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What Counts in the Development of Young Children's Number Knowledge?

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Prior studies indicate that children vary widely in their mathematical knowledge by the time they enter preschool and that this variation predicts levels of achievement in elementary school. In a longitudinal study of a diverse sample of 44 preschool children, we examined the extent to which their understanding of the cardinal meanings of the number words (e.g., knowing that the word “four” refers to sets with 4 items) is predicted by the “number talk” they hear from their primary caregiver in the early home environment. Results from 5 visits showed substantial variation in parents’ number talk to children between the ages of 14 and 30 months. Moreover, this variation predicted children’s knowledge of the cardinal meanings of number words at 46 months, even when socioeconomic status and other measures of parent and child talk were controlled. These findings suggest that encouraging parents to talk about number with their toddlers, and providing them with effective ways to do so, may positively impact children’s school achievement.

Keywords: parent input, number, cardinal number, mathematical skill, parent–child interaction

In the current study, we examined variation in parent talk about numbers during naturalistic interactions with their 14- to 30-month-olds and the relation of this variation to children’s subsequent numerical understanding. By the time children enter preschool, there are marked individual differences in their mathematical knowledge, as shown by their performance on standardized mathematics tests (e.g., Starkey, Klein, & Wakeley, 2004) as well as experimental tasks (Clements & Sarama, 2007; Entwisle & Alexander, 1990; Ginsburg & Russell, 1981; Griffin, Case, & Siegler, 1994; Jordan, Huttenlocher, & Levine, 1992; Klibanoff, Levine, Huttenlocher, Vasilyeva, & Hedges, 2006; Lee & Burkam, 2002; Saxe, Guberman, & Gearheart, 1987; Starkey et al., 2004). These early differences in mathematics knowledge are

concerning for several reasons. First, levels of mathematics knowledge at the time of school entry have been shown to predict later school achievement (e.g., Duncan et al., 2007; Lee & Burkam, 2002). For example, a meta-analysis of six longitudinal data sets revealed that the level of children’s early mathematics skills (at about the time of school entry) predicts subsequent mathematics achievement through at least the fifth grade (Duncan et al., 2007). Second, there is greater demand for high levels of mathematical skill as demands for a scientifically and technologically sophisticated workforce increase (National Research Council, 2009). Finally, level of mathematics skill is associated with socioeconomic status (SES), raising issues of equity in terms of employment opportunity (e.g., Ehrlich, 2007; Klibanoff et al., 2006; Starkey et al., 2004).

The existence of early variations in mathematics knowledge motivated our investigation of how particular aspects of early parent–child interactions may contribute to these variations. In this article, we examine whether differential exposure to “number talk” in the early home environment is an important factor in setting the course for children’s school achievement in mathematics. Although many studies have shown that specific early language and literacy practices predict later language and reading achievement (e.g., Dickinson & Tabors, 2001; Evans, Shaw, & Bell, 2000; Griffin & Morrison, 1997; Hart & Risley, 1995; Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991; Sénéchal & LeFevre, 2002; Snow, Burns, & Griffin, 1998; Whitehurst & Lonigan, 1998), much less is known about the nature and frequency of early mathematical interactions and about the extent to which these interactions predict the development of children’s mathematical knowledge.

In existing studies, information about number-relevant input was obtained from parental interviews and surveys (Blevins-Knabe & Musun-Miller, 1996; Saxe et al., 1987; Starkey et al., 1999). Findings from these studies indicate that the frequency,

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range, and complexity of mathematical activities that parents engage in with their preschool children vary widely and that these variations are associated with the SES background of families (Blevins-Knabe & Musun-Miller, 1996; Saxe et al., 1987; Starkey et al., 1999). In one study, Saxe et al. (1987) found that although the numerical activities engaged in by low- and middle-SES families did not differ in frequency, they did differ in complexity. For example, middle-SES mothers reported more frequently engaging in activities involving the comparison of set sizes and calculation than lower SES mothers, whereas the reverse was true for rote counting, recognizing number symbols, and labeling the numerosity of a single set. Although information from questionnaires and checklists is informative, it is also potentially problematic. First, because these measures rely on memory, parents may underreport certain kinds of number input, notably numerically relevant input that occurs incidentally, such as "Do you want one cookie or two cookies?" Second, parents may overreport certain kinds of input, such as reading number books to their children, because of demand characteristics of the instruments.

Observation of parent-child interactions provides a more direct way to gauge the frequency and nature of number input and avoids memory limitations and biases. Several observational studies have reported the number-related input that parents provide their preschoolers in the context of prescribed numerical activities given in a laboratory setting (e.g., Fluck, 1995; Saxe et al., 1987). For example, Saxe et al. (1987) observed mothers assisting 2- and 4-year-olds on a counting task and on a numerosity-matching task that involved producing a set of pennies that matched the number of Cookie Monster cards on the table. Consistent with their questionnaire findings, Saxe et al. found that the complexity of maternal instruction was highly related to children's knowledge level but that even when children's knowledge level was controlled, middle-class mothers set more challenging goals for their children than working-class mothers. In another study, researchers described the number words that mothers provided to their children (9–36 months old) while sitting in a laboratory room with minimal materials (Durkin, Shire, Riem, Rowther, & Rutter, 1986). Findings showed that the frequency of mothers' number words increased when children were between the ages of 9 months and 27 months and then leveled off. Number words were largely confined to the first four numbers, with some increase in number magnitude with the child's age.

Durkin et al. (1986) suggested that parent number word usages may be confusing to children. For example, numbers were frequently uttered in the context of routines such as "one, two, three, go" or "one, two, three, tickly," which contrasts with "one, two, three, four." Further, mothers sometimes asked children to repeat the number that the mothers had said, resulting in the following jointly constructed number string: "one, one, two, two, three, three." At other times, mothers asked children to alternate with them in producing the next number word, resulting in the jointly constructed number string "one, two, three," and so on. On the other hand, Bloom and Wynn (1997) suggested that linguistic regularities in parental number input, such as the use of number words to exclusively modify count nouns (as opposed to mass nouns), could help children infer that number words apply to countable sets and are distinct from other quantifiers. In any case, noise in the input and the documented difficulty children have in learning the cardinal meanings of the number words (e.g., Wynn,

1990, 1992) make it likely that children who receive higher amounts of exposure to number talk may be better able to figure out these meanings.

We carried out an exploratory study to examine the frequency of number talk parents and children engage in at home and the relation of this talk to the children's later number knowledge. First, we report on the findings of a longitudinal study in which parent and child number talk during naturalistic interactions at home was examined, beginning when the children were 14 months old and continuing every 4 months until the children were 30 months old. Second, we examine the relation of this number talk to the development of a central number concept—understanding the cardinal meanings of the number words. Cardinal numbers are used to quantify sets, for example, "two jumps," "three babies," "four ice cream cones" (e.g., Gelman & Gallistel, 1978; Piaget 1941/1965; Sophian, 1996). Although children typically can recite the count list in a rote manner and begin to use number words to refer to the cardinal values of sets as early as 2 years of age (e.g., Fuson, 1988; Wynn, 1990), these instances typically occur in familiar, frequently repeated routines, for example, Spencer's "Two shoes. One. Two." (Mix, 2009; Mix, Sandhofer, & Baroody, 2005). However, understanding that the purpose of counting is enumeration and achievement of a more decontextualized understanding of cardinal number—one that extends to any set in the child's count list—is a protracted developmental process (Wynn, 1990, 1992). Thus, on the give-a-number task, which involves producing sets containing a specified number of elements, children typically show that they understand the meaning of "one" sometime between the ages of 2 and 3 years and, over the next year, gradually learn the meanings of "two," "three," and "four," at which point they generalize their understanding of cardinal meanings to all the numbers in their count list and become "cardinal principle knowers" (Le Corre, Van de Walle, Brannon, & Carey, 2006; Wynn, 1990, 1992).

We focused on children's understanding of the cardinal meanings of the number words because this understanding reflects a deep and important mathematical insight that lies at the core of the ability to exactly quantify sets with more than three items, to compare the numerosity of different sets in an efficient manner, and to perform calculations to obtain an exact answer (e.g., Huttenlocher, Jordan, & Levine, 1994; Mix, Huttenlocher, & Levine, 2002; National Research Council, 2009; Sarnecka & Carey, 2008; Spelke, 2003; Spelke & Tsivkin, 2001). Further, findings from several studies have indicated that once children understand the cardinal meanings of the number words, they recognize equivalence relations not only across highly similar sets but also across dissimilar sets such as visual dots and auditory claps (Mix, 2008; Mix, Huttenlocher, & Levine, 1996, 2002).

Carey and colleagues have argued that acquiring the cardinal principle allows children to construct a representation of the natural numbers, that is, to understand that each successive number in their count string maps onto a set with one more element than the preceding number (Carey, 2004; Le Corre & Carey, 2007; Le Corre et al., 2006). The more advanced knowledge of cardinal principle knowers is reflected in their counting behavior. For example, such children usually count to produce a set size larger than three and if their count yields the wrong number, they correctly adjust the set. In contrast, children who have not reached this milestone do not typically count to produce sets of objects, and

if they do, they fail to adjust the set size when their count indicates an error (e.g., Le Corre et al., 2006; Wynn, 1990, 1992). In addition, only cardinal principle knowers understand that adding one item to a set changes its numerosity by exactly one number in the count list (Sarnecka & Carey, 2008).

Several different measures have been used to assess this knowledge. These include the point-to- x task (Wynn, 1992), the what's-on-this-card task (Gelman, 1993), and the give-a-number task (Wynn, 1990, 1992). Children's performance on these different measures is highly correlated (Le Corre et al., 2006; Wynn, 1992). In the current study, we used the point-to- x task to examine children's understanding of the cardinal meanings of the number words. Prior findings indicate that there is considerable individual variation in the age at which children understand these cardinal meanings. For example, by age 4, some children understand the cardinal meanings of the number words up through four and beyond, whereas others have not even mapped the words "one" and "two" (Ehrlich, 2007; Ehrlich & Levine, 2007; Klibanoff et al., 2006).

A notable omission from the literature on the acquisition of cardinal number knowledge is an exploration of the kinds of environmental supports that impact the acquisition of this important aspect of mathematical understanding. Exposure to talk involving number words is implicated by findings that show that knowledge of the exact cardinal value of sets is not universal and seems to depend on the existence of an elaborated counting system in the culture (e.g., Gordon, 2004; Pica, Lemer, Izard, & Dehaene, 2004). In the present study, we examined children's exposure to number talk *within* a culture in order to determine whether variation in the amount of number talk is related to children's development of cardinal number knowledge.

We purposely chose to focus on early parent input (when the child was between 14 and 30 months old), prior to the time when most children have mapped any but perhaps the smallest numbers onto the cardinal value of sets, because we wanted to obtain a measure of parent input that was less influenced by the child's prior knowledge than later parent input would be. In other words, our particular interest was whether the number talk that parents engage in prior to the child's acquiring cardinal number knowledge influences the acquisition of that knowledge at a later time point. We assessed child understanding at 46 months because this is an age at which some but not all children have become cardinal principle knowers. Testing 3-, 4-, and 5-year-olds, Le Corre and Carey (2007) found that the age ranges of children who were "one-knowers" through children who were "cardinal-principle-knowers" all included 46-month-olds. Thus, there should be ample variation in child cardinal number knowledge at the 46-month time point to allow detection of a relation between early parent number talk and later child cardinal number knowledge if such a relation exists.

Because our study took place in the context of a broader investigation of parent input and children's language development, we were able to examine the extent to which parent number talk covaries with child number talk as well as with more general aspects of parent and child talk. It is possible that parent number talk is highly correlated with parents' overall talk, and therefore is not a good specific predictor of children's cardinal number knowledge. Alternatively, parents who provide their children with a lot of linguistic input may not necessarily provide them with a lot of

number input. Further, because our sample was socioeconomically diverse, we were able to examine whether the frequency of parent and child number talk varies with family income and education of the primary caregiver and whether this frequency predicts the child's cardinal number knowledge once these socioeconomic variables are controlled. Finally, as a point of comparison, we also examined the relation of parent and child number talk and other talk to children's later vocabulary comprehension to further study the specificity of number talk as a predictor of cardinal number knowledge versus more general knowledge. Thus, our specific goals were (a) to examine the variability in parent talk about number with children between the ages of 14 and 30 months, (b) to determine whether parent talk about number during the toddler period, when children have little or no knowledge about the cardinal values of numbers, predicts children's performance at 46 months on the point-to- x task, a task that measures the children's knowledge of the cardinal meanings of the number words, and whether this is the case even when the effects of parent other talk, child talk about number, child other talk, and SES are controlled, and (c) to examine similar relations between parent-child talk about number (vs. other talk) and children's later vocabulary skill as measured by the Peabody Picture Vocabulary Test (3rd ed., Dunn & Dunn, 1997).

Method

Participants

Forty-four typically developing children (24 boys, 20 girls) participated in the study. Children were drawn from a larger sample of 63 families in a longitudinal study of language development. Recruitment was accomplished through direct mailings to families in targeted zip codes and an advertisement in a free monthly parenting magazine. Parents who responded participated in a screening questionnaire over the phone during which information was gathered on race, ethnicity, income, education, language(s) spoken in the home, and child gender. Sixty-three English-speaking families were selected to match as closely as possible the 2000 census data on family income and ethnicity in the greater Chicago area (U.S. Census Bureau, 2000). Children were included in the present study if they had data for all five visits made when they were between 14 and 30 months old, if they interacted with the same caregiver during those visits, and if they completed the point-to- x task at 46 months (see task description). From the larger sample of 63 families, 10 were eliminated because the caregiver changed over the course of the study or two caregivers were present at one or more sessions, and two were eliminated because the children did not complete the point-to- x task. Due to the cumulative nature of the predictor variables, seven additional families were eliminated because they missed one or more of the visits when their child was between 14 and 30 months old. The 44 remaining dyads (after we eliminated 19 for various reasons) were still representative of the original sample in terms of income and education. That is, of the 19 we removed, nine had incomes or education levels below the mean of the larger sample, and 10 had incomes or education levels above the mean. We measured SES as the annual family income level and the education level of the primary caregiver who interacted with the child during the visits. In both cases, data were collected categorically from

parents on a questionnaire at or before the first visit. We transformed parental education into a continuous scale using the total number of years of schooling (e.g., high school or GED was scored as 12 years, bachelor's degree as 16 years, and so on). On this scale, parental education ranged from 10 to 18 years ($M = 15.9$, $SD = 2.1$). We transformed income into a continuous scale using the midpoint of each category (e.g., the category \$15,000–\$35,000 was scored as \$25,000). The average family income level ranged from less than \$15,000 per year to over \$100,000 ($M = \$61,818$, $SD = \$31,542$; see Table 1 for frequencies of parental education and family income). Thirty-one of the 44 children included in this study were White, six were African American, three were Hispanic, two were Asian, and two were of mixed race.

Procedure

At the time of recruitment, families were told that they were participating in a study of language development. There was no mention of the particular aspects of language that we were examining and no mention of our interest in parent and child number talk.

Parent–child dyads were visited in the home every 4 months when the child was between 14 and 30 months of age. Appointment times for the visits were arranged at the convenience of the family. At each visit, dyads were videotaped for 90 min engaging in their ordinary activities. Parents were asked to interact with their child as they normally would. Our decision to carry out visits in the home environment was motivated by our goal of obtaining parent–child language samples that were as naturalistic as possible. Toy play, book reading, and meal or snack time were common activities during visits although no direction was given about engaging in any particular activities. After our observations of naturalistic interactions, children were given the point-to- x task at age 46 months and were given a measure of vocabulary comprehension, the Peabody Picture Vocabulary Test (Dunn & Dunn, 1997), at age 54 months.

All speech was transcribed. The unit of transcription was the *utterance*, defined as any sequence of words preceded and followed by a pause, a change in conversational turn, or a change in intonational pattern. All dictionary words, as well as onomatopoeic sounds (e.g., “woof-woof”) and evaluative sounds (e.g., “uh-oh”),

were counted as words. We established transcription reliability by having a second coder transcribe 20% of the videotapes; reliability was assessed at the utterance level and was achieved when coders agreed on 95% of transcription decisions.

Measures of Number and Other Talk

Cumulative number word tokens. Transcripts were searched by computer for uses of the number words one through 10. Each use of a number word was coded as a number word token. Thus, if a child or parent said “two ducks,” this would be coded as one number word token, and if a child or parent said “one, two, three,” this would be coded as three number word tokens. As the word *one* can be used numerically and nonnumerically, all uses of the word *one* were identified and were manually coded by a research assistant as either numerical or nonnumerical. A second researcher coded 20% of the sessions and achieved 99% reliability. Numerical uses of the word *one* included references to number symbols (e.g., “That’s the number one”), counting (e.g., “one, two, three”), cardinal values (e.g., “one of these,” “one truck”), reference to time or age (e.g., “one minute,” “when you turned one”) and uses of *one* with an emphasis of numerosity or individuation (e.g., “you can only have one,” “just one,” “one per day,” “one more,” “one at a time”). Although some uses of *one* were ambiguous with respect to their numerical content, we imposed relatively strict criteria and considered all other uses of *one* to be nonnumerical. These uses included deictics (e.g., “this one,” “that one”), use of *one* as a direct object (e.g., “that’s the pretty one,” “do you want one?”), and some idioms (e.g., “one day,” “one morning,” “one of these days”). All uses of number words (e.g., all number word tokens) over the five sessions were summed to form the measure of cumulative number word tokens for parent and child.

Parent elicitation of child number talk. We also searched transcripts by computer for parent uses of the words *count*, *how many*, and *number* in order to identify their elicitations of counting and calculating, set size responses, and numeral identification. These uses were then manually coded to ensure that they were used in a numerical context. All numerical elicitations were summed over the five sessions to form a measure of cumulative number elicitations for each parent.

Table 1
Frequencies of Income by Education Levels for the 44 Families in the Study

Parent education (years)	Family income (Thousands of \$US)						Total
	7.5	25.0	42.5	62.5	87.5	100.0	
10	1	1	0	0	0	0	2
12	1	0	0	0	1	0	2
14	1	3	2	0	0	1	7
16	1	0	4	6	4	3	18
18	0	2	2	2	3	6	15
Total	4	6	8	8	8	10	44

Note. Income and education were collected categorically and transformed into continuous variables. We transformed parental education into a continuous scale using the total number of years of schooling (e.g., high school or GED was scored as 12 years, bachelor's degree as 16 years, and so on). We transformed income into a continuous scale using the midpoint of each category (e.g., the category \$15,000–\$35,000 was scored as \$25,000).

Cumulative other word tokens. Other talk consisted of the cumulative word tokens produced by the child or parent over the five sessions minus the cumulative number word tokens. We controlled for other talk in our analyses of the relation between cumulative number talk and child cardinal number knowledge.

Measures of Child Number and Other Word Knowledge

Child comprehension of cardinal meaning of number words: Point-to- x task. In the point-to- x task (Wynn, 1992), children were administered 16 items. On each item, the child was presented with an 8.5" \times 11.0" piece of paper that had two vertically arrayed sets of squares, one on the left and one on the right half, with the two halves separated by a vertical line. On each item, children were asked to point to x , where x was a number between 2 and 6. The foil alternatives included arrays consisting of adjacent numbers such as 2 versus 3 (10 items) and also nonadjacent numbers such as 2 versus 4 (six items). The foil choice on the nonadjacent items differed from the target by no more than three and by no more than a 2:1 ratio. Children indicated their response by pointing to the set on the left side or the right side of the page (the location of the target set was counterbalanced across children). The items administered on this test are listed in Table 2. In addition, a sample item is provided in Figure 1.

Vocabulary comprehension: Peabody Picture Vocabulary Test, 3rd edition (PPVT). The PPVT (Dunn & Dunn, 1997) was administered when the children were 54 months old. Their scores on the test served as the outcome measure for later vocabulary skill. In this measure, children are presented with a verbal stimulus (i.e., a word) and are asked to indicate the picture (out of four possible pictures) that best depicts the verbal stimulus. The PPVT was chosen because it is a widely used measure of vocabulary comprehension with published norms and because it is

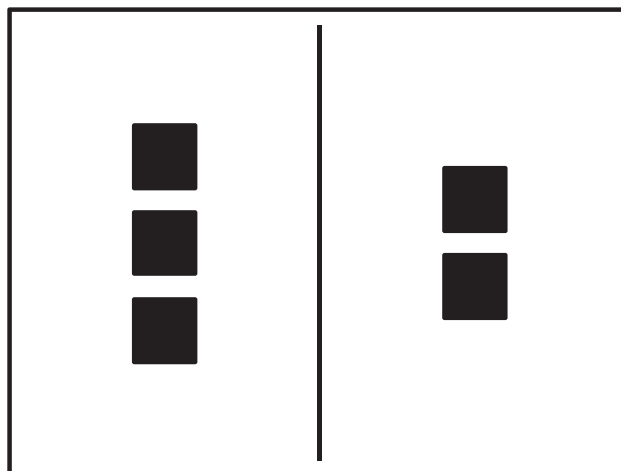


Figure 1. Sample item from the point-to- x task.

similar in administration format to the point-to- x task, the measure of cardinal number knowledge used in this study.

Socioeconomic Status (SES)

As noted earlier, parent education and family income served as measures of SES. Because parent education and family income were moderately related to one another ($r = .48, p < .01$), we combined them into one variable of SES using principal components analysis. The first principle component weighted education and income positively and equally and accounted for 74% of the original variance. The mean score of the composite was 0 ($SD = 1$). Families that scored high on the SES composite had high annual income levels and the primary caregiver had a high level of education.

Results

Variation in Number Talk

Descriptive statistics on amount of parent and child cumulative number talk and other talk during the five home visits (7.5 hr when the child was 14–30 months old) showed marked individual variation. On average, parents produced a total of 90.8 number words during interactions with their children over the five sessions ($SD = 61.3$), with a minimum of four and a maximum of 257. Mean cumulative child number word tokens was 35.3 and also varied widely ($SD = 31.2$), with a minimum of zero and a maximum of 126. Parents averaged 18,118 cumulative other word tokens (all word tokens beside number words; $SD = 8,217$), and children averaged 3,229 cumulative other word tokens ($SD = 1,866$). In addition, during the five home visits, parents produced an average of only 6.3 prompts ($SD = 6.5$; i.e., “how many,” “count,” and “number”) to elicit number talk from their children, with a minimum of zero and a maximum of 30. Because these elicitations were quite rare and were highly collinear with overall parent number talk ($r = .62, p < .001$), they are not considered further in our analyses.

Parent cumulative number word tokens were related to parent cumulative other word tokens ($r = .56, p < .001$). Similarly, child cumulative number word tokens were related to child cumulative

Table 2
Percentage of Children Responding Correctly to Each Item on the Point-to- X Task

Item	Target	Percentage correct
1 vs. 2	1	95
1 vs. 2	2	91
2 vs. 3	2	68
2 vs. 3	3	89
2 vs. 4	2	77
2 vs. 4	4	82
3 vs. 4	3	70
3 vs. 4	4	82
3 vs. 5	3	86
3 vs. 5	5	89
3 vs. 6	3	70
3 vs. 6	6	82
4 vs. 5	4	66
4 vs. 5	5	84
5 vs. 6	5	45
5 vs. 6	6	75
Total		78

Note. $N = 44$. Items were presented in a single random order, and the location of the target numerosity (left vs. right) was counterbalanced across children.

other word tokens ($r = .55, p < .001$). That is, parents and children who talked more overall also talked more about number. Not surprisingly, parent and child cumulative number word tokens produced over this period were positively related ($r = .35, p = .05$), as dyads often engaged in joint conversations about number. Parent cumulative number word tokens¹ were positively related to the SES composite ($r = .30, p < .05$), yet child cumulative number word tokens were not significantly related to the SES composite ($r = .05, ns$).

Nature of Parent and Child Number Talk

All uses of number words from one to 10 (number word tokens) were coded according to context at the 30-month session for both parents and children (i.e. counting, cardinal values of sets, numeral naming, and so on). The two most common types of parent input were cardinal values (50% of the number token input) and counting (32% of the input). The rest of the input (18%) consisted of interactions involving naming digits, using numbers with a unit of measure, using conventional nominatives, and making number comparisons (see Table 3 for examples and proportions of each type of utterance). There was much variability in the input that parents provided (mean cardinal value inputs = 9.35, $SD = 10.56$; mean counting inputs = 9.16, $SD = 14.60$).

Although children's number words also consisted predominantly of counting (61% of number tokens) and reference to the cardinal values of sets (28% of number tokens), children, unlike their parents, counted much more than they talked about the cardinal values of sets. Other uses of number were much less frequent (11% of number tokens; see Table 3 for examples and proportions). Like their parents, children showed marked variability in their use of number words (mean cardinal value production = 2.51, $SD = 3.56$; mean counting production = 9.85, $SD = 11.36$).

For both parents and children, we expected an increase in the use of number words over the 14- to 30-month age period, as children typically begin to talk about number and to learn the meanings of the first number words during this period (e.g., Fuson, 1988; Wynn, 1990, 1992). Figure 2 shows the average use of number words over time for parents and children. Contrast analyses were conducted and supported our hypothesis that there was a steady increase in number word use across the 14- to 30-month age period for both parents and children, $t(43) = 2.67, p < .05$, and $t(43) = 6.80, p < .001$, respectively (Furr, 2008; Rosenthal, Rosnow, & Rubin, 2000). Overall, parents produced an average of 12.5 number words when their child was 14 months old compared with 23.1 number words when their child was 30 months old. Overall, children produced an average of one number word at 18 months compared with 14.3 at 30 months. Only one child said a single number word, "two," at 14 months, and it was not until age 22 months that the majority of the children (61%) produced at least one number word (see Figure 3). At all five sessions during the 14- to 30-month age period, parents and children produced more low than high numbers. For example, cumulatively across the five sessions, parents produced the words "one" and "two" an average of 31 and 26 times each, "three" an average of 12 times, and "five" an average of 5.7 times compared with "nine" and "10," which were produced an average of 1.1 and 1.6 times, respectively. Cumulatively, children who produced number words (43 of 44 children) produced "one," "two," "three," and "five" an average of 7.2, 9.8, 5.1, and 2.3 times, respectively, compared with "nine" and "10," which were produced an average of 1.5 and 1.3 times, respectively (see Figure 4).

Point-to-X Task Performance

Children's knowledge of the cardinal meanings of the number words, as indexed by performance on the point-to- x task at age 46 months, varied considerably, with an average score of 12.52 (range, 6.0–16.0; $SD = 2.95$). Table 2 shows the percentage of children who answered correctly on each item administered. Children showed a higher number bias—that is, performance level was greater when the target was the higher number of the pair, $t(43) = 3.08, p < .01$ —as would be expected on the basis of reports that children in this age range generally have a "more" bias on choice tasks (e.g., Carey, 1978).

As would be expected from prior research showing that children map the number words onto their cardinal values in order, one by one, children's performance level decreased as the numerosity of the items in the pair increased. (e.g., Condry & Spelke, 2008; Le Corre & Carey, 2007; Wynn, 1990). In particular, children performed better on items involving smaller rather than larger numbers. This trend can be seen most easily in their performance on the 10 items (out of 16) that involved a target and distractor that were one digit apart (e.g., 1 vs. 2, 2 vs. 3, 3 vs. 4, 4 vs. 5, and 5 vs. 6, each with the lower and higher number as targets on different items). For example, averaging across the two items with the same number pair, we found that the average percentage correct for 1 versus 2 was 93%, compared with 76% for 3 versus 4, and 60% for 5 versus 6. The correlation between item numerosity and percentage correct was significant ($r = -0.94, p < .05$). Considering all 16 items on the test, we found that children performed better when at least one of two choice sets was a small number (1 to 3) than when both choice sets were greater than or equal to 4. Specifically, when the lower number in a pair was less than or equal to 3 (which was the case for 12 items), children answered correctly 82% of the time ($SD = 19.0$). In contrast, when the lower number in a pair was greater than 3 (which was the case for four or more items), children answered correctly only 68% of the time ($SD = 26.7$). This difference in performance levels on the lower and higher numerosity items was highly significant, $t(43) = 3.93, p < .001$ (see Table 2 for the percentage of children who answered each item correctly).

Relation Between Number Talk and Point-to-X Performance

We next examined the main question of interest, whether children's performance on the point-to- x task at 46 months of age was significantly related to parent number talk at child ages 14–30 months. In fact, this was the case. Children's point-to- x task performance was positively related to parent cumulative number talk² ($r = .47, p < .01$). This relationship is displayed in Figure 5.

¹ We used the natural log of parent cumulative number word tokens here to ensure a linear relation with SES. In its raw form the relation was curvilinear.

² We used the natural log of parent cumulative number word tokens to ensure a linear relationship with point-to- x performance at 46 months. Child cumulative number word tokens was logged as well (after adding 1), as it also showed a learning curve shape relation with point-to- x performance. None of the other variables (family income, education, parent other talk, child other talk) were transformed because they showed linear relations with point-to- x performance in their original form.

Table 3
Type of Number Talk and Proportions of Total Number Talk With 30-Month-Old Children

Type of number talk	Parent example	Child example	Parent % of number talk		Child % of number talk	
			<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Cardinal values	“Five little monkeys wake up with the sun.” [Reading a book]	“Eight arms.” [Referring to a picture of an octopus]	50.0	29.3	27.5	32.0
Counting	“Let’s count the balloons. Ready? One, two, three, four, five.”	“Mommy hiding. Two. Three. Four. Five. Six. Seven. Eight. Nine.” [Playing hide and seek]	31.7	30.6	61.5	36.9
Naming digits	“There’s a five.” [Playing with a toy with the number symbol 5 on it]	“A four. A ‘Y.’” [Playing with an alphabet/number toy]	7.9	16.7	4.3	16.7
Units of measure	“You were about, uh, I think you were 5 months old here.” [Looking at pictures]	“I pick up [for] one second.” [Cleaning up toys]	6.0	11.6	2.3	9.3
Conventional nominatives	“Oh, give me a high five.”	“Five-oh-five?” [Referring to an account number]	1.0	3.4	0.4	2.2
Number comparisons	“Three is after four.”	“One!” [Response to “What is after one?”]	0.3	1.3	0.1	0.8
Other	“I’ll start it from disc two.”	“Two.” [Response to “What color is that?”]	3.2	7.7	4.0	10.3

Note. Parents, *N* = 44; children, *N* = 41.

Children’s point-to-*x* performance also was positively related to parent cumulative other talk ($r = .39, p < .01$) and child cumulative number talk ($r = .34, p < .05$) but not to child cumulative other talk. Further, point-to-*x* performance was related to the SES composite ($r = .50, p < .001$).

We conducted multiple regression analyses to examine the relation between parent cumulative number talk and child point-to-*x* performance, controlling for SES and other talk measures. The results of these models are displayed in Table 4. Our approach to model fitting was as follows. We started by fitting a model showing just the relation between SES and point-to-*x* performance. This model (Model 1) thus served as a baseline for comparison to other models containing talk predictors. In the next model (Model 2), we addressed our primary question of the role of parent number talk in child cardinal number knowledge by including the effect of parent cumulative number talk, controlling for SES. In Model 3, we added the additional control of parent other talk, and then in the

final two models (4 and 5), we addressed the role of child number talk and child other talk. This analytic approach allowed us to build our models on the basis of our theoretical questions and to look at the effect of our variable of interest (number talk), controlling for SES and other talk. We explain the results of these models in more detail in the following paragraphs.

Model 1 in Table 4 shows that the SES composite is a significant predictor of children’s point-to-*x* performance, explaining 24.8% of the variation in children’s scores. Model 2 shows that after SES is controlled, parent cumulative number word tokens is a significant positive predictor of children’s point-to-*x* performance. In comparing Model 2 to Model 1, we found that when parent cumulative number word tokens is included in the model with SES, the effect of SES reduces by 22% (the parameter estimate reduces from 0.50 to 0.39) but is still significant. Taken together, SES and parent cumulative number word tokens combine to explain 36.2% of the variance in child point-to-*x* performance.³

In Model 3 (Table 4), we added in parent other word tokens and found that the relation between parent cumulative number word tokens and child point-to-*x* performance holds even when controlling for parent cumulative other word tokens in addition to SES. Thus, with SES controlled, parents who talked more about number over the early childhood period, not necessarily parents who talked more in general, had children with more knowledge of the cardinal meaning of the number words at age 46 months.

Further, Model 4 (Table 4) shows that child cumulative number word tokens relate to their point-to-*x* performance at the $p < .10$ level, which explains an additional 4.5% of the variance in point-to-*x* performance after SES and parent cumulative number tokens are controlled. Finally, in Model 5, we found that controlling for

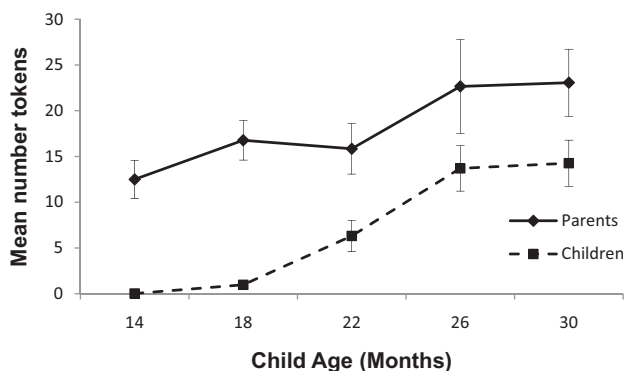


Figure 2. Change over time in use of number words for parents and children.

³ Residuals from all regression models were examined and did not violate model assumptions.

SES and parent and child cumulative number word tokens, child other word tokens is not related to point-to-*x* performance.

In sum, we found that with SES controlled, parental cumulative talk to children about number during the early childhood years positively related to children’s later cardinal number knowledge, over and above parental talk in general.⁴ Further, children’s own cumulative experience talking about number also contributed to their later cardinal number knowledge, yet children’s talkativeness in general did not. Thus, with SES controlled, talk about number in particular during early childhood predicted later cardinal number knowledge.

Relation Between Parent Talk and PPVT

The average normed PPVT score for our sample at 54 months⁵ was 111.4 (*SD* = 17.8), which is about two thirds of a standard deviation above the standardized mean score of 100. There was a significant positive relationship between children’s scores on the cardinal number knowledge task at 46 months and on the vocabulary comprehension task (PPVT) at 54 months (*r* = .65, *p* < .001). We examined relations between parent and child cumulative number tokens and other tokens and children’s later vocabulary skill to test the specificity of our input predictors. That is, one might expect children’s early experience with number talk to relate to cardinal number knowledge skill, not overall vocabulary. Similarly, we know from previous work that overall experience with verbal input relates to vocabulary, yet experience with number input might not. Not surprisingly, SES also relates to children’s PPVT scores (*r* = .58, *p* < .001); thus, we used partial correlations to examine relations between early number and other talk and later PPVT scores, controlling for the SES composite. We find it interesting that children’s normed scores on the PPVT at 54 months were marginally positively related to parent cumulative other input (*r* = .27, *p* = .08) and child cumulative other talk (*r* = .25, *p* = .10), yet were not related to parent cumulative number input nor to child cumulative number talk⁶, when SES was controlled. Thus, number input does not predict both comprehension of the cardinal meanings of the number words and general vocabulary knowledge. Instead, parent number input specifically predicts children’s cardinal number knowledge, whereas parents’ overall talkativeness predicts children’s word comprehension as assessed by the PPVT.

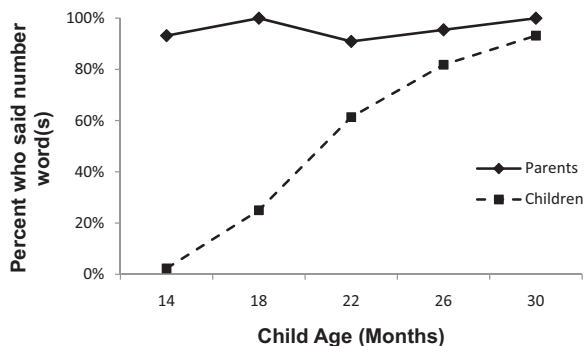


Figure 3. Percentage of parents and children producing number words at each session.

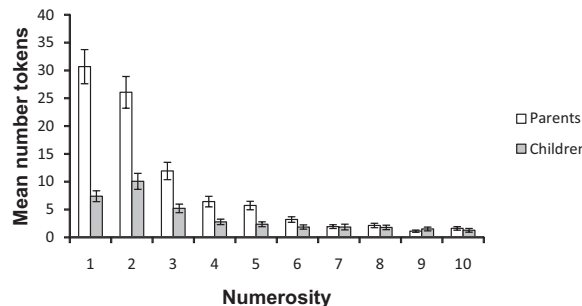


Figure 4. Cumulative production of each numerosity for parents and children.

Discussion

Our findings show some commonalities in the number talk of parent–child dyads during everyday interactions during the 14- to 30-month age period. First, low numbers predominated in both children’s and parents’ number talk at all time points. Second, when the children were 30 months old, the time point at which we carried out detailed qualitative coding, the majority of children’s and parents’ number talk concerned counting and labeling cardinal values of sets. However, whereas the most common type of parent number talk was labeling set size followed by counting, the opposite was true of children. Thus, children’s number word utterances did not directly mirror those of their parents. The preponderance of child counting at 30 months is consistent with findings showing that children learn to recite the count string before they understand the cardinal meanings of the number words (e.g., Fuson, 1988; Wynn, 1990, 1992).

Against this backdrop of commonality in the nature of number talk, there was marked variability in the frequency of parent and child number talk during everyday interactions when the children were between 14 and 30 months old. Some parents produced as few as four number words in more than 7.5 hr of interaction, whereas others produced as many as 257. This variation would amount to a range of approximately 28 to 1,799 number word tokens over a week. Thus, it is not surprising that variation in parents’ number talk to their toddlers related strongly to children’s cardinal number knowledge at 46 months, even when SES was controlled. Further, despite a moderate correlation between parent cumulative other word tokens and child cardinal number knowledge, when parents’ talk about number and parents’ cumulative other word tokens were pitted against each other, only number talk remained a significant predictor of later cardinal number knowledge. Finally, the relation between parent number talk and child cardinal number knowledge remained robust even when child

⁴ We had verbal and spatial IQ data (based on the vocabulary and block design subscales of the Wechsler Adult Intelligence Scale; Wechsler, 1997) from a subset of the parents (*n* = 37). We performed the same analyses for this subset, and the regression findings held even when parent verbal IQ and spatial IQ (which were not significant predictors) were controlled.

⁵ Raw forms of all parent and child talk measures showed linear relations with PPVT and were not transformed for correlational analyses.

⁶ One child did not complete the PPVT; thus, the sample size for this analysis was 43.

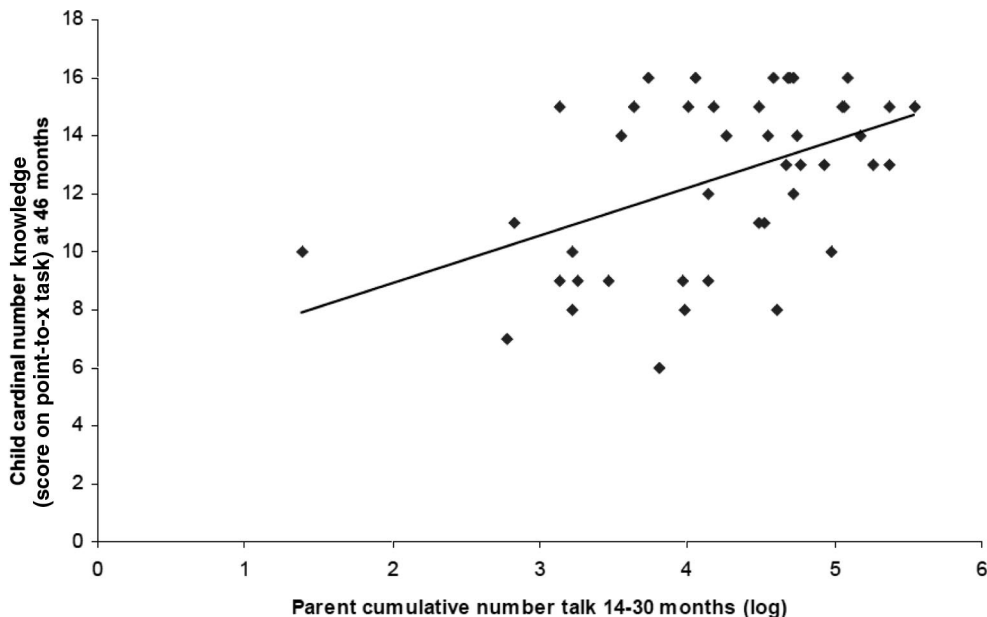


Figure 5. Scatterplot displaying the relation between parent cumulative number word tokens (log) when child age was between 14 and 30 months and child cardinal number knowledge at 46 months ($n = 44$).

number talk, in addition to SES, was controlled. Thus, the relation of parent number talk and child cardinal number knowledge held regardless of the child’s own use of number words.

This finding shows that parent number talk is not merely related to greater amounts of number talk by children. Rather, it is related to children’s greater understanding of the cardinal values of the number words as assessed on the point-to-x task.

Why does early parent number talk show such a strong relation to children’s later understanding of the cardinal values of the number words? Clearly, linguistic input is crucial for a child to learn words. Moreover, a large body of research indicates that verbal labels promote category formation by orienting attention to a labeled dimension

and by inviting comparisons between labeled entities (e.g., Loewenstein & Gentner, 2005; Lupyán, Rakison, & McClelland, 2007; Mix, 2008; Waxman & Markow, 1995; Yoshida & Smith, 2005). Thus, the role of number words in promoting children’s understanding of cardinal number may be similar to the role of labels for other categories (e.g., Mix et al., 2005). However, language may be particularly important in children’s learning of the cardinal meanings of number words as this mapping poses several unique challenges, discussed by Mix and colleagues (Mix, 2008; Mix et al., 2005). First, unlike other early categories, cardinal number does not refer to an object or a characteristic of an object but rather to a property of sets, and sets may be more difficult for parents to

Table 4
Multiple Regression Models Predicting Child Cardinal Number Knowledge at Age 46 Months

Variable	Parameter estimate (standardized)				
	Model 1	Model 2	Model 3	Model 4	Model 5
SES	0.50***	0.39**	0.39**	0.39**	0.40**
Parent					
Number word tokens ^a		0.35**	0.34*	0.28*	0.29*
Other word tokens			0.03		
Child					
Number word tokens ^a				0.23 [†]	0.29 [†]
Other word tokens					-0.11
R ² statistic (%)	24.8	36.2	36.2	40.8	41.5
F statistic	13.8**	11.6***	7.6***	9.2***	6.9***
Degrees of freedom for F statistic	1, 42	2, 41	3, 40	3, 40	4, 39

Note. $N = 44$. Models were based on parent and child cumulative number talk and other talk when child age was between 14 and 30 months, with effects of socioeconomic status (SES) controlled.

^a The natural log of parent and child number word tokens was used in these analyses to ensure linear relations with cardinal number knowledge. The SES composite and parent and child other word tokens did not require transformation.

[†] $p < .10$. * $p < .05$. ** $p < .01$. *** $p < .001$.

point out and for children to conceptualize than objects. Second, number words select sets that vary widely, only sharing numerosity (e.g., two claps, two dogs, two cookies). Thus, it may be difficult for children to grasp the meaning of “two” as there is only one possible dimension, “twoness,” rather than multiple dimensions, on which to align to extract commonalities (e.g., this contrasts with categories that share many features, such as “cat”; e.g., Gentner & Ratterman, 1991; Kotovsky & Gentner, 1996). If children focus on the wrong dimension (e.g., the shape of the objects in the set or length of the entire set), they may fail to abstract the numerical commonality of dissimilar sets. Finally, number words are special in that they are used not only in a cardinal sense to label set size but also as part of a count string, as labels for number symbols, and as labels for ordinal position (e.g., Gelman & Gallistel, 1978; Hughes, 1986; Mix, 2008). Thus, for number words, frequent exposure may be especially important in helping children coordinate these various uses and to understand the cardinal meaning of these words.

A final point concerns the correlational nature of our study. Because of this, it is possible that parent number talk is not causally related to children’s number knowledge. That is, parents who talk more about number may have children who are more interested in this topic or who are better at understanding number words and concepts. A follow-up study in which young children are randomly assigned to receive different amounts (as well as types) of number talk could shed light on the question of whether parent number talk is causally related to children’s mathematical development. Further, in such a study, researchers could investigate whether certain kinds of number talk are most effective in promoting children’s mathematical development. Another direction for future research would be investigation into why parents vary in their use of number talk with their young children. For example, some parents may be uncertain how to foster their children’s numerical development or may view numerical development as the responsibility of the school and not the home (e.g., Cannon & Ginsburg, 2008; Evans, Fox, Cremaso, & McKinnon, 2004). In the meantime, the finding of a strong relation between parents’ early number talk and children’s later understanding of the cardinal meaning of number words opens up the possibility that children’s developmental trajectories can be positively impacted by this simple but important kind of input.

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