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Causal Effects of Parent Number Talk on Preschoolers' Number Knowledge

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Individual differences in children's number knowledge arise early and are associated with variation in parents' number talk. However, there exists little experimental evidence of a causal link between parent number talk and children's number knowledge. Parent number talk was manipulated by creating picture books which parents were asked to read with their children every day for 4 weeks. $N = 100$ two- to four-year olds and their parents were randomly assigned to read either Small Number (1–3), Large Number (4–6), or Control (non-numerical) books. Small Number books were particularly effective in promoting number knowledge relative to the Control books. However, children who began the study further along in their number development also benefited from reading the Large Number Books with their parents.

A basic comprehension of numbers is crucial for achieving success in school, the workplace, and daily life. The number knowledge children have acquired by the time they enter kindergarten predicts future academic success (Duncan et al., 2007) and other important life outcomes (Murnane, Willett, & Levy, 1995; Reyna, Nelson, Han, & Dieckmann, 2009; Rivera-Batiz, 1992). Unfortunately, even at this early age, there is substantial variation in children's understanding of number and early math concepts (Dowker, 2008; Entwisle & Alexander, 1990; Ginsburg & Russell, 1981; Klibanoff, Levine, Huttenlocher, Vasilyeva, & Hedges, 2006; Starkey, Klein, & Wakeley, 2004; West, Denton, & Germino-Hausken, 2000).

A leading candidate for the source of variation in children's preschool numerical competence is the number input they receive from their parents. Indeed, previous research has linked variation in math and number-related language input from parents to differences in children's early number knowledge (Blevins-Knabe & Musun-Miller, 1996; Gunderson & Levine, 2011; LeFevre et al., 2009; Levine, Suriyakham, Rowe, Huttenlocher, & Gunderson, 2010) and later math achievement (Casey et al., 2016; Ginsburg & Baroody, 1990; Susperreguy & Davis-Kean, 2016). These studies raise the possibility that intervening on parent number talk could provide an avenue to improving children's number knowledge and to ameliorating disparities in early numerical competence.

Although there is a clear link between parent number talk and children's subsequent number knowledge, there is a relative lack of evidence showing that parent number talk is causally related to children's growth in number knowledge. Correlational findings, although informative and indicative of a possible causal role of parent number talk, are nonetheless consistent with many alternative explanations. For instance, children with greater number knowledge or interest in numbers may elicit more number input from their parents. In support of this, there is evidence that parents adjust the input they provide their children based on their child's current knowledge or skill level when

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solving simple math problems (Bjorklund, Hubertz, & Reubens, 2004) or problem solving more generally (Wood & Middleton, 1975).

Alternatively, the connection between parent number talk and child numerical competence could be explained by a third factor, such as a genetic predisposition to be numerically competent that is shared by parents and children and incidentally relates to parent number talk as well. For example, children's unlearned, nonverbal "number sense," which is related to their math achievement (e.g., Libertus, Feigenson, & Halberda, 2013; Starr, Libertus, & Brannon, 2013; vanMarle, Chu, Li, & Geary, 2014), is significantly correlated with the acuity of parents' number sense, suggesting numerical competence could be inherited (Braham & Libertus, 2017; Tosto et al., 2014). Furthermore, the acuity of parents' number sense is related to their use of larger (above 10) number words with their children (Elliott, Braham, & Libertus, 2017). Therefore, further research is needed to determine whether parent number input is causally related to children's numerical competence.

Determining causality becomes even more essential when considering how correlational studies have shown that different types of number talk differentially relate to children's number knowledge, and that these relations may change depending on the child's age and number knowledge (Gunderson & Levine, 2011). For instance, Levine et al. (2010) began recording parents' number talk when children were only 14-month old. Even if number talk does causally impact children's number knowledge, it is possible that number talk at this early age is merely an indicator of how much parents will talk about number when their children are older and in a better position to learn about numbers. Combining existing correlational evidence with experimental research can help clarify these important distinctions, which are necessary for understanding and intervening on the mechanisms that drive number learning.

Therefore, the present study aimed to provide a strong test of the relation between parent number talk and child number knowledge by randomly assigning parents and their children to number and non-number-related intervention conditions. Namely, our primary goal was to establish whether or not experimentally increasing parent number talk causes gains in children's number knowledge. By measuring children's number knowledge before and after the intervention period, we were not only able to measure the impact of number input on children in general but also to provide insight into the relative effectiveness of different types of parent number input for children at different stages of number development.

Development of Number Word Knowledge

Children learn the meanings of number words through a series of prolonged stages (e.g., Sarnecka & Carey, 2008; Sarnecka & Lee, 2009; Wynn, 1990, 1992). Around the age of 2 years, children begin to recite a portion of the count list (e.g., the number words "one" through "ten") but do not initially know what these words mean (e.g., Wynn, 1990). Next, children learn the actual meanings of the first few number words—"one," "two," "three," and sometimes "four"—through a series of lengthy stages (e.g., Sarnecka & Lee, 2009; Wynn, 1990, 1992). Children proceed through these stages sequentially, first learning the meaning of "one" and then spending several months as "one-knowers" before learning the meaning of two (thus, becoming "two-knowers"). Likewise, children typically spend several more months as two-knowers before learning the meaning of three. Finally, after becoming three- and sometimes four-knowers, children learn the cardinal principle that the last number reached when counting a set represents the cardinal value of that set. This typically occurs around the age of 4, roughly 2 years after first learning to recite the count list (Le Corre & Carey, 2007; Sarnecka & Lee, 2009; Wynn, 1990, 1992). Learning the cardinal principle is an important milestone in early numeracy, and children who acquire this concept at younger ages (e.g., before or during the first year of preschool) have greater overall math skill in first grade than those who learn the cardinal principle at later ages (Geary et al., 2018).

These stages of number knowledge indicate several important characteristics of how children acquire the meanings of number words. First, number words must be learned. Although infants less than a year old demonstrate some basic numerical competencies on nonverbal number tasks (see Feigenson, Dehaene & Spelke, 2004 for a review), children must slowly learn to map specific, exact quantities to the specific number words used in their native language. By definition, this is a process that involves number language and given the age that children learn the meanings of number words, parents are in a unique position to provide that number language to their children. Accordingly, much of early math learning likely begins in informal settings with knowledgeable adults (Gauvain, 2001; Vygotsky, 1962). However, this does not necessary mean that the driving force behind variation in children's number knowledge is variation in parents' number input to their children, and as described above, correlational studies fall short of establishing the causal direction between parent input and children's knowledge.

A second characteristic of number development revealed by the existence of knower-levels is that children typically acquire the meanings of number words in a common order (the same order as the count list). This suggests that children's acquisition of each number word may depend in part on their acquisition of the preceding number word and possibly even a partial understanding of the following number word (Barner & Bachrach, 2010; Gunderson, Spaepen, & Levine, 2015). One-knowers often go through a period during which they understand that "two" refers to two items but also use "two" to label sets greater than two (Barner & Bachrach, 2010). As children begin to learn about "three" they learn that "two" has an upper bound of three and therefore begin to limit their use of "two" to label two items. Accordingly, children's number word learning appears to benefit when numbers are contrasted with nearby numbers (Gibson, Berkowitz, & Levine, 2017; Huang, Spelke, & Snedeker, 2010).

Finally, the knower-levels suggest that learning the meanings of small number words like "two" and "three" may be fundamentally different than learning the meanings of large number words like "five" and "six." Learning the meanings of "two" and "three" occurs individually, and acquisition of each number word is typically separated by several months. In contrast, the meanings of larger number words, such as "five" and "six," are typically acquired simultaneously as part of a broader understanding of the cardinal principle (e.g., Carey, 2009; Sarnecka & Lee, 2009; Wynn, 1990, 1992). Accordingly, children may benefit from different types of number input at these various stages of number development. Despite the robust finding that children learn the meanings of number words through a series of knower-levels, it is not currently known whether children at different knower-levels benefit differentially from different kinds of input that are closely tuned to these levels.

Variation in Number Input

Many parents engage in number talk and number activities with their children (Blevins-Knabe & Musun-Miller, 1996; Durkin, Shire, Riem, Crowther, & Rutter, 1986). However, both self-report and observational measures have revealed that parents differ significantly in both the quantity and types of number input, both talk and activities, that they engage in with their children (Blevins-Knabe & Musun-Miller, 1996; Chang, Sandhofer, & Brown, 2011; Elliott et al., 2017; Gunderson & Levine, 2011; Levine et al., 2010; Saxe, Guberman, & Gearhart, 1987; Starkey et al., 1999; Vandermaas-Peeler, Nelson, Bumpass, & Sassine, 2009). Importantly, the variation in parent number talk is related to children's early number knowledge and math proficiency. Parents' self-reported frequency of using the words "one," "two," and "three" and mentioning simple number facts are correlated with kindergarten children's scores on the Test of Early Mathematics Ability-Second Edition (Blevins-Knabe & Musun-Miller, 1996). Likewise, how often parents report engaging their children in both formal and informal number-related activities (e.g., practicing arithmetic, board or card games, shopping, cooking) is related to children's early math competence (LeFevre et al., 2009; Ramani, Rowe, Eason, & Leech, 2015; Skwarchuk, Sowinski, & LeFevre, 2014). Going beyond self-report measures, Levine et al. (2010) videotaped the natural interactions of 44 parent–child dyads during five visits between the child ages of 14 and 30 months. They found that parents ranged from using a low of 4 to a high of 257 number words over the course of the five sessions (approximately 7.5 hr total). This variation in number talk predicted both children's own number talk and their number word comprehension at 46-month old, even controlling for overall talk and socioeconomic status.

In addition to quantity, a follow-up study revealed substantial variation in the quality of parent number talk and showed that it also predicts differences in children's number comprehension at 46 months. Specifically, Gunderson and Levine (2011) found that parent talk referencing "large" sets of visible objects (four to ten; e.g., "four sticks") was particularly predictive of children's number knowledge at 46 months. Parents' talk about large sets of present objects predicted children's future knowledge of both small (1–3) and large (4–10) numbers, whereas talk about small numbers only predicted children's knowledge of small numbers. Gunderson and Levine (2011) concluded that these results were consistent with the possibility that large number talk is important for children's learning of the cardinal principle. By this account, acquiring the cardinal principle may not only enables children to succeed at demonstrating knowledge of larger numbers (4–10) but also improves children's performance on test items involving smaller numbers (e.g., Negen & Sarnecka, 2009). In contrast, parents' small number talk only predicted children's performance on test items involving small numbers, suggesting small number talk alone may be insufficient for acquiring the cardinal principle. This account is consistent with the possibility that children might benefit from number input that is targeted to their knower-level, or in other words, number input that is within their zone of proximal development (Vygotsky, 1962).

Previous intervention studies have found a link between other characteristics of laboratory-administered number input and children's subsequent number knowledge. For instance, Mix, Sandhofer, Moore, and Russell (2012) used picture books with varying scripts to test whether the most effective type of experimenter-administered number talk involved counting, cardinal labeling, alternating cardinal labeling and counting, or a combination in which the same sets were counted and labeled. They found that the only condition that resulted in noticeable gains in number knowledge was the combination of counting and labeling the cardinality of a set. However, this improvement was limited to higher numbers (6 and 10), suggesting that the intervention had successfully taught some children the cardinal principle or increased the performance of children who were already cardinal principle-knowers but failed to improve the number knowledge of children at lower knower-levels. Moreover, when parents were asked to read the books to their children (without the scripts), they very rarely combined counting and cardinal labeling.

Other lab-based number interventions have similarly succeeded in improving only a subset of children's number knowledge (e.g., Gibson, Gunderson, Spaepen, Levine, & Goldin-Meadow, 2019) or in teaching children partial meanings for new number words (Huang et al., 2010). It is likely that more intensive interventions such as ones that increase number input in a child's home environment, may have a greater effect on children's number knowledge.

A few larger-scale interventions taking place in the laboratory, schools, and at home, have made impacts on slightly older children's early mathematical skills (Berkowitz et al., 2015; Ramani & Siegler, 2008; Sonnenschein, Metzger, Dowling, Gay, & Simons, 2016). Likewise, parent number talk has also been successfully manipulated in laboratory interventions (Vandermaas-Peeler, Ferretti & Loving, 2012; Zippert, Daubert, Scalise, Noreen & Ramani, 2019). However, the extent to which parent-driven interventions can make a causal impact on the earliest stages of number development, when children are initially learning the meanings of number words, remains an open question. Understanding the source of variation in children's understanding of the meaning of number words is critical since this is an important foundational step for later achievement in mathematics.

To experimentally test the role of parent number talk on children's number knowledge, we developed and tested a parent-administered intervention. As described in detail below, for various reasons, we chose books as the vehicle to manipulate the quantity and quality of parent number talk.

Current Study

The first objective of the current study was to determine whether parent-administered number talk could have a causal impact on children's number knowledge. Given the largely correlational evidence for the link between parent number input and children's number knowledge, our primary question was whether this link is causal. As reviewed above, much of the evidence that has established a link between parent number input and children's number knowledge is based on correlations between naturally occurring variation in parent number talk and children's numerical competence. To provide a stronger test of whether differences in parent administered number input cause changes in children's number knowledge, we randomly assigned parents to provide their children with various number or non-number-related input. Importantly, by randomly assigning families to number and non-number input conditions, we were able to eliminate the concern that observed associations between differences in number input and subsequent number knowledge were driven by hidden variables such as parents' and children's shared genetic predisposition to math or children's preexisting numerical competence.

To effectively and systematically implement the conditions into which parents were randomly assigned, we used picture books of our own design. Manipulating parent talk using picture books had several advantages over other types of manipulations. First, using books provided all parents, regardless of any individual differences, such as their comfort talking to children about numbers, with a script for the interaction. Unlike previous book-based interventions (e.g., Mix et al., 2012), the books we provided parents contained both pictures and text to ensure that parents were providing the type of number talk that has been previously found to be correlated with children's subsequent number knowledge. Second, using books allowed us to effectively implement different number and non-number conditions. Although parents could provide number and non-number input that went beyond the books, the books anchored at least a portion of the input they provided their children to the specific conditions we created.

Importantly, the sort of structured input provided via book-reading may not generalize to all types of parent number input. However, it has already been reported that some types of parent number input, such as rote counting without a referent, are not associated with changes in children's number development (e.g., Gunderson & Levine, 2011). Therefore, it is important to first establish that some types of parent number input, in particular types that have some support from the literature, are causally related to children's developing understanding of number before testing the limits of this effect.

In addition to our main question regarding the existence of a causal link between parent input and children's number knowledge, we were also interested in exploring the extent to which the intervention conditions led to the same pattern of learning in children at different stages of number development. Based on their correlational findings, Gunderson and Levine (2011) predicted that children might learn the meanings of small number words ("one," "two," and "three") from small number talk and require larger number talk ("four" or more) to learn the meanings of larger number words, generally associated with learning the cardinal principle. Therefore, one- and two-knowers may benefit from number talk that focuses on the meanings of "one," "two," and "three," whereas three- and four-knowers might benefit more from number talk involving "four" and higher numbers. However, Gunderson and Levine (2011) found that parents' large number talk also predicted children's small number knowledge, suggesting that large number talk could also positively impact children's understanding of small numbers. Importantly, however, Gunderson and Levine did not examine how the parent number talk about small and large sets corresponded to the child's number word understanding, and whether this mattered. Furthermore, Carey (2004, 2009) suggested that children become cardinal principle-knowers by noticing the relation between sets of one, two, and three and making the inference that this relation continues beyond three. As such, three- and four-knowers, who are on the cusp of learning the cardinal principle, might also benefit from talk involving small numbers. Finally, it is possible that one or more types of parent number talk are related to children's number knowledge through some third, hidden factor and are not causally linked.

To address these questions, we measured children's cardinal number knowledge before and after a 4-week intervention period. During this period, we manipulated parent number input by asking parents to read one of three possible types of picture-books: Small Number (1–3) books, Large Number (4–6) books, or Control (non-numerical adjectives) books. Each participating family received two books, which were identical with regards to each participant's condition but provided some variety in terms of their theme. The number books were designed to provide children with rich number input. The books included cardinal labels for each set (e.g., "there are three") and prompts to count each set (Mix et al., 2012). In addition, each number book included multiple examples of each set size and provided opportunities for children to compare and contrast the same and different set sizes (see Gentner, & Colhoun, 2010). The books also included use of each number word after the noun label (e.g., "Look at the rabbits, there are two!") in addition to use of each number word before the noun label (e.g., "Can you count the three rabbits?") since it has been suggested that post-nominal uses of number words may be beneficial for learning the meanings of number words (Ramscar, Yarlett, Dye, Denny & Thorpe, 2010). Small Number books and Large Number books were identical apart from the set sizes in each book. Control books were carefully matched to the number books in terms of the overall story, number of words, and opportunities for the child to engage with the book.

Method

Participants

In all, 100 children (52 female) participated in the study between July 2013 and October 2015. Participants were recruited through a database of families who had previously expressed interest in participating in psychology studies. At each visit, parents received a $10 travel reimbursement and children were allowed to pick out a small toy as a thank you gift (such as a plastic dinosaur or plush animal). Families were also allowed to keep the books at the end of the experiment. The study was approved by the institutional review board at the first author's institution.

The mean age of the children who participated was 3.10 years (SD = 0.43, range = 2.54–4.36 years).

Participants came from a range of socioeconomic backgrounds. Family income ranged from less than \$15,000 per year to more than \$100,000 with families reporting on average to earn between \$50,000 and \$75,000 (n = 95). Parents' education (considered the maximum of each of the child's parents) ranged from a high school degree to a graduate degree, although most (92.8%) had at least a college degree (n = 97). Fifty-two percent of the children in our sample identified as White (according to their parents), 30% identified as Black or African American, 11% identified as multiple race categories, 2% identified as Asian, 1% identified as American Indian, and the remaining 4% did not identify their race.

Additional participants were initially assessed but were considered ineligible for the study because they did not complete the pretest (n = 8), did not return for the posttest (n = 25), their knower-level data were not classifiable (e.g., a child met criteria for knowing "three" while failing to meet criteria for knowing "two," n = 4), or were already cardinal-principle-knowers at pretest (n = 49).

Child Pretest and Posttest Measures

The present study consisted of an identical pretest and posttest, separated by a roughly 4-week span (M = 32.99 days; SD = 8.53 days, range = 23–81 days). Although most participants returned for the posttest after approximately 4 weeks, given this wide range of intervals, we controlled for the number of days between pretest and posttest in all analyses.

Give-N

Our primary dependent measure was children's knower-level as determined by the Give-N task[1] (Wynn, 1990). In this task, each child was asked to place a certain number of toy fish into a "pond." After each response, the child was asked to confirm their answer (e.g., "Is this two?"). If the child did not give an affirmative answer, the experimenter gave the child an opportunity to check and revise their response. Children's final answers were recorded. The experimenter always began by asking the child to place one fish in the pond. The experimenter then proceeded to increase the number requested by one fish every time the child answered correctly, and decreased the number requested by one fish every time the child answered incorrectly, following the procedure of Wynn (1990). Children were considered N knowers when N was the highest number for which they responded correctly on two out of three requests for N fish, and gave the experimenter N fish less than half as often when asked for more than N fish than when asked for N fish. If children succeeded on all numbers up to 6, they were considered cardinal-principle-knowers. If they failed to meet the one-knower criteria, they were considered preknowers.

Parent Measures

In addition to providing information about income and education, parents were asked to keep a record of each reading session using a reading log in the back of one of the books. The log prompted parents to record each session, how many books they read during each session, their child's engagement during each session (on a scale from 1 [*not very engaged*] to 5 [*very engaged*]), and the start and end times of each reading session. Additionally, parents were given a survey at the end of the experiment and asked to estimate how often they read the books.

We also asked parents to read the books with their children before leaving the lab at pretest and posttest. Using the CLAN Program (MacWhinney, 2000), transcriptions of the reading sessions were coded for how many number words (one through ten) the parents said while reading the book as well as the fidelity to the text of the book, which was determined by the percentage of lines of the book that the parents read verbatim.

Design and Procedure

The goals of the present study were to (a) test whether number input delivered by parents had a causal effect on children's subsequent number

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[1] As part of a larger study of numerical and language development, children also completed measures of rote counting, numerical estimation, Arabic numeral identification, letter identification, and vocabulary. These measures were not expected to be affected by the training condition and preliminary analyses indicated that children's pretest performance did not differ by condition on any measure. We also planned to include a second measure of cardinal number knowledge, What's-on-this-Card (WOC), in order to test for the possibility that children would learn partial meanings of numbers beyond their knower-level, something the titration method of Give-N would not detect. However, a strikingly low response rate—on average children failed to provide a cardinal label response on 30% of pretest trials and 23% of posttest trials, with only 29% and 41% of children providing a cardinal response on every pretest and posttest trial, respectively. Therefore, we did not include WOC in our main analyses, but a description of the methodology and results from this task are reported in Supporting Information.

knowledge and (b) explore whether small versus large number input had a differential effect based on children's initial level of number word knowledge.

To manipulate parent input between the pretest and posttest, children and their parents were randomly assigned to one of three possible conditions and given different types of picture books based on their condition: Small Number (1–3) Books, Large Number (4–6) Books, or Control (Non-numerical Adjectives) Books. The number books were designed to give children the opportunity to see multiple examples of each set size (within the range defined by participants' condition) and opportunities to count and label each set (see Figure 1 for sample pages). Each participant received two books that were identical with respect to their condition but provided some variety in terms of the subject matter. The books' minimal story was focused on matching animals to a food they ate (the "What Do They Eat?" book) or a location where they liked to sit (the "Where Do They Sit?" book).

To ensure that participants at different stages of number development were distributed across conditions, participants were randomly assigned to one of the three conditions within three groups of children based on children's pretest knower-level: pre-

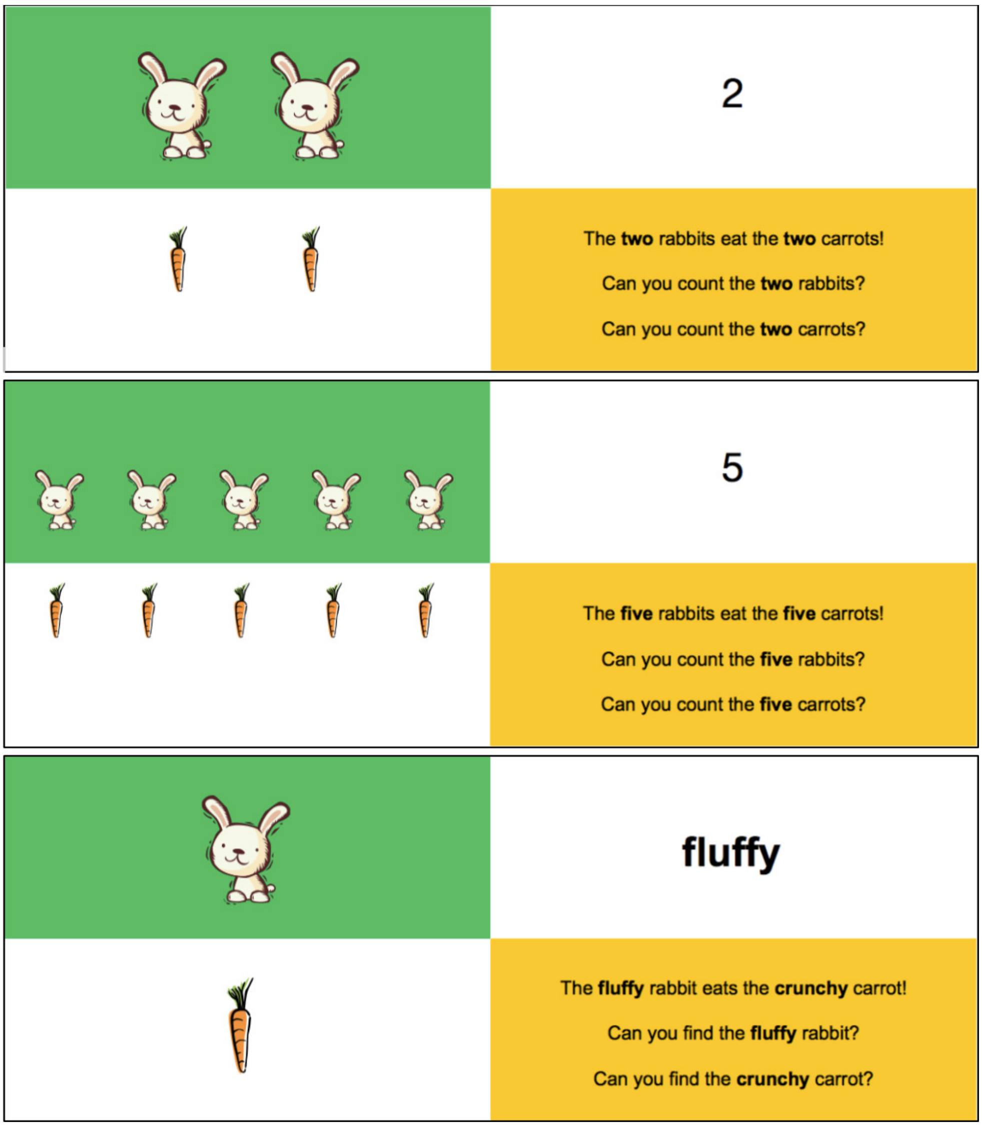

Figure 1. Sample pages from the "What Do They Eat?" book from the three conditions: Small Number (top), Large Number (middle), Control (bottom).

knowers, one- and two-knowers, and three- and four-knowers. These groups were chosen based on the numbers that children at each knower-level needed to learn in relation to our intervention. Specifically, pre-knowers had not yet begun learning the meanings of any number words and could still be in the process of becoming familiar with the words themselves and the count list; one- and two-knowers still needed to learn the meanings of numbers within the range targeted by the Small Number Books; and three- and four-knowers needed to learn the meanings of the numbers within the range targeted by the Large Number Books.

Parents were told the goal of the study was to understand the role that book reading plays in children's early literacy and numeracy development. Along with the books, parents were given a handout detailing some "helpful tips" on effective reading. These tips included giving their child an opportunity to respond to the questions in the book and encouraging the parents who read the number books to both count and provide the cardinal label for sets within the book. Parents were asked to read the books every day and track their reading in a reading log attached to one of the book. They were given an email reminder after 2 weeks to continue reading the book with their child. In cases where the interval between pretest and posttest extended beyond 4 weeks, email reminders to read the books stopped after 4 weeks but parents were not explicitly told to stop reading or recording their reading behavior.

Results

The goal of the present study was to measure the effects of two types of parent administered number talk in the context of book reading, manipulated via Small Number books and Large Number books, on children's cardinal number knowledge compared to number improvement in a control, non-numerical reading condition. Moreover, we aimed to test the relative effectiveness of small and large number input overall and with respect to children's different levels of number knowledge at the beginning of the study. At pretest, 25 participants were pre-knowers, 49 participants were one- or two-knowers (23 one-knowers, 26 two-knowers), and 25 participants were three- or four-knowers (19 three-knowers, 7 four-knowers).

Analyses of the transcripts of parents reading the books with their children showed that the books manipulated parent number talk as intended. We obtained useable transcription data from 82 parent–child pairs at pretest and 75 parent–child pairs at posttest. Table 1 shows the mean number of number words used by parents during the book reading sessions at pretest and posttest across the three conditions. Furthermore, parents read 84% of the lines in the book verbatim at pretest and 76% of the lines verbatim at posttest, suggesting parents read the book with a high degree of fidelity, especially considering that this analysis did not count lines in which a single word was misspoken. We coded a subset of the transcripts by hand ($n = 30$) and found that parents only skipped about 3% of the lines in the book entirely.

Table 1
Mean (SD) Number Words Spoken by Parents While Reading Picture Books by Condition and Session

Condition	Small number	Large number	Control
Pretest ($n = 82$)	35.07 (16.17)	44.03 (19)	0.5 (1.03)
Posttest ($n = 75$)	30.74 (14.1)	47.73 (25.71)	0.31 (0.62)

Participants' age at the start of the experiment did not differ by Condition ($F(2, 99) = 0.12$, $p = .884$) but did differ across Knower-Level Groups ($F(2, 99) = 6.58$, $p = .002$). On average, three-and four-knowers ($M = 3.34$; $SD = 0.41$) were older than pre-knowers ($M = 2.95$; $SD = 0.40$; $t(49) = 3.45$, $p = .001$) and one- and two-knowers ($M = 3.05$; $SD = 0.41$; $t(73) = 2.89$, $p = .005$). One- and two-knowers did not significantly differ in age from pre-knowers, $t(72) = 1.04$, $p = .300$. Given the significant difference in age across Knower-Level Groups, we controlled for age in all analyses examining children's change in knower-level.

Participants were asked to return for a posttest 4 weeks after the pretest; however, the actual number of days between pretest and posttest varied according to the availability of each family. On average, participants received the posttest 32.99 days after the pretest ($SD = 8.53$ days; range = 23–81 days). The number of days between pretest and posttest did not differ by Condition ($F(2, 97) = 0.99$, $p = .374$), or Knower-Level Group ($F(2, 97) = 1.75$, $p = .180$).

According to the reading logs that parents filled out, they read one or the other book an average of 29.74 times over the course of the intervention period ($SD = 16.91$, range = 2–76, $n = 97$) during an average of 17.39 reading sessions (parents sometimes read multiple books in a given sitting; $SD = 7.19$, range = 1–38, $n = 97$). According to parents' posttest surveys of their reading frequency, they estimated engaging in 4.43 reading sessions a week (SD = 2.38, range = 1.0–14.00, n = 81). These two measures of reading frequency (reading logs and posttest surveys) were highly correlated (r(78) = .63, p < .001). The number of times parents reported reading the books in the reading log did not differ by Knower-Level Group (F(2, 94) = 0.81, p = .448, η_p^2 = .017) but did differ by Condition (F(2, 94) = 3.77, p = .027, η_p^2 = .074; see Table 2). Parents read the Large Number Books fewer times than Small Number Books (t(64) = 2.81, p = .007) but not significantly fewer times than the Control Books (t(64) = 1.72, p = .091). Parents did not significantly differ in how often they read the Small Number Books and Control Books with their children, t(60) = 1.06, p = .294.

The difference in number of reads in the Small and Large Number Books conditions was partially counteracted by longer reading sessions in the Large Number Books condition (Small Number: M = 8.91 min, SD = 4.53 min; Large Number: M = 11.89 min, SD = 4.66 min; Control: M = 11.44 min, SD = 5.46 min). Indeed, there was not a significant effect of Condition on the Total Minutes that parents reported reading the books with their children, F(2, 83) = 0.94, p = .394, η_p^2 = .022. Given this and the fact that that differences in reading frequency may be part of the treatment, we did not include reading frequency in the following analyses (although we did account for variability for parents' opportunity to read the books by controlling for the number of days between pretest and posttest). Parents rated their child's engagement in the book an average of 3.83 out of 5 (SD = 0.65, range = 2.20–5.00, n = 97; see Table 2). There was not a significant difference in parents' reports concerning how engaged children were in the books as a function of Condition, F(2, 92) = 2.48, p = .089 (see Table 2).

Table 2
Mean (SD) *Reported Reading Frequencies and Engagement by Condition*

Measures	Small number	Large number	Control
Child engagement 1–5 (reading log)	3.83 (0.78)	3.66 (0.61)	4.01 (0.50)
Total number of reads (reading log)	35.37 (20.46)	24.27 (10.66)	30.27 (17.31)
Reading sessions/ week (posttest report)	4.42 (2.53)	3.66 (1.81)	5.00 (2.75)
Minutes spent reading (reading log)	196.96 (176.13)	151.16 (104.16)	199.83 (151.67)

Change in Cardinal Number Knowledge

Knower-Level

Knower-level change was calculated by subtracting children's knower-level at pretest from their knower-level at posttest (0 = pre-knower, 5 = cardinal-principle-knower). An analysis of covariance of the effect of Condition (Small Number Books, Large Number Books, Control Books) on knower-level change, controlling for Age at Pretest and Number of Days Between Pretest and Posttest revealed an effect of Condition, F(2, 95) = 6.36, p = .003, η_p^2 = .118 (Figure 2). There were no significant effects of the covariates, Age (F(1, 95) = 2.90, p = .087, η_p^2 = .030) or the Number of Days Between Pretest and Posttest (F(1, 95) = 0.14, p = .713, η_p^2 = .001). We conducted follow-up analyses to examine the effect of Condition by performing pairwise comparisons on children's change in knower-level for each condition, controlling for Age and Number of Days Between Pretest and Posttest. Figure 2 displays the means of children's change in knower-level by Condition. Using a Bonferroni correction for multiple (3) comparisons, we considered p values < .0166 to be statistically significant. Children who received the Small Number Books moved

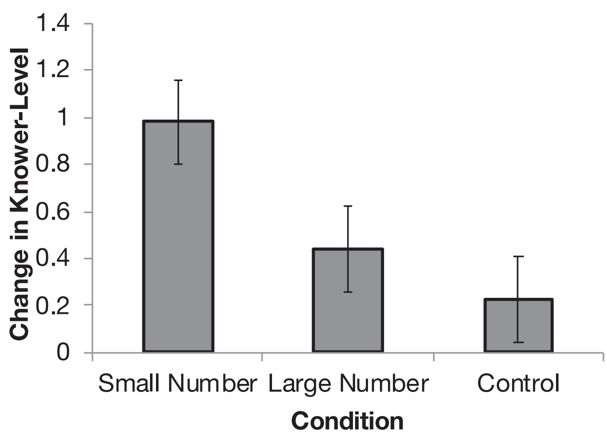

Figure 2. Change in knower-level by condition among all participants.

up more knower-levels than children who received the Control books ($t(95) = 3.32$, $p = .001$) or the Large Number Books ($t(95) = 2.80$, $p = .006$). There was not a significant difference in knower-level gain between the Large Number Books and the Control books, ($t(95) = 0.68$, $p = .500$).

Although our study was underpowered to detect an interaction between Condition and children's starting Knower-Level, we were interested in exploring whether the same pattern of results held for children who began the study at different stages of number development. Critically, analyses on our whole sample may underestimate the effectiveness of Large Number Books due to the relatively small number of three- and four-knowers, who were expected to benefit the most from these books, in our sample. We therefore ran separate analyses of covariance for each of three groups of children (pre-knowers, one- and two-knowers, and three- and four-knowers) on knower-level change, controlling for Age and Number of Days between Pretest and Posttest. Figure 3 displays the mean change in knower-level by condition and whether children began the study as pre-knowers, one- or two-knowers, or three- or four-knowers. Precise means, standard deviations, and number of children in each condition and knower-level group are reported in Table 3.

Among the pre-knowers, we found no effect of Condition ($F(2, 20) = 1.18$, $p = .328$, $\eta_p^2 = .106$), but there was a significant effect of Age on Knower-Level Change ($F(1, 20) = 4.42$, $p = .029$, $\eta_p^2 = .216$) such that pre-knowers were more likely to improve in knower-level if they were older when they entered the experiment ($b = 1.10$, $t(20) = 2.25$, $p = .029$). There was no effect of the Number of Days Between Pretest and Posttest on knower-level change ($F(1, 20) = 1.57$, $p = .225$, $\eta_p^2 = .073$).

Among one- and two-knowers, we found a significant effect of Condition ($F(2, 44) = 4.89$, $p = .012$, $\eta_p^2 = .182$) and no effects of Age ($F(1, 44) = 0.38$, $p = .543$, $\eta_p^2 = .008$) or Days between Pretest and Posttest ($F(1, 44) = 0.09$, $p = .769$, $\eta_p^2 = .002$). To understand the effect of Condition, we performed pairwise comparisons using the Bonferroni adjustment for three multiple comparisons. In line with the results of the whole sample, one- and two-knowers who received the Small Number Books gained significantly more knower-levels than one- and two-knowers who received the Control Books ($t(44) = 2.51$, $p = .016$, $\eta_p^2 = .125$) or the Large Number Books ($t(44) = 2.90$, $p = .006$, $\eta_p^2 = .160$), controlling for Age and Days between Pretest and Posttest. One- and two-knowers placed in the Control condition or the Large Number condition did not significantly differ in knower-level change ($t(44) = 0.08$, $p = .935$, $\eta_p^2 = 0$), controlling for Age and Days between Pretest and Posttest.

Finally, among three- and four-knowers, there was a significant effect of Condition ($F(2, 21) = 5.22$, $p = .014$, $\eta_p^2 = .332$) and a significant effect of Days Between Pretest and Posttest ($F(2, 21) = 6.52$, $p = .018$, $\eta_p^2 = .237$) in which a larger number of Days Between Pretest and Posttest was actually associated with lower gains in Knower-Level, $b = -1.01$, $t(21) = 2.25$, $p = .018$. There was not a significant effect of Age ($F(2, 21) = 3.58$, $p = .072$, $\eta_p^2 = .146$). Pairwise comparisons (using the Bonferroni adjusted significance level of .0166) revealed that three- and four-knowers in both the Large Number and Small Number conditions gained more than participants in the Control

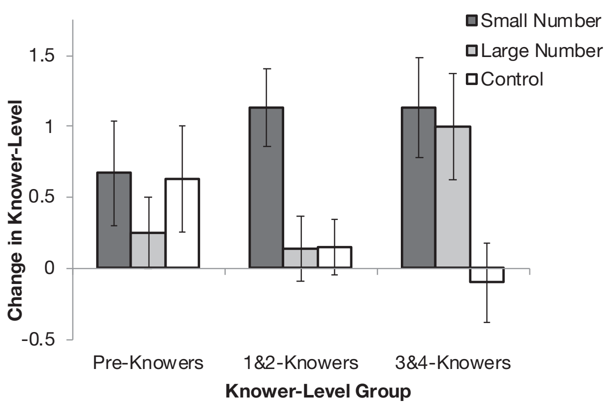

Figure 3. Change in knower-level by condition and knower-level group.

Table 3
Mean (SD) Knower-Level Change by Condition and Knower-Level Group

	Condition		
Knower-level	Small number *M* (*SD*)	Large number *M* (*SD*)	Control *M* (*SD*)
Pre	0.67 (1.12)	0.25 (0.71)	0.63 (1.06)
	n = 9	*n* = 8	*n* = 8
One and two	1.13 (1.06)	0.14 (1.06)	0.15 (0.69)
	n = 15	*n* = 21	*n* = 13
Three and four	1.13 (0.99)	1.00 (1.07)	−0.10 (0.88)
	n = 8	*n* = 8	*n* = 10
Total	*n* = 32	*n* = 37	*n* = 31

condition controlling for Age and Days between Pretest and Posttest (Large Number: $t(21) = 2.73$, $p = .013$, $\eta_p^2 = .262$; Small Number: $t(21) = 2.85$, $p = .010$, $\eta_p^2 = .279$). There was no significant difference in Knower-Level Change between three- and four-knowers in the Small and Large Number book conditions ($t(21) = 0.04$, $p = .965$, $\eta_p^2 = 0$).

Since each increase in knower-level may not represent an equal advance in number knowledge, we also analyzed these data by predicting whether or not children improved in knower-level at all (a dichotomous outcome), ignoring differences in how much children's knower-level changed over the course of the study. Consistent with our main analysis, a logistic regression controlling for Age and Days between Pretest and Posttest revealed that children who received the Small Number Books were more likely to improve in knower-level than children than children who received the Large Number Books ($b = 1.16$, Wald(1, $N = 100$) = 4.75, $p = .029$ or the Control Books ($b = 1.49$, Wald(1, $N = 100$) = 6.56, $p = .010$), Again, there was not a significant difference in the likelihood of improving in knower-level between children who received the Large Number Books and those who received the Control Books ($b = 0.33$, Wald(1, $N = 100$) = 0.34, $p = .560$).

When children were broken into subgroups based on their knower-level at pretest, we again found that one- and two-knowers were significantly more likely to improve in knower-level after reading the Small Number Books than after reading the Large Number Books ($b = 1.93$, Wald(1, $N = 49$) = 6.28, $p = .012$ or the Control Books ($b = 2.49$, Wald(1, $N = 49$) = 6.64, $p = .010$), controlling for age and Days between Pretest and Posttest. We found no significant condition differences among the pre-knowers or the three- and four-knowers. However, the three- and four-knowers who read the large number books were marginally more likely to improve after reading the Large Number Books compared to the Control Books ($b = 2.41$, Wald(1, $N = 26$) = 3.28, $p = .070$).

Discussion

Through a randomized experiment, the present study shows that parent number talk in the context of book reading has a significant causal impact on children's number knowledge. Previously, evidence for a link between parent input, including their number talk, and children's number knowledge has come from correlational studies (Blevins-Knabe & Musun-Miller, 1996; Ginsburg & Baroody, 1990; Gunderson & Levine, 2011; LeFevre et al., 2009; Levine et al., 2010), leaving open the possibility that this relation was not causal, but rather due to factors such as shared genetics, parents' responses to children's interest in number, or another variable. However, in the present study, children were randomly assigned to receive different types of number input (manipulated using picture books). Children who received the most effective number books, the Small Number Books, gained an average of almost one full knower-level over the course of roughly 1 month, compared to 0.23 knower-levels gained by children who received the Control Books. Since it generally takes several months for children to gain a new knower-level (Sarnecka & Lee, 2009; Wynn, 1990, 1992), this represents a significant acceleration of children's verbal number knowledge.

Looking at the sample as a whole, we found no evidence that reading the Large Number Books led to gains in children's knower-level. This is at odds with at least one possible interpretation of Gunderson and Levine's (2011) findings in which parent talk about large numbers (4–10) was more predictive of children's subsequent number knowledge than talk about small numbers (1–3). Specifically, based on the analysis of the entire sample, it appears that 2½–4½ year old children, who are subset knowers, on average benefitted more from small number talk than large number talk. However, Gunderson and Levine (2011) argued that the relation between children's number knowledge and large number talk was likely driven by children who were further along in the knower-levels and that children at earlier stages of number development may benefit more from small number talk.

Of note, our sample included more participants at the one- and two-knower-levels than participants' at the three- and four-knower-levels, whom Gunderson and Levine (2011) predicted would benefit from large number talk. Therefore, we sought to understand the role of children's current knower-level in determining the most effective input. Previous number training experiments have often trained and tested children on the number immediately above their knower-level with the implicit assumption that training will be most effective if targeted to that number (e.g., Gibson et al., 2019; Huang et al., 2010). However, to our knowledge, this has not been explicitly tested.

In line with the idea that number input is most effective when it is tailored to young children's current knowledge levels, among one- and two-knowers, we found significant improvements in knower-level after reading the Small Number Books relative to the Control books but no difference between the gains of children in the Large Number Books and the Control books conditions. Importantly, the Large Number Books provided one- and two-knowers with more counting practice than the Small Number Books (counting up to six rather than up to three) but did not include counting and labeling sets that were at and immediately above their knower-level. Although one might expect one-and two-knowers not to benefit from labeling larger sets, it is conceivable that the extra counting-practice could benefit their performance on smaller sets. However, the practice counting and labeling sets further from their knower-level, provided by the Large Number Books, had no impact on their knower-level compared to the control condition. This reinforces the observation that counting may not play a large role in children's acquisition of the first few number words (e.g., Carey, 2009). In contrast, three- and four-knowers who were given either the Small or Large Number Books gained more knower-levels than three- and four-knowers in the Control books condition. This suggests that three- and four-knowers were able to learn from the Small Number Books beyond learning the names of individual number words or the count sequence. To become cardinal principle-knowers, children must learn something beyond the meaning of an individual number word; they must learn that the last number reached when counting represents the cardinal value of the set. Experience connecting counting with the cardinal values of numbers within their knower-level range may have helped children arrive at this insight. The Small Number Books could also have given children on the verge of becoming cardinal principle-knowers more evidence of the successor relation between small numbers—that each successive number in the count list represents a set with one more element than the number that precedes it—setting them up to make this induction over the rest of their count list (Carey, 2004, 2009).

Interestingly, among three- and four-knowers, there was no difference in the effectiveness of the Small and Large Number Books. Thus, counterintuitively, we found no evidence that large number talk was more helpful for children learning the meanings of larger numbers and the cardinal principle. This might suggest that the greater predictive power of large number talk on children's subsequent number knowledge observed by Gunderson and Levine (2011) is not due to greater importance of large number talk in children's acquisition of symbolic number language. Rather, the relationship identified in their correlational study may have been indexing other variables such as shared genetics, parent or child interest in and/or level of engagement with math. Again, at this stage of number development, children may have progressed from learning the meanings of individual number words and are now in the process of learning to connect the counting procedure to the cardinal meanings of number words. For this purpose, both small and large number talk could be helpful.

Among pre-knowers, we found no significant differences in knower-level change between the three conditions. Our knower-level criteria categorized anyone who was not yet a one-knower as a pre-knower; therefore, the group of pre-knowers may have included children who were not yet ready to learn from the input provided by the number books, perhaps as a result of low levels of relevant prior knowledge. Interestingly, among pre-knowers we did find that age was a significant predictor of learning. Future research should explore whether there are ways of measuring whether certain pre-knowers are on the verge of beginning to learn the meanings of number words (e.g., children's ability to represent small set sizes correctly in gesture; Gibson et al., 2019; Gunderson, Spaepen, Gibson, Goldin-Meadow, & Levine, 2015).

Limitations and Future Directions

It is important to note that our study was conducted on a relatively small number of subjects ($n = 100$), and in particular a small number of participants who began the study as three- or four-knowers ($n = 26$). Therefore, while the present study provides fairly strong support for a causal link between small number (1–3) input and children's growth in cardinal number knowledge, the analyses of our subgroups (pre-knowers, one- and two-knowers, and three- and four-knowers) should be interpreted with caution. A conservative interpretation of these results is that while overall, the small number books proved to be the only effective type of number input compared to the non-numerical control condition, it may be misleading to assume this finding applies to pre-knowers, who did not show any condition differences when analyzed separately, and to three- and four-knowers who may also benefit from large number input. More research is necessary to understand how the type of number input children receive interacts with their preexisting number knowledge.

Another unknown and complicating factor is the amount of number talk that children received outside of the context of the book reading intervention either from parents or from other sources such as daycares and other caregivers. It is possible that receiving a number book (of either size range) increased the frequency with which parents talked to children about both small and large numbers, and the frequency with which children elicited conversations about numbers from their caregivers. If this were the case, however, we might expect to have seen one- and two-knowers improve in the Large Number Books condition, as parents would presumably be less likely to restrict their number talk outside of book reading to sets of 4–6 items, but this was not the case. Therefore, it seems more likely that parent–child interactions with the book had an impact on children's number knowledge. Nonetheless, the extent to which parents supplemented the number talk surrounding the book with additional number input beyond the reading context is an open and interesting question for future research.

Relatedly, an important question for future investigation is the extent to which the present findings generalize to other types of parent-led number interventions. We designed picture books with highly structured prompts involving the types of number language that have been shown to helpful in previous laboratory studies of children's number development (e.g., Mix et al., 2012; Ramscar, Dye, Popick, & O'Donnell- McCarthy, 2011). In contrast, commercially available counting books vary in terms of how well they align with research on number development (Ward, Mazzocco, Bock & Prokes, 2017). Moreover, counting books may elicit less number talk from parents and children than other informal number-related activities such as board games (Ramani et al., 2015). Therefore, while the present study found that providing families with number books was effective in promoting number knowledge, it is possible that some commercially available number books may not yield the same result or that other parent-led interventions such as ones involving board games or tablets may have an even greater impact.

Conclusion

The present findings confirm and extend the findings of correlational work, suggesting that differences in parental number input can lead to differences in children's subsequent number knowledge. Importantly, we demonstrated this by randomly assigning parents and children to conditions designed to increase the frequency of specific types of parent number talk versus an active control. Our results thus indicate that parent number talk can be successfully manipulated through number books and that this kind of manipulation has important consequences for children's subsequent number knowledge. In addition, the present study provides some initial evidence that children's current stage of number development may influence the type of number input that they find most beneficial. Three- and four-knowers moved up more knower-levels after receiving either small (1–3) or large (4–6) number input relative to the non-numerical control condition, whereas one- and two-knowers only showed greater improvement after receiving small number input (1–3). Of course, more research is necessary to understand the generalizability of the present findings and to explore the challenges associated with creating a larger-scale intervention. The present study provokes many new questions concerning which aspects of the books and parent–child interactions were most important in driving learning and how much interaction is necessary to yield effects on children's number knowledge. Additionally, the question of whether the gains children made have long-lasting consequences on their math learning remains open. Nevertheless, interventions such as the present one paint a clearer causal picture of the factors that influence children's number development and could be useful in promoting early number knowledge and reducing early-arising disparities in number knowledge. Our results suggest that one important component of successful interventions may be recognizing the importance of children's prior knowledge, particularly when they are just starting to learn the meanings of the first number words.

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Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's website:

Appendix S1. What's on This Card Task