44*(5), 1457–1465. doi:10.1037/a0012682

Halberda, J., Taing, L., & Lidz, J. (2008). The development of "most" comprehension and its potential dependence on counting ability in preschoolers. *Language Learning and Development, 4*(2), 99–121. doi: 10.1080/15475440801922099

Harris, M., Barrett, M., Jones, D., & Brookes, S. (1988). Linguistic input and early word meaning. *Journal of Child Language, 15*(1), 77–94. doi:10.1017/S030500090001206X

Hohaus, V., & Tiemann, S. (2009). " . . . this much is how much I'm taller than Joey . . . ": A corpus study in the acquisition of comparison constructions. *Proceedings of AquisiLyon,* 90–93.

Hudson, L. M., Guthrie, K. H., & Santilli, N. R. (1982). The use of linguistic and non-linguistic strategies in kindergarteners' interpretations of "more" and "less." *Journal of Child Language, 9*(1), 125–138. doi: 10.1017/S0305000900003664

Huntley-Fenner, G. (2001). Why count stuff? Young preschoolers do not use number for measurement in continuous dimensions. *Developmental Science, 4*(4), 456–462. doi:10.1111/1467-7687.00187

Huttenlocher, J., Duffy, S., & Levine, S. (2002). Infants and toddlers discriminate amount: Are they measuring? *Psychological Science, 13*(3), 244–249. doi:10.1111/1467-9280.00445

Izard, V., Sann, C., Spelke, E. S., & Streri, A. (2009). Newborn infants perceive abstract numbers. *Proceedings of the National Academy of Sciences of the USA, 106*(25), 10382–10385. doi:10.1073/pnas.0812142106

Jeong, Y., Levine, S. C., & Huttenlocher, J. (2007). The development of proportional reasoning: Effect of continuous versus discrete quantities. *Journal of Cognition and Development, 8*(2), 237–256. doi:10.1080/15248370701202471

Le Corre, M., & Carey, S. (2007). One, two, three, four, nothing more: An investigation of the conceptual sources of the verbal counting principles. *Cognition, 105*(2), 395–438. doi:10.1016/j.cognition.2006.10.005

Lidz, J., Halberda, J., Pietroski, P., & Hunter, T. (2011). Interface transparency thesis and the psychosemantics of most. *Natural Language Semantics, 19*(3), 227–256.

Lourenco, S. F., & Longo, M. R. (2010). General magnitude representation in human infants. *Psychological Science, 21*(6), 873–881. doi:10.1177/0956797610370158

Meck, W. H., & Church, R. M. (1983). A mode control model of counting and timing processes. *Journal of Experimental Psychology: Animal Behavior Processes, 9,* 320–334. doi:10.1037/0097-7403.9.3.320

Mehler, J., & Bever, T. G. (1967). Cognitive capacity of very young children. *Science, 158*(3797), 141–142. doi:10.1126/science.158.3797.141

Morgan, M. (2005). The visual computation of 2-D area by human observers. *Vision Research, 45*(19), 2564–2570. doi:10.1016/j.visres.2005.04.004

Nachmias, J. (2008). Judging spatial properties of simple figures. *Vision Research, 48*(11), 1290–1296. doi:10.1016/j.visres.2008.02.024

Odic, D., Pietroski, P., Hunter, T., Lidz, J., & Halberda, J. (2012). *Interface transparency and the count/mass distinction.* Manuscript submitted for publication.

Palermo, D. S. (1973). More about less: A study of language comprehension. *Journal of Verbal Learning and Verbal Behavior, 12*(2), 211–221. doi:10.1016/S0022-5371(73)80011-8

Piaget, J. (1965). *Child's conception of number.* New York, NY: Norton.

Piazza, M., Facoetti, A., Trussardi, A. N., Berteletti, I., Conte, S., Lucangeli, D., . . . Zorzi, M. (2010). Developmental trajectory of number acuity reveals a severe impairment in developmental dyscalculia. *Cognition, 116*(1), 33–41. doi:10.1016/j.cognition.2010.03.012

Pica, P., Lemer, C., Izard, V., & Dehaene, S. (2004). Exact and approximate arithmetic in an Amazonian Indigene group. *Science, 306*(5695), 499–503. doi:10.1126/science.1102085

Pietroski, P., Lidz, J., Hunter, T., & Halberda, J. (2009). The meaning of "most": Semantics, numerosity and psychology. *Mind & Language, 24*(5), 554–585. doi:10.1111/j.1468-0017.2009.01374.x

Soja, N. N., Carey, S., & Spelke, E. S. (1991). Ontological categories guide young children's inductions of word meaning: Object terms and substance terms. *Cognition, 38*(2), 179–211. doi:10.1016/0010-0277(91)90051-5

Teghtsoonian, M. (1965). The judgment of size. *The American Journal of Psychology, 78*(3), 392–402. doi:10.2307/1420573

Thomas, G. (2010). Incremental *more*. *Proceedings of SALT (Semantics and Linguistics Theory), 20,* 233–250.

Townsend, D. J. (1974). Children's comprehension of comparative forms. *Journal of Experimental Child Psychology, 18*(2), 293–303. doi: 10.1016/0022-0965(74)90109-X

Weiner, S. L. (1974). On the development of more and less. *Journal of Experimental Child Psychology, 17*(2), 271–287. doi:10.1016/0022-0965(74)90072-1

Wynn, K. (1992). Children's acquisition of the number words and the counting system. *Cognitive Psychology, 24*(2), 220–251. doi:10.1016/0010-0285(92)90008-P

Received June 17, 2011
Revision received April 24, 2012
Accepted May 1, 2012 ■