Child & Youth Care Forum
https://doi.org/10.1007/s10566-022-09671-3

ORIGINAL PAPER

Assessing Efficacy and Benefit of a Behavioral Math Talk Intervention for Caregivers of Young Children

Sherry He[1] · Eileen Graf[2] · Robert J. Webber[3] · Kristin R. Leffel[4] · Elizabeth Suskind[5] · Susan Levine[6] · Dana Suskind[5]

Accepted: 3 January 2022

Abstract

Background Use of numerical and spatial language, also known as math talk, is critical to the development of foundational number and spatial skills in early childhood. However, caregivers and children of low socioeconomic status (SES) tend to use less math talk than their higher-SES peers.

Objective The current efficacy study tested the hypothesis that quantity of math talk among low-SES caregivers and children is increased via a caregiver education curriculum aimed at improving caregivers' language input to children.

Methods Caregiver-child dyads ($n=37$; children aged 17 to 36 months) participated in either the language input or a control intervention. Math talk (operationalized as number and spatial word tokens) was coded from video recordings of each dyad engaging in free play at three time points: baseline, post-intervention, and follow-up.

Results The language input curriculum significantly increased caregivers' amount of spatial talk and cildren's amount of number and spatial talk for up to 4 months after the intervention.

Conclusions A caregiver education intervention increased caregivers' use of math talk, which resulted in higher math talk usage by their children. Further verification is needed through an adequately powered longitudinal randomized controlled trial.

Keywords Math talk · Parenting style/process · Social class/SES · Parent–child communication · Conversation/dialogue · Lexical development

Introduction

Early childhood is a period of rapid cognitive and linguistic growth, and caregivers' language input plays a substantial role during this time. One domain for which this is true is the development of numerical and spatial skills, and children's acquisition of these skills is related to the numerical and spatial language that they hear their caregivers use (Gunderson & Levine, 2011; Levine et al., 2010; Pruden et al., 2011). This language is commonly

✉ Dana Suskind
dsuskind@surgery.bsd.uchicago.edu

Extended author information available on the last page of the article

referred to as "math talk" (Klibanoff et al., 2006), and can be separated into two main components: number talk and spatial talk. Number talk to young children includes number words used to describe features such as cardinality and measurement of time, but mainly occurs in the context of counting. Spatial talk to young children refers to the locations of objects and their dimensional features, including shape and size.

A number of studies document the relationship between caregiver math talk and child use of math and spatial language. In toddlerhood, the development of early numeracy skills, such as knowledge about number and quantity, buttresses mathematical abilities and problem solving up to six years later (Clements & Sarama, 2011; Duncan et al., 2007). Similarly, a longitudinal study of caregiver-child dyads from Chicago found that caregiver spatial talk sampled over 32 months predicted children's use of spatial language as well as their spatial problem-solving at 4.5 years (Pruden et al., 2011). For preschoolers, content-specific language—including spatial language, such as "above" or "beneath," or shape names, such as "circle" or "triangle"—was found to be more important for math development than general vocabulary (Purpura & Reid, 2016). Ramani et al. (2015) studied caregiver-child dyads (aged 3–5) at a Head Start program, finding that teacher number talk during play interactions was positively associated with children's performance on number skill measures. Susperreguy and Davis-Kean (2016) found in a sample of U.S. caregiver-child dyads (children aged 3–5) that amount of math talk during naturalistic interactions correlated with children's mathematical abilities a year later.

This growing body of research demonstrates that math talk during the toddler and preschool years predicts the development of foundational math concepts and thinking (see also Levine et al., 2010; Pruden et al., 2011). Most importantly, these skills and concepts have implications for children's preparedness for school; for example, Sonnenschein and Galindo (2015) showed that math proficiency at kindergarten entry was associated with math achievement at the end of kindergarten.

Relationship Between Socio-Economic Status (SES), Caregiver Math Talk, and Children's Developing Number and Spatial Skills

In investigating the variations observed among children's vocabulary sizes and early-developing number and spatial skills, researchers have identified socioeconomic status as a key factor in both caregivers' math talk and children's developing vocabularies and math-related skills. Levine et al. (2010) found in a sample of caregivers in Chicago that SES was positively correlated with quantity of caregiver number talk. In Verdine et al.'s (2014) study of U.S. preschoolers and families, lower-SES parents reported using fewer spatial words than higher-SES parents. With regard to children's skills, prior research (Jordan & Levine, 2009; Starkey et al., 2004) indicated that children from low-SES backgrounds demonstrate weaker spatial and number abilities than their peers from higher-SES backgrounds.

Variations in both caregivers' math talk and children's early-developing number and spatial skills are related to socioeconomic status. Low-SES caregivers tend to use less number talk (Levine et al., 2010, 2011), set less complex math goals than middle-class caregivers when talking about number (Saxe et al., 1987), spend less time teaching number skills (Jordan et al., 2006), and report using fewer spatial words with their children (Verdine et al., 2014). In terms of children's skills, children from low-SES backgrounds tend to demonstrate weaker spatial and number abilities than their peers from middle- or high-SES backgrounds, a gap that is present by the preschool years (Jordan & Levine, 2009). Children of low-SES appear to fall behind middle- and high-SES children on counting ability, number understanding, ordering and comparison of numbers and quantities, arithmetic, and recognition of written number symbols (Jordan & Levine, 2009; Jordan et al., 2006; Klibanoff et al., 2006; Starkey et al., 2004). They are also more likely to be behind their higher-SES peers in recognizing, matching, and transforming standard shapes; comparing object lengths; building block structures; duplicating and extending patterns; ordering figures by size; and understanding area proportions such as "half" (Klibanoff et al., 2006; Starkey et al., 2004; Verdine et al., 2014). In the same vein, low-SES kindergarteners tend to be overrepresented among those who begin with low mathematics competence and demonstrate little growth in mathematics throughout the kindergarten year (Jordan & Levine, 2009; Jordan et al., 2006).

Math Talk as a Mediator Between SES and Children's Number and Spatial Skills

Reduced math talk from low-SES caregivers during the preschool years may be a key factor in explaining why low-SES children begin school at a math disadvantage. Both number talk and spatial talk are instrumental to helping children develop the foundational number and space skills required to learn math.

Number talk appears to predict children's understanding of foundational math concepts (Gunderson & Levine, 2011; Levine et al., 2010; Ramani et al., 2015). Moreover, the stronger a preschooler's knowledge of number words and their meanings, the better their performance on both verbal and nonverbal number tasks is likely to be (Mix, 2008; Mix et al., 1996). Similarly, spatial talk helps children to categorize, compare, and contrast elements of their spatial environment (Newcombe & Frick, 2010). Parent use of spatial language largely predicts children's use of spatial language, spatial problem-solving skills on non-verbal spatial tasks (Pruden et al., 2011), and growth in spatial thinking over time (Albro, Booth, Levine, & Massey, 2009).

Related to low-SES caregivers' reduced use of math talk relative to higher-SES caregivers, low-SES children themselves understand and use less math talk, leading to difficulties with numerical and spatial thinking, particularly for mathematical tasks that involve verbal information. Many number and spatial tasks, such as symbolic arithmetic and shape naming, are linguistic by nature (Jordan & Levine, 2009), and SES most strongly correlates with the linguistic aspects of children's math performance (Dowker, 2005; Jordan et al., 1994). Without a strong foundation of math talk, low-SES children learn math language and verbal skills later and at a slower rate than their higher-SES peers. These SES-based differences persist at least through the end of kindergarten (Jordan & Levine, 2009; Jordan et al., 2006).

Taken together, these findings indicate that caregivers' less frequent use of math talk in particular may be an early contributor to documented challenges in numerical and spatial thinking in children of low-SES backgrounds as compared to their higher-SES peers. However, there is evidence that aspects of the child's home environment can mitigate differences in math achievement based on SES. For example, Sonnenschein and Galindo (2015) showed that the availability of learning tools (e.g., books, CDs) and children's involvement in reading activities significantly attenuated the relationship between SES and children's math proficiency.

Increasing Caregiver Math Talk

A question of practical and social importance, then, is whether the math talk of caregivers and children from low-SES backgrounds can be effectively increased. A growing body of research suggests that language input by caregivers (who are either parents/guardians or teachers) is malleable to systematic instruction, with positive effects for children's development (Suskind et al., 2016). Meta-analyses (Kong & Carta, 2013; Roberts & Kaiser, 2011) and randomized controlled trials (Roberts & Kaiser, 2015) of caregiver language-based interventions indicate a significant, positive impact of such interventions upon child outcomes in language, social, and emotional domains. For example, Bleses et al. (2020) showed that an intervention providing teachers of toddlers with an age dependent sequence and scope of weekly language, math language, and numeracy to support instructional quality and use of content-rich language resulted in positive, medium- to large-sized effects on math skills. Ribeiro, Schmitt, Schütze, and Gurevych (2020) found that when mothers provided higher levels of spatial support when interacting with their two-year-olds during a puzzle task involving spatial visualization skills, the children had significantly fewer math difficulties in second grade.

Recent interventions aimed at reducing early SES performance gaps indicate that caregiver and child math talk can also be augmented. For example, Hojnoski et al. (2014) provided middle- to high-SES parents of children aged 3–5 with reader's guides and training to focus on math concepts and math vocabulary during shared book reading and found that the intervention was effective at increasing parents' and/or children's math talk for four out of six dyads. Vandermaas-Peeler et al. (2011) studied middle- to high-SES parent–child dyads (children aged 3–5), randomly assigning parents to receive either training for incorporating number talk into a board game or no training. Parents in the training group provided more verbal guidance for numeracy skills relative to the comparison group, and their children responded correctly more often to numeracy and math questions. Purpura, Napoli, Wehrspann, and Gold (2017) trained interventionists to deliver a math talk intervention for children in Head Start programs. Three children (aged 5) were randomly assigned to either an 8-week math talk intervention using dialogic reading focused on numerical and spatial language or to a control group. Children who received the intervention showed improvements of small to medium effect sizes on math language and non-linguistic math abilities relative to controls.

The literature to date suggests that caregiver math talk is associated with young children's number and spatial language ability, which in turn predicts children's later math proficiency and academic achievement, particularly for children from low-SES backgrounds. The current study assesses the efficacy and benefit of a math talk intervention for caregivers of toddlers and young preschoolers from low-SES backgrounds. Where previous studies have focused on low-SES caregiver interventions with children aged 3–5 years, the current study includes low-SES caregivers of toddlers and preschoolers ranging in age from 17 to 36 months. The intervention uses a home-visiting model integrating evidence-based behavior change-techniques and information on the language environment caregivers provide for their children (see section on *Curriculum and Programmatic Framework* below).

With this study, we probe if providing low-SES caregivers with these broad and varied supports, as well as specific math-talk-related resources, will lead to (1) an observable and sustainable increase in caregiver math talk and (2) a concomitant increase in their young children's math talk.

Method

The study reported here occurred under the oversight of and with approval from the Division of Biological Sciences Institutional Review Board (IRB) at the University of Chicago Medicine.

Curriculum and Programmatic Framework

At the heart of the intervention was a curriculum designed to increase caregiver knowledge of children's early language and cognitive development in multiple domains (Suskind et al., 2016). The curriculum was delivered by one home visitor over eight one-hour weekly sessions. The child was present at each session. Each session consisted of one laptop-based curriculum module (35 min) demonstrating concrete ways in which a caregiver might engage their child in conversation. These modules focused on specific topics, one of which was math talk (see Table 1 for an overview of the entire curriculum). The math talk module presented a variety of ways to talk about numbers, such as counting, using numbers to label values of sets, and comparing numbers and quantities. It also encouraged the description of everyday objects using spatial terms such as size (e.g., big, small), weight (e.g., light, heavy), shape (e.g., triangle, circle), and geometric feature (e.g., round, sides).

Additionally, the intervention incorporated two behavior-change techniques: (1) a video-modeling exercise (10 min), during which a caregiver video-recorded themselves practicing a module activity with the child and reviewed it together with the home visitor; and (2) the review of a quantitative linguistic feedback report based on caregiver recordings of a typical day with their child, using LENA technology (Gilkerson & Richards, 2008) (15 min). For a detailed description of all program components and curriculum content, please refer to Suskind et al. (2016).

Design

The study employed an uncontrolled, quasi-experimental design and follows Transparent.

Reporting of Evaluations with Nonrandomized Designs (TREND, http://www.cdc.gov/trendstatement/) guidelines.

Participants

All participants were recruited to test the efficacy of the larger caregiver education curriculum. Participants were caregiver-child dyads recruited from several low-income areas in Chicago via flyers hung in the respective neighborhoods or placed at local pediatric offices. Potential participants were also recruited from a pediatric office associated with the hospital where the study was conducted. Income proxies were used to assess participant eligibility. Low-SES status was determined based on Medicaid and/or Women, Infants and Children (WIC), and U.S. Federal Supplemental Nutrition Program eligibility. Children were 17–36 months at the start of the intervention and were without developmental delay (screened via the Ages & Stages Questionnaire, Third Edition [ASQ-3]). All participants were English speakers. Table 2 displays additional participant demographics.

Table 1 Overview of the intervention curriculum from Suskind et al., 2016 [*Reprinted with permission*]

Module	Description
Day 1	This foundational module introduced caregivers to the overarching themes and concepts revisited throughout the intervention curriculum. The module included information about the critical period for language development, the lasting impact of language on the brain, and a description of quantitative linguistic feedback (Gilkerson & Richards, 2008; Hart & Risley, 1995; Suskind et al., 2013)
Narration	Discussed the importance of caregiver language input during the critical period. Concepts and strategies designed to increase adult word count through 'talking more' while incorporating responsive parenting behaviors, namely co-constructed narration and joint attention (Kaiser & Hancock, 2003; The Hanen Centre, 2011)
Conversational turns	Expanded on the concepts and skills covered in the Narration module, adding responsive parenting skills that encouraged longer conversations between caregiver and child (i.e., increasing wait time, increasing child-directed speech, and adjusting input to the child's level during play) (Kaiser & Hancock, 2003; The Hanen Centre, 2011)
Directives	Provided caregivers with strategies to reduce directive language by increasing prompts and encouragements. It is important to note that this module did not evaluate parenting styles, but presented prompts and encouragements as methods for increasing amount of talk and conversational turn taking. For example, an animation of a caregiver asking her child to put his shoes on by using a directive ("Go get your shoes") is contrasted with an animation of the caregiver using prompts to achieve the same goal ("What do we have to put on before we go outside?") (Landry et al., 2006)
Book sharing	Introduced caregivers to the differences between *sharing* a book *with* their child and *reading* a book *to* their child. Dialogic book reading was modeled to provide caregivers with an activity that supported caregiver-child interaction and increased caregiver language input (Whitehurst et al., 1994; Zevenbergen & Whitehurst, 2003)
TV & media diet	Discussed the importance of reducing children's television and screen time exposure. Described the negative impact of technology, such as cell phones, on caregiver language input (Christakis et al., 2004)
Fun with numbers	Discussed incorporating math and spatial language into everyday routines and conversations, further building caregivers' repertoire of descriptive language (Levine et al., 2010)
It Takes a village	Reviewed the concepts and strategies in the previous modules. In order to further enrich the children's language environments and harness social capital, caregivers were encouraged to share what they learned with other important persons and caretakers in their children's lives (Small, 2010)

Figure 1 displays a flow chart of participant dyads through the quasi-experimental intervention trial. Participants were assigned to either the treatment condition or the control condition. All participants recruited in the hospital were assigned to the treatment condition, due to their likely familiarity with the intervention offered at the hospital. Thirty-seven dyads ($n=18$ treatment; $n=19$ control) began the study, but 10 dyads ($n=5$ treatment; $n=5$ control) discontinued participation prior to completing all baseline data collection activities. In these cases, caregivers enrolled in the study and were assigned to a condition but discontinued their involvement prior to starting any intervention activities. In addition, 4 dyads ($n=1$ treatment; $n=3$ control) dropped out midway through the study after having completed some but not all of the required data collection components of the study. These participants became unresponsive partway through their intervention experience or had their phones disconnected. Data collection

Table 2 Participant demographics

	Control group	Treatment group	*p*-value
Sample size	14	13	
Child characteristics			
Mean (SD) age in months	25.23 (5.61)	30.06 (5.07)	0.03*
Gender			
Female (*n*)	28.57% (4)	38.46% (5)	0.89
Male *(n)*	71.43% (10)	61.54% (8)	0.89
Caregiver characteristics			
Mean (SD) age in years	27.76 (5.15)	27.50 (5.52)	0.90
Gender			
Female (*n*)	100.00% (14)	100.00% (14)	1.00
Race			
Black (*n*)	92.86% (13)	84.62% (11)	0.95
White (*n*)	7.14% (1)	15.38% (2)	0.95
Household income below $15,000 (*n*)	64.29% (9)	69.23% (9)	1.00
Graduated 4-year college (*n*)	14.29% (2)	7.69% (1)	1.00
Single-caregiver household (*n*)	64.29% (9)	92.31% (13)	0.20

$* = p < .05$; $** = p < .01$; $*** = p < .001$

for 2 dyads ($n = 0$ treatment; $n = 2$ control) was corrupted and could not be used. Hence, 21 ($n = 12$ treatment; $n = 9$ control) dyads had complete data, although partial data were collected, coded, and analyzed for all 27 dyads ($n = 13$ treatment; $n = 14$ control).

Curriculum Delivery

Both the treatment and the control curricula consisted of eight weekly home visits. The treatment group received the curriculum described above, delivered by a home visitor. The control group received a nutrition education, in which a research assistant spent 5–10 min each week reviewing a nutrition information sheet with the caregiver. While home visits in the control condition were shorter than in the treatment condition, control participants received the same number and frequency of home visits and completed the same measures as the treatment group. Note that the home visitor and the research assistant were not the same person.

Free-Play Video Sessions

Dyads were video-recorded engaging in free-play sessions of approximately 30 min at three time-points: three weeks before the intervention (*baseline*), 1–2 weeks after the intervention (*post-test*), and approximately four months after the intervention (*follow-up*). The sessions occurred in a laboratory setting. Caregivers were instructed to read and play with their child as they normally would. No other instructions were provided. Each session was audio-recorded by a LENA device and video-recorded by a laptop camera. Researchers were not present in the room during the sessions.

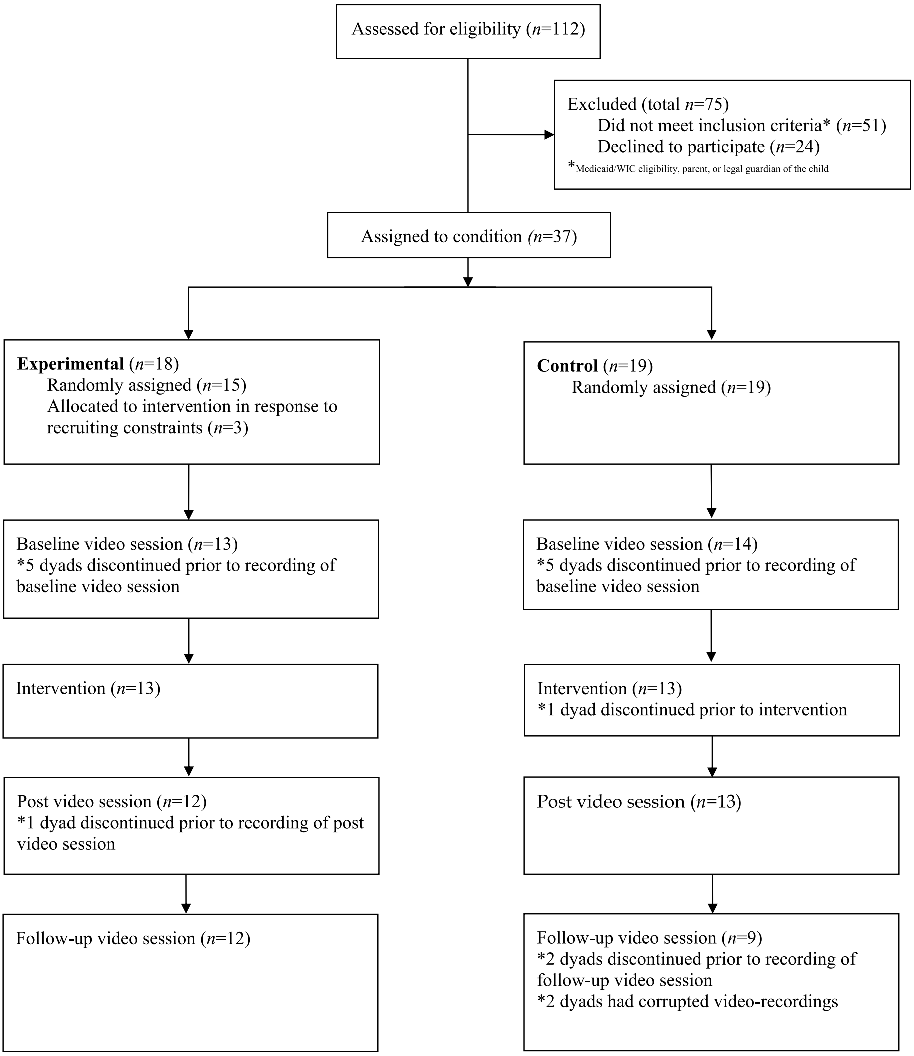

Fig. 1 Participant flowchart

The study period, including curriculum delivery and all video sessions, lasted about six months.

Transcription

The video sessions were transcribed using a system detailed in Suskind et al. (2016). The primary transcriber was blind to condition and time-point. A second blinded transcriber transcribed 10 min of a random 20% of the sessions. Word reliability (percentage of words transcribed in agreement) between the two transcribers was 90.69%. Utterance boundary reliability (percentage of utterance boundaries marked in agreement) was 94.28%.

Math Talk Coding

For the purposes of this study, we operationalized math talk as either number words or spatial words. The coding scheme was adapted from Levine et al. (2010) for number talk and from Cannon, Levine, and Huttenlocher (2007) for spatial talk (see Table 3). Non-spontaneous usages (e.g., number/spatial words directly read from a book) and non-numerical/non-spatial usages (e.g., *this one*, *high five*, *Big Bird*) were not coded.

Number talk was quantified by counting number instances (Gunderson & Levine, 2011). For example, one occurrence (or *token*) of a number word (e.g., "You have *two* cookies and *one* apple.") was counted as two instances while sequential strings of number words in a counting sequence (e.g., "one-two–three-four") was counted as one instance. Spatial talk was measured by quantifying spatial instances, defined as one token of a spatial word.

All coders were blind to both the study condition and the time-point of data collection at the time of coding. A second coder independently double-coded 20% of the completed transcripts. Math talk coding reliability (the percentage of number and spatial instances coded in agreement between coders) was 93.21% for caregivers, and 97.80% for children.

Analytic Plan

For this pilot study, we focused our attention on a small subset of possible language outcomes. Gunderson and Levine (2011) combined caregiver measures of number and spatial instances to derive an overall composite score of caregiver math talk per video session. Number instances and spatial instances produced by the child were similarly combined into child math talk. We assessed the number of math talk instances without controlling for overall speech levels.[1] This outcome has been robustly associated with SES differences in the child language environment (Gunderson & Levine, 2011; Levine et al., 2010; Verdine et al., 2014).

Data were available for 27 caregiver-child dyads, across 72 videos. A total of $N=21$ dyads completed all three videos, $n=3$ dyads completed two videos, and $n=3$ dyads completed one video. Videos varied in length, $Range=17.6–36$ min, $M=31.8$ min, $SD=2.6$ min. Therefore, all video data was converted into rates per 30 min (to ensure that data can be interpreted as the typical number of times that number or spatial instances might appear in a single recorded video session).

To test the impact of the treatment on verbal outcomes using linear regression, the authors specified a linear mixed effects model, which is recommended for analysis in repeated-measures experiments (Goldstein, 2011), because all available data are included in the regressions. Inference is not limited to participants with perfect attendance but also includes participants that missed one or two recording sessions. The model accounts for typical increases in quantity of math talk with increasing child age. It also accounts for variability in math talk between dyads and the variability between different recordings for each dyad. Lastly, the model controls for preexisting differences between the control and treatment groups. The treatment coefficients measure additional increases in math talk experienced by the treatment group at post-test and follow-up beyond the typical increases

[1] Information on additional analyses controlling for overall speech as well as overall number and spatial tokens is available upon request.

Table 3 Math talk coding scheme

Category	Description	Examples
Number talk		
Counting	Use of number words in a sequence. Includes basic counting, co-counting in which the caregiver and child took turns with the count sequence, and counting with nouns	One, two, three One block, two blocks, three blocks, four blocks One, two bears
Cardinality	Labeling the cardinal value of a set size or referring to the quantity of a set. For number words to be coded as cardinality, they could not be part of a counting sequence; if they were part of a counting sequence, they were coded as counting	Three cats Two blocks
Other	Other uses of number, such as measurement of time, labeling a visual symbol of a number, and putting objects in one-to-one correspondence	Three years That's a three (with obvious reference to a picture of the number 3) One for you, one for me
*Spatial talk**		
Dimension	Words that describe the size of two- and three-dimensional objects and spaces. Weight terms were also included in the curriculum and coded in this category: although weight is not visible, it is a salient property of three-dimensional objects that children may associate with visual size	Long Wide Shallow Heavy
Shape	Words that describe the standard or universally recognized form of enclosed two- and three-dimensional objects and spaces. This category did not include words such as *heart*, *star*, and *crescent moon* because it is unclear whether these usages refer to the shape of the object or to its identity (Cannon, Levine, & Huttenlocher, 2007). Similarly, usages like *ice cream cone* and *ice cube* were not included because they do not always have sthe standard form of the shape whose name they use (i.e., an ice cream cone need not be cone-shaped, and an ice cube need not be cube-shaped)	Triangle Circle Square
Feature/property	Words that describe the features and properties of two- and three-dimensional objects and spaces, as well as the properties of their features. *Top* and *bottom* were not included, as Cannon, Levine, and Huttenlocher (2007) consider them to be descriptors of *location* rather than *feature/property*	Side Curved Round Straight

**Note* Categories of spatial talk that were coded have been explicitly shown in prior research (Pruden et al., 2011) to be related to children's spatial skills

Table 4 Mean number of instances per 30 min

Category	Control caregiver			Treatment caregiver		
	Baseline	Post-test	Follow-up	Baseline	Post-test	Follow-up
Cardinality (Number)	4.33	4.23	4.35	4.85	8.09	5.61
Counting (Number)	2.49	5.21	1.39	2.13	3.67	3.06
Other (Number)	2.99	1.82	4.43	6.80	1.96	2.51
Dimension (Space)	3.58	3.78	3.94	3.69	12.31	12.01
Shape (Space)	0.00	3.35	7.38	1.25	7.82	6.14
Feature (Space)	2.09	0.88	2.55	4.40	2.77	5.74
Category	Control child			Treatment child		
	Baseline	Post-test	Follow-up	Baseline	Post-test	Follow-up
Cardinality (Number)	1.92	1.35	2.64	2.11	3.43	4.24
Counting (Number)	3.25	2.86	2.82	1.71	4.50	4.23
Other (Number)	0.00	0.00	1.47	0.00	0.90	1.49
Dimension (Space)	0.00	1.30	1.91	1.57	3.36	5.89
Shape (Space)	0.00	1.67	0.92	0.89	3.06	3.75
Feature (Space)	0.00	0.00	0.94	0.00	0.00	0.92

experienced by the control group. The analyses reported in the paper and in the supplementary online only file use all available videos without imputation.

$$\text{outcome} = \left(\beta_0, \beta_1, \beta_2, \beta_3, \beta_4\right)^T (1, \text{age}, \text{treat}, \text{posttest}, \text{followup}) + (\gamma_1, \gamma_2)^T (\text{treatposttest}, \text{treatfollowup}) + \epsilon^{(1)}_{child} + \epsilon^{(2)}_{child,video}$$

β coefficients in the model provide statistical controls for the age of the child, as well as the baseline difference in math talk between control/treatment groups and baseline/post-test/follow-up time periods. The linear mixed effects model controls for baseline performance of different child-caregiver dyads through the coefficient ϵ_child. Γ coefficients are the treatment coefficients, which indicate whether the treatment produced a statistically significant increase in math talk at post-test and follow-up.Significance testing involved conducting *t*-tests on regression coefficients, with *p*-values of $p<0.05$ indicating significance. All analyses were run in R (2016), using the packages "lme4" (Bates, Mächler, Bolker, & Walker, 2015) for regressions and "pbkrtest" (Halekoh & Højsgaard, 2014) for *p*-values.

Results

Table 2 confirms that the control and treatment groups are statistically indistinguishable at baseline across child and caregiver characteristics ($p>0.10$), apart from child age. Because there is a preexisting difference in age (treatment children were older at Time 1), age is controlled for in all regressions.

Table 4 presents the different categories (e.g., number/spatial words) and subcategories (e.g., cardinality/counting/other and dimension/shape/feature) of average rates of math talk across all participants. The most prevalent category in number words was cardinality, and

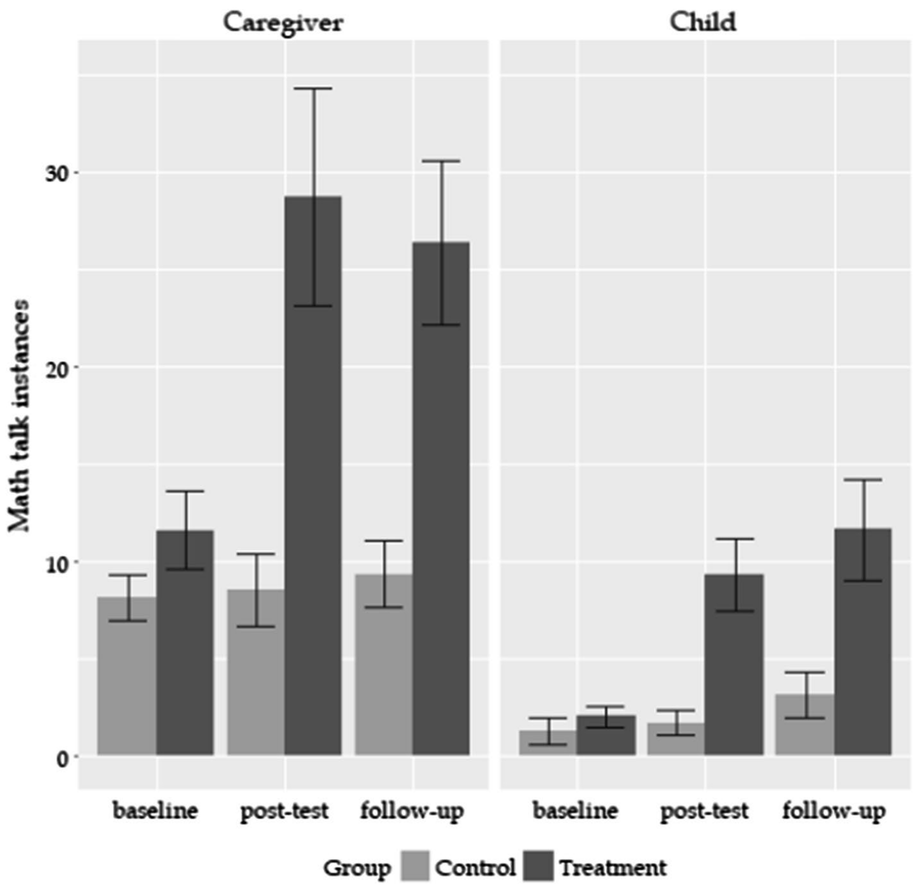

Fig. 2 Bar plot of math talk instances per 30 min, with ± 1 standard error bars

the most prevalent category in spatial words was dimension. The table shows a general pattern of increasing math talk at post-test and follow-up time-points, compared to the baseline time-point, for treatment participants. The only anomalous results are caregiver use of the other number category at post-test and follow-up and caregiver use of the feature category at post-test.

Figure 2 shows the means and standard errors in the composite math talk measure at the three time-points. In the treatment group, child math talk increases from baseline to post-test and post-test to follow-up, and treatment group caregivers show a significant upward trend in math talk from baseline to post-test and follow-up.

Table 5 presents the results of the formal linear regression model. The model confirms that participating in the intervention led to increases in caregiver and child math talk at both post-test and follow-up periods. The model also includes a positive coefficient on the age of the child, illustrating that caregivers and children in the study used more math talk as children grow older (children were 1.5–3 years old at enrollment and aged 6–7 months throughout the length of the experiment).

Following the results from the first regression, Table 6 presents additional regressions separately examining spatial talk and math talk. Regressions related to number

Table 5 Regression model results testing the math talk measure

Term	Caregiver math talk			Child math talk		
	Estimate	Std. err	*p*-value	Estimate	Std. err	*p*-value
Intercept	− 6.05	7.34	0.43	− 4.47	3.45	0.23
Age (in months)	0.55	0.27	0.05	0.22	0.13	0.10
Treat	1.00	4.19	0.84	− 0.26	1.90	0.90
Posttest	− 0.99	3.70	0.78	− 0.11	1.60	0.93
Followup	− 2.94	4.43	0.56	0.33	1.94	0.87
Treatposttest	16.02	5.20	0.00***	6.61	2.24	0.01**
Treatfollowup	14.03	5.49	0.03*	7.82	2.37	0.00***

$* = p < .05$; $** = p < .01$; $*** = p < .001$

Table 6 Regression model results testing spatial and number instances

Type	Caregiver number instances			Child number instances		
	Estimate	Std. err	*p*-value	Estimate	Std. err	*p*-value
Intercept	0.81	4.18	0.86	−2.52	2.33	0.31
Age (in months)	0.17	0.15	0.30	0.15	0.08	0.10
Treat	1.24	2.28	0.61	−0.35	1.30	0.82
Posttest	−0.31	1.88	0.85	−0.36	1.12	0.75
Followup	−2.58	2.28	0.28	0.08	1.35	0.96
Treatposttest	4.95	2.62	0.07	4.30	1.57	0.01**
Treatfollowup	3.61	2.78	0.22	3.94	1.66	0.03*
	Caregiver spatial instances			Child spatial instances		
Term	Estimate	Std. err	*p*-value	Estimate	Std. err	*p*-value
Intercept	−7.17	5.08	0.20	−1.90	1.96	0.36
Age (in months)	0.40	0.18	0.05	0.07	0.07	0.34
Treat	−0.28	2.98	0.93	0.10	1.07	0.93
Posttest	−0.71	2.73	0.79	0.25	0.88	0.77
Followup	−0.53	3.24	0.88	0.26	1.07	0.83
Treatposttest	11.01	3.85	0.01**	2.31	1.23	0.08
Treatfollowup	10.47	4.06	0.02*	3.87	1.30	0.01**

$* = p < .05$; $** = p < .01$; $*** = p < .001$

talk reveal a treatment effect for children at post-test and follow-up, but not for caregivers at either time-point. Regressions related to spatial talk reveal a treatment effect for caregivers at post-test and follow-up and for children at follow-up.

To test for potential effects of selective attrition (assessing whether dyads who dropped out were systematically different from those who remained in the study), we repeated the above reported analyses, using only the dyads with complete data.

Treatment coefficients changed very little, and the standard errors increased by a small margin due to the decreased quantity of data.

Discussion

The current study added to existing evidence of the efficacy of a caregiver education program aimed at enriching children's language input. In particular, a closer look at caregiver and child math talk showed that the intervention significantly increased caregivers' and children's math talk (specifically, number, and spatial words). After participating in the intervention, caregivers' math talk significantly increased both immediately following the intervention and four months later, indicating sustained gains for this time frame.

Even though overall math talk increased significantly, when broken down by talk category, caregiver number talk did not change, potentially because our small sample size resulted in insufficient power to detect the effects of the intervention (VanVoorhis & Morgan, 2007). In addition, it is possible that slight decreases in the sporadically used "other number" category contributed to weaker number talk findings.

Overall, the results are consistent with prior research (Hojnoski et al., 2014; Vandermaas-Peeler et al., 2011) suggesting that caregiver-directed math talk interventions can positively influence caregivers' use of math talk. Though the intervention was not a standalone math talk intervention, the current study suggests that a broader language intervention providing a range of supports can increase low-SES caregivers' math talk. Spatial talk may be more malleable in this regard than number talk, and the resulting increases are sustainable over a short term.

The effects of the intervention on children at follow-up closely mirrored those for caregivers. Children whose caregivers participated in the program showed greater use of number and spatial words than children in the control group four months after the intervention, suggesting that increases in child math talk occur in response to increases in caregiver math talk. These results are consistent with prior literature (Pruden et al., 2011; Purpura et al., 2017; Susperreguy & Davis-Kean, 2016).

Children's number talk increased following the intervention, even though caregivers' number talk did not differ by condition. The non-significant increase in caregiver number talk may then have been sufficient to catalyze the increases in children's number talk. This possibility is speculative, and further research using larger sample sizes is necessary.

Overall, the results suggest that the program can increase children's use of math talk. Subsequent longitudinal studies are required to show whether this increase is associated with a reduction of weak spatial and number abilities often found in children of low-SES backgrounds. These findings have practical significance, as math talk during the toddler and preschool years has been shown to predict the development of foundational math concepts and thinking (Levine et al., 2010; Pruden et al., 2011).

Limitations and Future Directions

Given the limited sample size and power of this feasibility pilot, the current study did not examine measures of math talk quality, such as diversity of number and spatial word types used. The age range of children in the current study (17 to 36 months) was relatively broad, and given the small sample size of this pilot, we cannot offer conclusions about how intervention impact may differ based on child age. Furthermore, the current study did not measure children's math abilities beyond use of math talk, and there was no further follow-up beyond the four months post-intervention.

These limitations are currently being addressed in a longitudinal RCT with a greater range of math talk measures, evaluating the effect of caregiver-directed math talk intervention upon children's later math achievement. This RCT will improve on the current study in several ways. First, based on effect sizes determined in the feasibility trial, the RCT will be adequately powered. Second, only children aged 12–15 months will be included. Third, participants will be recruited city-wide, through a range of ads placed on social media, public transportation, and pediatric offices. Fourth, assignment to condition will only occur after baseline measures are completed, because participants will be randomized as matched pairs based on language input. This will be done to ensure that children's inputs are equal at baseline. Fifth, children will be followed longitudinally to measure potential impacts on school readiness indicators.

The current study cannot separate the impact of the math talk module from the broader language enrichment curriculum. It is not clear whether the information provided in the math talk module and session would have been sufficient to increase math talk, or whether caregiver number and spatial language changed as a function of their participation in the larger program. Prior research suggests that math talk may be particularly malleable; however, further research is needed to examine benefits of math talk interventions. Future research examining the social and economic efficiency of such interventions (i.e., whether they are an effective use of practical resources) is also needed. The research and development team is addressing these issues by concurrently rolling out and testing different intervention formats, tailored to different audience and community needs.

Finally, the control group received a different intervention (a nutrition program), which did not parallel the treatment intervention regarding session length, activity types, and overall engagement with the home visitor. A treatment session included four activities over 60 min, and an intervention session included one activity that lasted 10 min. Additionally, while the treatment group received home visits by a dedicated home visitor, the control group received visits by a research assistant. This difference in procedure was due to time and funding restrictions of the efficacy trial. In these respects, the control group might have functioned more like a comparison ("business-as-usual") group that did not receive treatment, which affects the strength of the conclusions that can be drawn. In addition, this may have factored into participants' decision to discontinue their participation in the control condition.

Conclusion

The current study and its caregiver-education program revealed promising findings on the importance of language interactions for various aspects of child development. In particular, it showed that the intervention significantly effects caregivers' spatial talk, and children's numerical and spatial talk, up to four months after the end of the intervention. Both aspects of talk are thought to be important supports for mathematical achievement. Number talk during the preschool years has been shown to predict development of foundational math concepts (Levine et al., 2010). Additionally, spatial talk has been found to support spatial thinking (Pruden et al., 2011), which is a significant predictor of STEM achievement and career paths, even controlling for both verbal and mathematical ability (Wai et al., 2009).

Our findings indicate that it may be possible to increase the math talk that caregivers from low-SES backgrounds engage in with their young children, and that these increases can have effects on children's use of number and spatial language. As a next step, we will investigate whether children's increased math talk is associated with their improved math ability, kindergarten readiness, and long-term academic outcomes. If these associations are found, they provide a rationale for the investment in caregiver interventions during the early years.

Acknowledgements We would like to thank the participating families for so generously allowing us into their homes and for devoting a significant amount of their time to this study. The ideas and opinions expressed herein are those of the authors alone, and endorsement by the authors' Institutions is not intended and should not be inferred.

Funding This work was supported by a Clinical and Translational Science Award [UL1 RR 024999, KL2 RR 025000] and by the Hemera Regnant Foundation. None of the funders or sponsors of this research had any role in the design and conduct of the study; collection, management, analysis, and interpretation of data; preparation, review, or approval of the manuscript; or decision to submit the manuscript for publication.

Availability of Data and Material The data and materials for all experiments are available upon request from the corresponding author. The study was not preregistered.

Declarations

Conflict of interest None of the authors reported any financial or other conflicts of interest in relation to the work described.

Human and Animal Rights The authors affirm having followed professional ethical guidelines in preparing this work. These guidelines include obtaining informed consent from human participants, maintaining ethical treatment and respect for the rights of human or animal participants, and ensuring the privacy of participants and their data, such as ensuring that individual participants cannot be identified in reported results or from publicly available original or archival data.

References

Albro, E., Booth, J., Levine, S., & Massey, C. (2009). Making cognitive development research relevant in the classroom. In *Cognitive Development Society Conference. Paper presented at 2009 Cognitive Development Society Conference*, San Antonio, TX.

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Bleses, D., Jensen, P., Slot, P., & Justice, L. (2020). Low-cost teacher-implemented intervention improves toddlers' language and math skills. *Early Childhood Research Quarterly, 53*(4), 64–76. https://doi.org/10.1016/j.ecresq.2020.03.001

Cannon, J., Levine, S. C., & Huttenlocher, J. (2007). *A system for analyzing children and caregivers' language about space in structured and unstructured contexts*. Spatial Intelligence and Learning Center (SILC) technical report

Christakis, D. A., Zimmerman, F. J., DiGiuseppe, D. L., & McCarty, C. A. (2004). Early television exposure and subsequent attentional problems in children. *Pediatrics, 113*(4), 708–713. https://doi.org/10.1542/peds.113.4.708

Clements, D. H., & Sarama, J. (2011). Early childhood mathematics intervention. *Science, 333*(6045), 968–970. https://doi.org/10.1126/science.1204537

Dowker, A. (2005). Early identification and intervention for students with mathematics difficulties. *Journal of Learning Disabilities, 38*(4), 324–332. https://doi.org/10.1177/F00222194050380040801

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., & Japel, C. (2007). School readiness and later achievement. *Developmental Psychology, 43*(6), 1428–1446. https://doi.org/10.1037/0012-1649.43.6.1428

Gilkerson, J., & Richards, J. A. (2008). *The power of talk: Impact of adult talk, conversational turns, and TV during the critical 0–4 years of child development* (Technical Report LTR-01-2). Retrieved from: https://www.lena.org/wp-content/uploads/2016/07/LTR-01-2_PowerOfTalk.pdf.

Goldstein, H. (2011). *Multilevel Statistical Models*. John Wiley & Sons.

Gunderson, E. A., & Levine, S. C. (2011). Some types of parent number talk count more than others: Relations between parents' input and children's cardinal-number knowledge. *Developmental Science, 14*(5), 1021–1032. https://doi.org/10.1111/j.1467-7687.2011.01050.x

Halekoh, U., & Højsgaard, S. (2014). A Kenward-Roger approximation and parametric bootstrap methods for tests in linear mixed models the R package pbkrtest. *Journal of Statistical Software, 59*(9), 1–32. https://doi.org/10.18637/jss.v059.i09

Hart, B., & Risley, T. R. (1995). *Meaningful differences in the everyday experience of young American children*. Brookes Publishing.

Hojnoski, R. L., Columba, H. L., & Polignano, J. (2014). Embedding mathematical dialogue in parent-child shared book reading: A preliminary investigation. *Early Education and Development, 25*(4), 469–492. https://doi.org/10.1080/10409289.2013.810481

Jordan, N. C., Huttenlocher, J., & Levine, S. C. (1994). Assessing early arithmetic abilities: Effects of verbal and nonverbal response types on the calculation performance of middle- and low-income children. *Learning and Individual Differences, 6*(4), 413–432.

Jordan, N. C., Kaplan, D., Nabors Oláh, L., & Locuniak, M. N. (2006). Number sense growth in kindergarten: A longitudinal investigation of children at risk for mathematics difficulties. *Child Development, 77*(1), 153–175. https://doi.org/10.1111/j.1467-8624.2006.00862.x

Jordan, N. C., & Levine, S. C. (2009). Socioeconomic variation, number competence, and mathematics learning difficulties in young children. *Developmental Disabilities Research Reviews, 15*(1), 60–68. https://doi.org/10.1002/ddrr.46

Kaiser, A. P., & Hancock, T. B. (2003). Teaching parents new skills to support their young children's development. *Infants & Young Children, 16*(1), 9–21. https://doi.org/10.1097/00001163-200301000-00003

Klibanoff, R. S., Levine, S. C., Huttenlocher, J., Vasilyeva, M., & Hedges, L. V. (2006). Preschool children's mathematical knowledge: The effect of teacher "math talk." *Developmental Psychology, 42*(1), 59–69. https://doi.org/10.1037/0012-1649.42.1.59

Kong, N. Y., & Carta, J. J. (2013). Responsive interaction interventions for children with or at risk for developmental delays: A research synthesis. *Topics in Early Childhood Special Education, 33*(1), 4–17. https://doi.org/10.1177/0271121411426486

Landry, S. H., Smith, K. E., & Swank, P. R. (2006). Responsive parenting: Establishing early foundations for social, communication, and independent problem-solving skills. *Developmental Psychology, 42*(4), 627–642. https://doi.org/10.1037/0012-1649.42.4.627

Levine, S. C., Gunderson, E. A., & Huttenlocher, J. (2011). Number development in context: Variations in home and school input during the preschool years. In N. L. Stein & S. W. Raudenbush (Eds.), *Developmental cognitive science goes to school* (pp. 189–202). Routledge.

Levine, S. C., Suriyakham, L. W., Rowe, M. L., Huttenlocher, J., & Gunderson, E. A. (2010). What counts in the development of young children's number knowledge? *Developmental Psychology, 46*(5), 1309–1319. https://doi.org/10.1037/a0019671

Mix, K. S. (2008). Children's equivalence judgements: Crossmapping effects. *Cognitive Development, 23*(1), 191–203. https://doi.org/10.1016/j.cogdev.2007.03.001

Mix, K. S., Huttenlocher, J., & Levine, S. (1996). Do preschool children recognize auditory-visual numerical correspondences? *Child Development, 67*(4), 1592–1608. https://doi.org/10.2307/1131720

Newcombe, N. S., & Frick, A. (2010). Early education for spatial intelligence: Why, what, and how. *Mind, Brain, and Education, 4*(3), 102–111. https://doi.org/10.1111/j.1751-228X.2010.01089.x

Pruden, S. M., Levine, S. C., & Huttenlocher, J. (2011). Children's spatial thinking: Does talk about the spatial world matter? *Developmental Science, 14*(6), 1417–1430. https://doi.org/10.1111/j.1467-7687.2011.01088.x

Purpura, D. J., Napoli, A. R., Wehrspann, E. A., & Gold, Z. S. (2017). Causal connections between mathematical language and mathematical knowledge: A dialogic reading intervention. *Journal of Research on Educational Effectiveness, 10*(1), 116–137. https://doi.org/10.1080/19345747.2016.1204639

Purpura, D. J., & Reid, E. E. (2016). Mathematics and language: Individual and group differences in mathematical language skills in young children. *Early Childhood Research Quarterly, 36*(1), 259–268. https://doi.org/10.1016/j.ecresq.2015.12.020

Ramani, G. B., Rowe, M. L., Eason, S. H., & Leech, K. A. (2015). Math talk during informal learning activities in Head Start families. *Cognitive Development, 35*, 15–33. https://doi.org/10.1016/j.cogdev.2014.11.002

Ribeiro, L. F. R., Schmitt, M., Schütze, H., & Gurevych, I. (2020). Investigating pretrained language models for graph-to-text generation. Retrieved from https://arxiv.org/abs/2007.08426.

Roberts, M. Y., & Kaiser, A. P. (2011). The effectiveness of parent-implemented language interventions: A meta-analysis. *American Journal of Speech-Language Pathology, 20*(3), 180–199. https://doi.org/10.1044/1058-0360(2011/10-0055)

Roberts, M. Y., & Kaiser, A. P. (2015). Early intervention for toddlers with language delays: A randomized controlled trial. *Pediatrics, 135*(4), 686–693. https://doi.org/10.1542/peds.2014-2134

Saxe, G. B., Guberman, S. R., & Gearhart, M. (1987). Social processes in early number development. *Monographs of the Society for Research in Child Development, 52*(2), 162. https://doi.org/10.2307/1166071

Small, M. L. (2010). *Unanticipated gains: Origins of network inequality in everyday life*. Oxford University Press.

Sonnenschein, S., & Galindo, C. (2015). Race/ethnicity and early mathematics skills: Relations between home, classroom, and mathematics achievement. *The Journal of Educational Research, 108*(4), 261–277. https://doi.org/10.1080/00220671.2014.880394

Starkey, P., Klein, A., & Wakeley, A. (2004). Enhancing young children's mathematical knowledge through a pre-kindergarten mathematics intervention. *Early Childhood Research Quarterly, 19*(1), 99–120. https://doi.org/10.1016/j.ecresq.2004.01.002

Suskind, D., Leffel, K. R., Hernandez, M. W., Sapolich, S. G., Suskind, E., Kirkham, E., & Meehan, P. (2013). An exploratory study of 'quantitative linguistic feedback': Effect of LENA feedback on adult language production. *Communication Disorders Quarterly, 34*(4), 199–209. https://doi.org/10.1177/1525740112473146

Suskind, D. L., Leffel, K. R., Graf, E., Hernandez, M. W., Gunderson, E. A., Sapolich, S. G., & Levine, S. C. (2016). A parent-directed language intervention for children of low socio-economic status: A randomized controlled pilot study. *Journal of Child Language, 43*(2), 366–406. https://doi.org/10.1017/S0305000915000033

Susperreguy, M., & Davis-Kean, P. E. (2016). Maternal math talk in the home and math skills in preschool children. *Early Education and Development, 27*(6), 841–857. https://doi.org/10.1080/10409289.2016.1148480

The Hanen Centre. (2011). The Hanen Centre: Helping you help children communicate. Retrieved from http://www.hanen.org/Home.asp

Vandermaas-Peeler, M., Ferretti, L., & Loving, S. (2011). Playing the ladybug game: Parent guidance of young children's numeracy activities. *Early Child Development and Care, 182*(10), 1289–1307. https://doi.org/10.1080/03004430.2011.609617

VanVoorhis, C. R., & Morgan, B. L. (2007). Understanding power and rules of thumb for determining sample sizes. *Tutorials in Quantitative Methods for Psychology, 3*(2), 43–50. https://doi.org/10.20982/tqmp.03.2.p043

Verdine, B. N., Golinkoff, R. M., Hirsh-Pasek, K., Newcombe, N. S., Filipowicz, A. T., & Chang, A. (2014). Deconstructing building blocks: Preschoolers' spatial assembly performance relates to early mathematical skills. *Child Development, 85*(3), 1062–1076. https://doi.org/10.1111/cdev.12165

Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology, 101*(4), 817–835. https://doi.org/10.1037/a0016127

Whitehurst, G. J., Arnold, D. S., Epstein, J. N., Angell, A. L., Smith, M., & Fischel, J. E. (1994). A picture book reading intervention in day care and home for children from low-income families. *Developmental Psychology, 30*(5), 679–689.

Zevenbergen, A. A., & Whitehurst, G. J. (2003). Dialogic reading: A shared picture book reading intervention for preschoolers. In A. van Kleeck, S. A. Stahl, & E. B. Bauer (Eds.), *Center for Improvement of Early Reading Achievement, CIERA*. *On reading books to children: Parents and teachers* (pp. 177–200). NY: Routledge.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Authors and Affiliations

Sherry He[1] · Eileen Graf[2] · Robert J. Webber[3] · Kristin R. Leffel[4] · Elizabeth Suskind[5] · Susan Levine[6] · Dana Suskind[5]

Sherry He
xsherryhe@gmail.com

Eileen Graf
graf-eileen@norc.org

Robert J. Webber
robertjacobswebber@gmail.com

Kristin R. Leffel
kleffel@ruvos.com

Elizabeth Suskind
bsuskind@surgery.bsd.uchicago.edu

Susan Levine
s-levine@uchicago.edu

1 New York City Department of Education, New York, USA

2 Academic Research Centers, NORC at the University of Chicago, Chicago, USA

3 Department of Mathematics, New York University, New York, USA

4 Ruvos, Tallahassee, USA

5 TMW Center for Early Learning and Public Health, University of Chicago, Chicago, USA

6 Department of Psychology, University of Chicago, Chicago, USA