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Parents' use of number talk with young children: Comparing methods, family factors, activity contexts, and relations to math skills☆

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ABSTRACT

Variability in children's early math skills may stem from differences in experienced math learning opportunities at home. Previous studies have quantified math-learning opportunities at home through engagement with math-related activities or exposure to number talk during parent-child conversations, but little is known about how specific activities relate to talk about math. The current study aims to explore how math activities and number talk occur at home and understand how these associations may vary across different types of families. Number talk was quantified for 97 parent-child dyads during in-lab and in-home play sessions. Results show that time spent in math-related activities during home observations was related to parent reports of math activities as well as parent number talk at home and in the lab. Interestingly, during non-math-related activities, we found that parents with higher education levels and parents of boys used more number talk than parents with lower education levels and parents of girls. During math-related activities, however, no such educational or gender differences were seen in number talk. These results highlight the importance of considering the contextual influences and constraints that affect children's opportunities for learning math, especially when designing interventions to increase math learning in families' homes.

At the time of school entry, children already differ in their mathematical abilities (Duncan et al., 2007). Approximately 5% of children starting kindergarten can already solve simple number problems, whereas another 5% cannot yet identify numerals or count to ten (Bassok and Latham, 2014; Engel et al., 2013; Zill and West, 2001). Early math skills have been shown to predict children's subsequent math and overall academic achievement (Bailey, Siegler, & Geary, 2014; Duncan et al., 2007). Thus, understanding the origins of individual differences in young children's math abilities is of paramount importance to combat low math achievement and to prepare students with the foundations to succeed in school.

Many past studies have examined how parents support their children's math learning through one of two approaches: the types of activities that parents engage in (e.g., playing board games or puzzles) and the talk that parents use (e.g., using number words or words to describe spatial concepts). It remains unclear how these two measures are related to one another, as conversations about math can occur in any activity, regardless of whether the activity is explicitly focused on math or not. In this study, we compare these two approaches to measuring math input and assess how they relate to one another. In addition, we examine how reports of math activities and observations of number talk vary between dyads as a function of parent or child characteristics (i.e., parental math anxiety and beliefs, parental education, child gender).

1. Measures of parental support for math learning

To date, most research addressing parental support for math learning, or the Home Numeracy Environment (HNE), has relied on parental reports of activities. In this work, researchers typically measure a wide range of practices in the home that may expose children to math concepts that include playing board games, counting objects, or talking about money. Early studies indicated that children with more exposure to numeracy activities tend to

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have stronger math skills (Blevins-Knabe & Musun-Miller, 1996; LeFevre et al., 2009). Although several additional studies have since replicated these findings (Dearing et al., 2012; Kleemans, Peeters, Segers, & Verhoeven, 2012; Manolitsis, Georgiou, & Tziraki, 2013; Niklas & Schneider, 2014; Ramani, Rowe, Eason, & Leech, 2015), others find no links between the HNE and children's math learning (e.g., DeFlorio & Beliakoff, 2015; Missall, Hojnoski, Caskie, & Repasky, 2014) or inconsistencies in which specific types of activities included in these scales predict math skills (LeFevre et al., 2009; LeFevre, Polyzoi, Skwarchuk, Fast, & Sowinski, 2010). Therefore, the impact of the HNE on math skills remains unclear.

In contrast, a growing body of research has utilized direct observations to examine how parents talk about math concepts with their children. Measures of parents' math or number talk (i.e., talk consisting of number words such as *one, two,* or *three*) differ from these traditional survey-based measures. Surveys often focus on the activities parents and children engage in, assuming that certain activities involve a discussion of math concepts, whereas measures of math or number talk instead focus on parent speech regardless of the context of that speech. Although fewer studies have employed this method, the extant literature consistently points to the notion that children who are exposed to more number talk from their parents have stronger math abilities (Casey et al., 2018; Elliott, Braham, & Libertus, 2017; Gunderson & Levine, 2011; Levine, Suriyakham, Rowe, Huttenlocher, & Gunderson, 2010; Susperreguy & Davis-Kean, 2016). Some evidence suggests that specific types of number talk are more strongly related to children's skills than others, such as counting and labeling sets of objects or using larger numbers (Elliott et al., 2017; Gunderson & Levine, 2011).

Two recent studies compared parent report and direct observation to obtain a more complete picture of children's exposure to math-related learning opportunities in the home. First, Ramani and colleagues (2015) collected both parent reports of math activities as well as direct observations of parental number talk during the Three Bags Task (Vandell, 1979). In this task, parents and children were given a book, a puzzle, and a simple board game. Reports of math activities predicted children's foundational math skills such as counting, whereas number talk during the Three Bags Task predicted children's advanced math skills such as identifying the larger of two verbally presented numbers. However, no information regarding the relation between parental report of math activities and number talk during the direct observations was provided. Second, Mutaf Yildiz, Sasanguie, De Smedt, & Reynvoet (2018) also examined both parent reports of math activities and observational measures of number talk during a block building and a storybook reading activity. In this study, math activities and the number-related talk during observations were not correlated. In contrast to the findings of Ramani and colleagues (2015), parent reports of math activities were positively correlated with children's calculation skills, but number talk was negatively related to children's calculation skills. Together, these findings suggest that math activities and conversations about number reflect unique constructs and opportunities for children to learn math at home.

2. How number talk occurs across activities

Expanding our understanding of the relation between number talk and math-related activities, including how number talk occurs within and outside of the context of math-related activities, is critical to understand how these factors might promote children's math learning. In other words, it is necessary to explore number talk that occurs during activities that directly expose children to math concepts, as well as those that may not. As suggested above, direct observations of number talk may be influenced by the types of activities that parents and children engage in (Mutaf Yildiz et al., 2018). For example, levels of number talk differ greatly across reading a counting book, doing a puzzle, or playing a board game, as rates of number talk during a board game were two times higher than rates of number talk during a puzzle, and over three times higher than during a counting book (Ramani et al., 2015; see Daubert, Ramani, Rowe, Eason, & Leech, 2018, for a more detailed analysis). Another study shows that providing parents with prompts to increase numeracy activities significantly increases number talk (Vandermaas-Peeler, Boomgarden, Finn, & Pittard, 2012). Together, these findings show that different activities encourage varying amounts of parent number talk, and that parents may respond to the same opportunity for number talk in differing ways.

Other studies have examined how parents talk about numbers within the context of activities that are not explicitly related to math. For example, one study examined how parents and children discussed mathematical concepts while engaging in shared book reading (Anderson, Anderson, & Shapiro, 2004). Nearly all families in this sample engaged in some math talk, demonstrating that math-related conversations can emerge from more neutral activities, although the amount of math talk may also depend on characteristics of the particular book that parents read (Hojnoski, Columba, & Polignano, 2014). Other work has examined how parents use number talk during mealtimes (Susperreguy & Davis-Kean, 2016) and found that mothers who used more number talk during mealtimes with their children tended to have children with stronger math skills one year later. As such, number talk appears to predict children's math skills even when it occurs outside of the context of math-related activities, but some activities seem more likely to foster conversations about math than others.

3. Predictors of variability in parental support for math learning

Although many studies have examined how variability in the HNE or number talk relates to children's math skills, we know much less about the factors that predict individual variability in parents' engagement in math activities or how parents use number talk in different types of activities. Below, we review evidence linking parents' attitudes and beliefs, parents' socioeconomic status, and children's gender to parental provision of math learning opportunities in the home.

Math beliefs and anxiety. Theories such as academic socialization and the theory of reasoned action suggest that parents' beliefs about and attitudes toward math should relate to their practices in the home to support math (Ajzen & Fishbein, 1980; Taylor, Clayton, & Rowley, 2004). The existing empirical literature regarding parents' beliefs is largely consistent with this claim, as parents who believe that math skills are more important or believe that they are responsible for children's learning report engaging in activities to support math learning more frequently than do their peers (Missall et al., 2014; Sonnenschein et al., 2012).

In contrast, the evidence regarding parents' negative attitudes about math is mixed. While some studies found that parents with more positive math attitudes who report enjoying math activities tend to engage in math activities more frequently at home (Blevins-Knabe, Austin, Musun, Eddy, & Jones, 2000; LeFevre, Polyzoi, Skwarchuk, Fast, & Sowinski, 2010), other studies found no such link between parents' math attitudes and the HNE (Skwarchuk, Sowinski, & LeFevre, 2014; Sonnenschein et al., 2012). In this study, we examine parents' extreme negative attitudes about math, particularly their math anxiety (Ashcraft, 2002), consistent with some recent work indicating that math anxiety is negatively related to parents' reports of math activites with their preschool-aged children (authors, in press). In contrast, only one study has examined links between parents' beliefs and number talk and found no links between parents' preference for math and their number talk (Elliott et al., 2017). In sum, parents' beliefs and anxiety about math are likely related to the frequency with which they engage in math activities, but little is known about how these psychological factors relate to parents' number talk, either overall or differentially across various types of activities.

Socioeconomic status (SES). In addition to parents' math anxiety and beliefs about math, some work suggests that parent SES may also positively predict math enrichment at home, both in terms of the HNE as well as number talk. Some evidence demonstrates that income and educational attainment, two key components of SES, are predictive of math activities at home (DeFlorio & Beliakoff, 2015; Levine, Ratliff, Huttenlocher, & Cannon, 2012; Ramani & Siegler, 2008; Saxe, Guberman, & Gearhart, 1987). Similar findings are seen with measures of parent number talk (Levine et al., 2010), but several additional studies have observed null or even negative associations between SES indicators and the HNE (Hart, Ganley, & Purpura, 2016; LeFevre et al., 2010; Niklas & Schneider, 2014; Tudge & Doucet, 2004). Thus, SES may relate to both the activities and conversations that parents engage in to support their children's math learning, yet these associations may be much more complex if parents of low and high SES use number talk across various activities in different ways.

Child gender. Finally, in considering parental provisions of math learning opportunities at home, it is important to recognize the dyadic nature of these interactions and account for the ways that parents' behaviors may be shaped by perceptions about their children. In particular, several studies have examined how children's gender related to the HNE and the gender stereotype that boys naturally tend to excel in math (Bandura, Barbaranelli, Caprara, & Pastorelli, 2001; Frome & Eccles, 1998; Jacobs & Eccles, 1985). Parents may underestimate girls' abilities and interest in math and create a different HNE for girls. Indeed, survey-based studies indicate that parents of boys report significantly higher levels of the HNE than do parents of girls (Hart et al., 2016) and mothers are more likely to purchase science- or math-related toys for their elementary school-aged sons than daughters (Jacobs & Bleeker, 2004). Similarly, mothers of preschool-aged children appear to use more number talk during free play with boys than with girls (Chang, Sandhofer, & Brown, 2011), whereas gender differences in number talk are not seen within resource distribution contexts, i.e., situations where items are shared between two or more parties (Chernyak, 2018). Thus, gender bias in number talk may vary across different activities and play contexts. Understanding how number talk occurs across different types of activities for boys and for girls is particularly interesting given that boys and girls often play with very different types of toys that may be perceived differently by parents. Toys that are traditionally associated with boys and gender-neutral toys, such as action figures and board games, respectively, are perceived to have more educational value than toys that are traditionally associated with girls, such as dolls (Blakemore & Centers, 2005), and so it is possible that parents may interact with their children differently depending on the toys and activities they are using. However, no research has directly compared how parents of boys and girls differentially use number talk across a range of activities.

4. The current study

In this study, we addressed four research questions. (1) To what extent are various measures of math learning opportunities related to one another? To answer this question, we examined interrelations between various measures of math learning opportunities, including parental number talk and the amount of time spent in math activities during brief home observations, as well as how these measures relate to more common measures such as parents' reports of frequency of math activities in the past and number talk in a structured, homogeneous lab setting. In these analyses, we were particularly interested in how math activities and number talk co-occur in the home, i.e., whether parents who chose to spend more time in math-related activities used more number talk with their children during these interactions. (2) Do associations between math activities and number talk vary depending on parent and child characteristics? Specifically, we utilized hierarchical linear modeling (HLM) to examine within-individual variability in number talk across activities. (3) Do measures of math learning opportunities relate to children's math outcomes? We hypothesized that the various methods used to measure math-learning opportunities would be correlated with one another and that parents would be more likely to use number words in math-related activities. Additionally, we expected the strength of this association to vary depending on child and parent characteristics and we predicted that all math learning opportunities would relate to child math achievement.

5. Methods

5.1. Participants

A total of 105 parent-child dyads participated in this study. However, eight dyads had to be excluded from the final sample due to attrition prior to the first home observation (5 dyads), poor audio quality of the home observations (1 dyad), refusal to complete parent-report measures (1 dyad), or speaking in a language other than English for a substantial amount of time (>10%) during all in-home observations (1 dyad). Seven other families used another language occasionally during either the lab or home free play observations; for these families, only conversations in English were included in the analyses. If the parent spoke in another language for a substantial amount of the interaction (i.e., more than 10% of the ten minutes of play), this session was excluded from analyses (three home free play sessions and one lab free play session).

The final sample consisted of 97 parent-child dyads (mean age at the beginning of the study = 3 years 11 months; 50 boys). Of the parents, 94% were mothers and 85% were White. Parents had relatively high levels of education, i.e., 16% of parents had an associate's degree or less, 32% of parents had a bachelor's degree, and 52% had a graduate degree. Most families in this sample were monolingual, as over 77% of parents reported that their child only heard English or heard English at least 95% of the time at home. However, 5% of families used a language other than English more often or as often as English at home, which included families that primarily spoke Spanish or Bulgarian. Most children in this sample were enrolled in some form of regular childcare either in preschool, daycare center, or another home (74%); children reportedly spent an average of 28 h per week in these out-of-home care arrangements.

5.2. Procedures

This study was part of a larger longitudinal study that examined the relation between parent and child cognitive abilities and parent-child interactions during play sessions in the lab, as well as at home. The longitudinal study started when children were 46 months old and followed them for six months with visits to the lab approximately every two months. Recruitment was accomplished through e-mail, phone, and mailing lists. Parents were told that the researchers were studying general cognitive development and math was not mentioned as a specific focus to keep parent-child interactions as natural as possible.

All data included in this paper were gathered during the parent-child dyad's first two visits to the lab and the three home video calls to observe interactions at home approximately every two weeks between these lab visits. The average time between lab visits was 8.84 weeks and ranged from 6.71 weeks to 14 weeks. The average time between the home video calls was 2.23 weeks, ranging from 0.43 weeks to 8.14 weeks. Most dyads completed all three home free play sessions (79%), but 15% of families completed only two home free play sessions and 5% completed only one home free play session.

During each visit to the lab, parents and children were first asked to play in a room filled with a standard set of toys for ten minutes (referred to as *lab free play*). The set of toys consisted of books, cars, puppets, wooden blocks, coloring paper and pencils, play food, a cash register, and dining utensils. The entire lab free play session was video recorded for later analyses. After the lab free play session, parents completed the home numeracy questionnaire, the math anxiety rating scale, and a brief demographic survey (see below). In addition, parents and children also completed a battery of cognitive tests that are not included in the present paper.

Between the two visits to the lab, parents and children participated in three video conference calls from their homes (*home free play*). During these calls, parents were asked to play with their child for 10 min using their own toys. Families connected with a researcher using their own laptop, tablet, or phone and received live instructions to position their camera so that the parent, child, and any toys could be seen clearly. Typically, the parents' phone or laptop would be placed on the floor far enough away from the parent and child to be visible. During the play sessions, the researcher's camera and microphone were disabled to avoid potential distractions for the family. The entire home free play session was recorded for later analyses.

5.3. Measures

Home math activity coding. Parents' and children's activities were coded during the 10-minute home free play sessions. Activity codes were defined empirically based on an extensive, iterative review of the recorded sessions by the first and third author. Specifically, coders compiled a description of all activities that parents and children engaged with during over 50 video sessions, which were then grouped based on similarity and combined (e.g., playing piano, painting, and writing with a marker were collapsed into a single *arts and crafts* code). The final set of codes used in these analyses is shown in Table 1.

For each home free play session, parents' and children's activities were coded based on the toys present in the video and the way these toys were used. Parent-child conversation during each activity was also used to help code activities (e.g., determining when an activity started if the toys were not visible or determining what children were playing with). Specifically, for each activity, the start and stop time, the specific activity coded, and whether the parent, the child, or both were engaged in the activity was noted. Parent and child activities were coded separately in order to capture times in which the parent and child were engaging in different activities, which was infrequent in these data and typically occurred during transitions between activities (e.g., if the parent continued an activity while the child moved on to a new activity or was briefly distracted). When parent and child activities codes did not match, data from the parent codes were used, given that we were interested in predictors of parental behaviors.

To ensure that the activities were coded reliably (e.g., activities would be assigned the same code by different coders) and that the designated start and stop times were reliable (e.g., different coders marked the same time stamp at which parents transitioned from one activity to another), a subsample of sessions were double-coded. Specifically, the first and third authors double-coded 35 randomly selected home free play sessions (13.3% of all home free play sessions; 347.03 min of double-coded data). Reliability in timing of when an activity occurred was particularly important to ensure that number talk was marked in the correct activity. As such, intercoder reliability was checked at the second level. For each second of double-coded data, agreement between the two coders was checked, such that if one coder marked the same activity as starting one second later than the other, this second would be coded as a disagreement whereas later seconds would be coded as agreements. The two coders reached 91% agreement on timing and categorization of parents' activities.

Activities were then coded based on whether they are typically included in surveys of math activities and explicitly involved math concepts. Although many activities that do not explicitly involve math concepts could nonetheless include discussion of math content (e.g., counting while reading a storybook or comparing sets of objects while playing with cars), our definition of math activities was based on play with toys and more general activities that are reported on home numeracy environment surveys as math-related. In general, activities that explicitly involved math concepts were labeled math-related and those that did not (but could nonetheless be made into opportunities for learning math) were labeled as not math-related. Activities that involved numbers, math or spatial skills, or manipulation of quantities were coded as math-related activities. This included board games, building/making activities, card games, cash register play, matching games, and puzzles. Remaining activities, such as playing with dolls or reading a book, were coded as non-math-related. Although parent talk was used to help code activities, the use of number talk did not necessarily indicate that an activity was math-related (e.g., a parent saying "why don't we play with your three dolls now?" would indicate the activity was *Dolls/Action Figures* and thus not math-related, despite the use of number words). Similarly, math-related activities were coded as such regardless of the content of the parent-child conversations. The proportion of time spent in math activities was calculated as the total number of seconds that the parent was coded as engaging in a math-related activity divided by the total number of seconds coded in the video. To control for chance agreement, a Cohen's Kappa was calculated for whether activities were coded as number talk, and a value of .95 was found.

Home number talk. Home free play videos were also manually transcribed and coded for number talk at the word level. Transcriptions were completed by trained research assistants, who were instructed to type out all spoken words in a video and were checked for accuracy by a second trained research assistant. Consistent with past work, number talk included parents' uses of all numbers zero or greater (Elliott et al., 2017; Gunderson & Levine, 2011; Levine et al., 2010). The number word "one" was coded only when used numerically (e.g., "There is one toy here") but not when used non-numerically (e.g., "I want this one"). The frequency of number talk was determined by tallying all instances a number word was said, with all types of number words (e.g., counting present vs. absent objects, small and large number words) combined. These frequencies were checked by a second coder for each session, and discrepancies in the count of number talk, which were observed for 39 of the 263 videos, were resolved by a third coder. The proportion of parent number talk was then calculated by dividing the frequency of parent number talk by the total number of words uttered by the parent during the session.

Number talk proportion scores were calculated for each individual activity. Given the large number of activities in which no number talk was used (58%), activity-level number talk was recoded to a dichotomous variable indicating whether any num-

Table 1
Codes used to describe activities during home free play sessions.

Activity category	Description	Percentage of activities coded	Average length of activities
Math-related			
Board Games	Playing a board game, including those with dice/spinners (e.g., Monopoly) as well as without (e.g., Candyland)	6%	5.47 (3.80)
Card Games	Playing a game with cards (e.g., playing with a deck of cards, Uno)	2%	5.55 (3.74)
Puzzles	Any activity that required children to place correct shapes in correct slots	5%	5.09 (3.92)
Matching Games	Games which involve memory (e.g., finding matching cards)	1%	7.96 (2.37)
Cash Register	Any instance when a child/parent is playing with a cash register or money	1%	1.76 (1.52)
Building/Making	Any activities that involved three-dimensional construction (e.g., Legos, Playdoh)	16%	4.73 (3.68)
Non-math-related			
Cars/Trains	Activities in which parents and children played with toy vehicles (e.g., trains, car ramps)	9%	3.27 (3.15)
Sports	Any activity involving physical activity and common sports equipment	2%	4.59 (3.26)
Kitchen/Food	Any activities that involve play food or a play kitchen	3%	3.49 (3.28)
Arts and Crafts	Any activities that contain a creative aspect (e.g., writing, painting, playing an instrument)	5%	6.05 (3.98)
Dolls	Activities with toys or objects that are characters or could serve as a character (e.g., action figures, dolls)	16%	4.26 (3.61)
Books	Reading a book with the child	2%	5.19 (4.03)
Other	Any other activity outside of those above (e.g., imaginative play without toys, gross motor play)	7%	2.14 (2.17)
Transition	Any time between activities when parents were not clearly engaged in one activity	27%	0.74 (0.92)

Note. Length of activities coded are shown in minutes (with standard deviations in parentheses) and represent how long activities that were coded as each type persisted, on average.

Table 2
Descriptive statistics for key study variables.

Variable	*M* (SD)	*N*
Time spent in math activities (in percentages)		
Home Free Play Session 1	45.19 (43.86)	91
Home Free Play Session 2	41.93 (43.39)	90
Home Free Play Session 3	44.64 (44.70)	82
Average	42.89 (32.30)	97
Home number talk proportion scores (in percentages)		
Home Free Play Session 1	1.03 (1.20)	87
Home Free Play Session 2	1.37 (1.66)	88
Home Free Play Session 3	2.52 (3.50)	80
Average	1.58 (1.50)	97
Lab number talk proportion scores (in percentages)		
Lab Visit 1	1.31 (1.08)	92
Lab Visit 2	1.97 (1.62)	84
Average	1.66 (1.21)	97
Parent-reported math activities		
Lab Visit 1	1.62 (0.53)	96
Lab Visit 2	1.79 (0.60)	90
Average	1.70 (0.53)	97

Note. Number talk proportion scores reflect the count of parents' number words used divided by the total count of all words used by the parent. Scores above three standard deviations over the mean were removed from all analyses. For parent-reported math activities, values reflect the frequency of various activities occurring at home (0 = *never*; 1 = *a few times a month*; 2 = *about once a week*; 3 = *a few times a week*, 4 = *almost daily*).

ber talk occurred in the activity or not. Additionally, we examined parental number talk across the entire home free play session. For parents and children who engaged in a single activity during the session, this was identical to the number talk described above. However, for parents and children who engaged in multiple activities throughout the session, overall number talk was the sum of parent number talk in each activity. Fewer sessions included no instances of number talk (15%), and so session-level number talk was modeled continuously. Eight cases were removed as outliers from these analyses given proportion scores over three standard deviations above the mean (see Table 2 for descriptive statistics for each session after outliers were removed from the sample).

Lab number talk. Similar to the way home number talk was measured, all videos of the lab free play sessions were transcribed, and parental number talk, total talk, and number talk proportion scores were calculated by dividing parental number talk by the amount of total talk. Frequencies of number talk were checked by a second coder for each session, and discrepancies in the count of number talk, which were observed for 70 of the 176 videos, were resolved by a third coder. Number talk proportion scores were also moderately correlated between the first and second lab visits, $r = 0.22$, $p = .049$, so number talk proportion scores were averaged across the two lab free play sessions. Two dyads were missing lab free play data from the first session and twelve dyads were missing data from the second lab session. Additionally, three sessions were excluded as outliers as parents' proportion scores fell over three standard deviations above the mean.

Parent-reported math activities. To measure the time parents spent with their children engaging in various types of activities, parents were given the Home Numeracy Questionnaire (LeFevre et al., 2009). Parents were asked to self-report how often they had engaged their child in 20 numeracy activities, including counting objects, playing board games with a die or spinner, or measuring ingredients when cooking, over the past month on a five-point scale ranging from 0 (*did not occur*) to 4 (*almost daily*). Internal reliability for this measure was high ($\alpha_{\text{Visit 1}} = .79$ and $\alpha_{\text{Visit 2}} = .84$). An additional 20 items from the original scale describing literacy or motor activities were administered but not utilized in these analyses. Parents completed this survey at both lab sessions; responses were averaged to form a composite, $r = 0.80$, $p < .001$.

Math anxiety. Parents completed a paper version of the Mathematics Anxiety Rating Scale (MARS), which consists of 30 items describing various mathematical situations, such as *taking the mathematics section of a college entrance examination*. Parents were asked to report their anticipated level of anxiety in these situations on a five-point scale, with higher values corresponding with higher levels of anxiety. Responses were averaged across all items to represent the overall math anxiety of the parent. As shown in a previous study, the reliability of this questionnaire was .96, indicating high internal consistency (Suinn & Winston, 2003). One parent failed to complete this questionnaire at the first visit but did have valid data from a later time point not included in this study. Given high autocorrelations between two time points in our study ($r = 0.93$), math anxiety scores from this later survey were used for this one parent.

Math beliefs. To measure academic beliefs for their children, parents also completed a measure of academic benchmarks drawn from the Home Numeracy Questionnaire (LeFevre et al., 2009). Parents rated how important they believe it is for their child to reach each of four math-related benchmarks prior to entering kindergarten (e.g., "Count to 10"; "Simple sums") on a 5-point scale. The ratings were averaged to derive a total score ($\alpha = 0.76$). For two parents who did not complete this measure at the first lab visit, survey responses from the second visit were used instead ($r = 0.78$ between these two time points for the rest of the sample). Parents also completed four items describing literacy benchmarks, which were not utilized in this study.

Child math skills. Children's math skills were assessed at the second visit to the lab using the Test of Early Math Abilities (TEMA-3, Ginsburg and Baroody, 2003), a standardized assessment of young children's formal and informal number knowledge. The TEMA-3 has been validated with children between the ages of 3 and 8 years. Past work has demonstrated high levels of internal consistency and test-retest reliability as well as content-description validity and criterion-prediction validity (see Hoffman & Grialou, 2005, for a detailed psychometric review). The TEMA-3 was administered by the second author or by a female graduate student or one of four female full-time research staff members trained and supervised by the second author (including reviewing video-recorded and live administrations and being observed during administrations). Given the narrow age range of children in this study, we used raw scores on this assessment in our analyses.

5.4. Analysis plan

Interrelations between measures of math input. As a preliminary step, we tested whether time spent in math activities at home and number talk in this context correlated with one another. We then estimated a series of three-level generalized hierarchical linear models (HLMs) to account for within-person variability in number talk across activities. In contrast to the correlations described above, these analyses allowed us to explore whether parents used more number talk during certain activities than others. In these models, activities were modeled at level 1, with observations modeled at level 2 and families modeled at level 3. As such, we accounted for the fact that families may engage in similar levels of number talk across home free play sessions and may show similar levels of number talk across activities within the same home free play session. Given the low frequency of number talk within individual activities, we estimated whether parents used any number talk during each activity using logistic HLMs.

Level 1 predictors included whether the activity was math-related, which was dummy coded, as well as the length of time spent in the activity in seconds and the number of words used by the parent during this activity. No level 2 predictors were included, but level 3 predictors included parents' math anxiety and math beliefs as well as their education as well as children's gender (0 = female, 1 = male). Education was dummy coded (Bachelor's degree and graduate degree, with less than college as the reference group). We were primarily interested in the estimate for math-related activities at level 1, indicating whether number talk was more or less likely among math-related activities, and the estimates at level 3, indicating whether certain types of parents were more likely to engage in number talk in general (i.e., regardless of activities). In addition to these theoretically identified factors, i.e., parent gender (0 = female, 1 = male) was also included as covariates at level 3. As such, mothers with an Associate's degree participating with their daughters were the reference group in these analyses.

Variability in associations between number talk and math activities across families. We then included cross-level interactions to address whether math anxiety, math beliefs, or demographic factors predicted the strength of the relation between whether an activity was math-related and the likelihood of parents using number talk during that activity. These analyses revealed whether there were between-person differences in how much parents talked about number across different types of activities. Each interaction was first tested individually, with significant interactions then entered into a single model as a robustness check.

Relations between math input and children's math skills. Finally, as a post hoc analysis, we explored how each of the measures of math learning opportunities (i.e., number talk at home, time spent in math activities at home, number talk in the lab, and survey reports of math activities) related to children's math skills. Each predictor was individually regressed on children's math abilities at the second home visit, assessed by the TEMA-3, as well as parent education and race/ethnicity, and child gender.

6. Results

6.1. Preliminary analyses

Throughout the 10-minute free play sessions, parents and children engaged in 1–14 different activities, with an average of 3.1 different activities. Activities ranged in duration from 3 to 714 seconds ($M = 203.61$, $SD = 212.02$). 2% of activities lasted 10 seconds or less, which were primarily transitions between activities, 36% of activities lasted between 11 seconds and one minute, 36% lasted between one and five minutes, and 27% of activities lasted longer than five minutes. Table 1 shows the percentage of activities that were classified into each code; of the 799 activities that were coded for the 263 home free play sessions across our 97 parent-child dyads, 30% were coded as math-related. Additionally, Table 1 shows the average length of activities that were classified into each code. Notably, although transitions were coded most frequently, these activities were often quite short, such that the average amount of time in transition for each video was 35.91 seconds ($SD = 61.31$). We found between 0 and 205 number words per activity ($M = 4.79$, $SD = 15.38$) resulting in an average number talk proportion score of 0.014 for each individual activity ($SD = 0.03$). Furthermore, parents used between 0 and 205 number words across the entire home free play session ($M = 14.43$, $SD = 25.35$) resulting in an average proportion of number talk across the entire home free play session of 0.016 ($SD = 0.02$). Parents used a total of 0 to 62 number words across the two lab free play sessions ($M = 10.96$, $SD = 8.73$ at visit 1 and $M = 15.85$, $SD = 13.45$ at visit 2) resulting in average proportions of number talk of 0.013 ($SD = 0.01$) and 0.020 ($SD = 0.02$) for the two lab free play sessions respectively.

Across the three home free play sessions, time spent in math-related activities during the third free play session was significantly correlated with time spent in math-related activities during the first and second session, $r(76) = 0.31$, $p = .006$, and $r(79) = 0.29$, $p = .010$, respectively, but associations between the first two free play sessions did not reach statistical significance, $r(83) = 0.14$, $p = .198$. In contrast, the proportions of parental number talk were unrelated across time (first and second home free play sessions: $r(77) = 0.09$, $p = .456$; first and third home free play sessions: $r(72) = 0.13$, $p = .286$; second and third home free play sessions: $r(73) = 0.14$, $p = .222$). Data across the three sessions were averaged for both time spent in math activities and proportion of number talk in order to obtain a more representative estimate of these

Table 3
Results from logistic hierarchical linear models predicting the occurrence of number talk in activities within home free play sessions nested in families, $N = 97$.

Fixed effects	Est. (S.E.)	Est. (S.E.)
Intercept	−2.89*** (0.77)	−3.80*** (0.86)
Activity characteristics		
Math-related activity	1.20*** (0.23)	3.90*** (0.78)
Activity time	0.00003 (0.001)	0.0005 (0.001)
Total number of words	0.01*** (0.001)	0.01*** (0.001)
Parent and child characteristics		
Parent math anxiety	−0.13 (0.18)	−0.13 (0.18)
Parent math beliefs	0.06 (0.15)	0.02 (0.16)
Parent education		
Bachelor's degree	0.70† (0.39)	1.38** (0.52)
Graduate degree	0.50 (0.38)	1.34** (0.51)
Parent is male	0.43 (0.48)	0.45 (0.49)
Child is male	0.36 (0.24)	0.81** (0.29)
Cross-level interactions		
Math-related activity × child gender		−1.46** (0.47)
Math-related activity × parent education		
Bachelor's Degree		−1.95* (0.80)
Graduate Degree		−2.26** (0.77)
Random effects	**Var. (S.E.)**	**Var. (S.E.)**
Parent	0.000 (0.000)	0.000 (0.000)
Visit	0.54 (0.31)	0.62 (0.34)

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

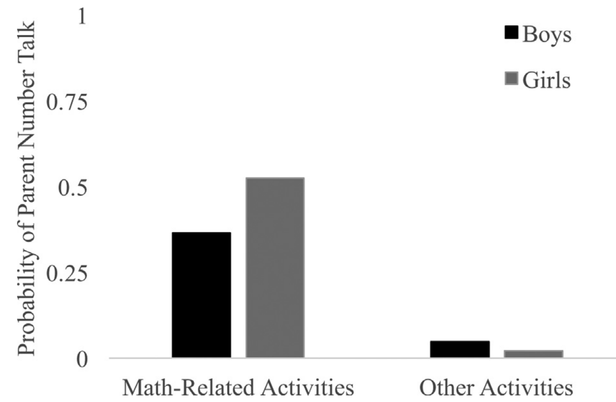

Fig. 1. Probability of parents using number talk in a given activity depending on child gender and the activity type. Probability estimates are based on the average activity (in terms of length and number of total words) and the average parent (in terms of math anxiety and math beliefs) in the reference category (mothers with an associate's degree).

interactions (i.e., based on 30 minutes of play rather than only 10). Descriptive statistics for key study variables are shown in Table 2.

6.2. *Associations among measures of math input*

We first examined whether parents who spent more time in math-related activities across the three home free play sessions engaged in significantly more home number talk. Bivariate correlations between observed time spent in math activities in the home and the proportion of number talk in the home were positive and highly significant, $r(95) = 0.35$, $p < .001$. As expected, observed time in math activities at home was significantly related to parent-reported math activities, $r(95) = 0.35$, $p < .001$. Additionally, observed math activities in the home related to parents' number talk in the lab context, $r(95) = 0.24$, $p = .019$. Surprisingly, parents' number talk at home was not significantly related to their number talk in the lab, $r(95) = 0.14$, $p = .188$, but was associated with parent reports of math activities, $r(95) = 0.21$, $p = .043$.

6.3. *Number talk within math activities*

In order to understand individual variability in parents' home number talk and home math activities, we then examined number talk separately for math and non-math-related home activities. Given the high right skew of the home number talk data (see Home Number Talk section in Methods), this variable was dichotomized to reflect whether any home number talk occurred in the activity; as such, outliers were not removed from these analyses.

Results of the logistic HLMs are shown in Table 3. These models estimate the likelihood of a parent using any number words during an activity in the home given characteristics of that activity and of the parent while accounting for similarities in number talk for activities that occur within the same home free play session and across sessions for the same family. We first estimated main effects of all predictors. At level 1, the odds of using any number words were 3.31 times higher in activities that were coded as math-related. These odds also increased by 1.01 for every additional word used by the parent in the activity, suggesting that parents were more likely to use number words during activities in which they were talking more in general. At level 3, parental education marginally predicted number talk. Specifically, parents with a bachelor's degree had 2.01 times higher odds of using number talk with their children in these activities compared to the reference group, parents with less than a bachelors' degree. A similar pattern was seen for parents with a graduate degree, but this association failed to reach significance. Parents' math anxiety and math beliefs were unrelated to number talk, as were parent race and parent and child gender.

6.4. *Individual variability in how number talk occurred within activities*

We then tested a series of cross-level interactions in order to examine whether the association between engaging in a math-related activity and number talk varied across families. Neither math anxiety nor math beliefs significantly predicted the strength of the association between math-related activities and number talk. In contrast, interaction terms for both child gender and parent education were significant. As is shown in Table 3, these interactions remained significant when entered into a single model. Although overall math-related activities were more likely to yield number talk than other activities, this association was stronger for girls than for boys. Put differently, although boys had 2.25 times higher odds of hearing number talk than did girls in activities that were not related to math, girls were somewhat more likely to hear number talk in math-related activities (odds ratio = 1.92), although this simple effect of gender was not significant. A plot of this interaction is shown in Fig. 1. Additionally, number talk in the two types of activities was modulated by parental education. During math-related activities, no differences in number talk were seen among parents with varying levels of education. However, in non-math-related activities, the odds of using any number talk were 3.99 and 3.80 times higher among parents with a bachelor's or graduate degree, respectively, compared to parents with an Associate's degree or less. A plot of the interaction is shown in Fig. 2.

6.5. *Relations between math input and children's math skills*

Several children were missing scores on the TEMA-3 due to failure to complete the full assessment ($n = 10$) or attrition ($n = 6$). As such, the sample in these analyses included only 81 children. Results from regression models are shown in Table 4. A non-significant trend was seen between number talk proportions scores across the three home visits and children's math achievement,

Table 4
Child math abilities regressed on measures of math learning opportunities.

Variable	B (S.E.)	B (S.E.)	B (S.E.)	B (S.E.)
Home number talk proportion scores	95.31† (48.37)			
Time spent in math activities		2.85 (2.18)		
Parent-reported math activities			2.61* (1.27)	
Lab number talk proportion scores				60.70 (56.34)
Child is male	−1.75 (1.35)	−1.55 (1.36)	−1.25 (1.33)	−1.37 (1.36)
Parent education				
Bachelor's Degree	4.01† (2.13)	4.22† (2.17)	3.46 (2.14)	4.16† (2.18)
Graduate Degree	3.77† (2.04)	4.13† (2.06)	4.30* (2.03)	4.05† (2.06)
Constant	8.32*** (2.00)	8.28*** (2.14)	5.04† (2.89)	8.48*** (2.18)
$F(4, 76)$	2.23†	1.66	2.32†	1.51

† $p < .10$.
* $p < .05$.
*** $p < .001$.

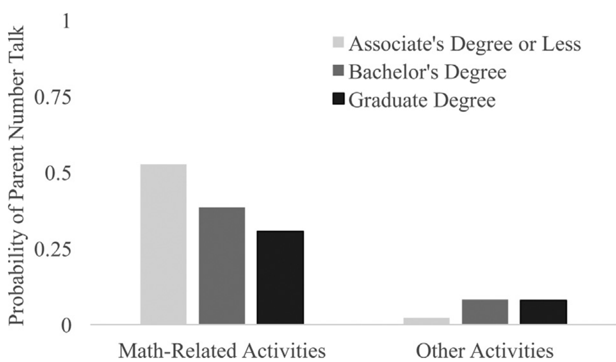

Fig. 2. Probability of parents using number talk in a given activity depending on parent education and activity type. Probability estimates are based on the average activity (in terms of length and number of total words) and the average parent (in terms of math anxiety and math beliefs) in the reference category (mothers who have a female child).

$r(79) = .20$, $p = .070$, but home number talk was significantly related to math ability when controlling for children's gender and parents' education. Specifically, a 1 SD increase in home number talk was associated with a 0.22 SD increase in math skills. Survey measures of the home numeracy environment also correlated with math skills, $r(79) = .22$, $p = .049$, and a 1 SD increase in this scale was associated with a 0.23 SD increase in math skills when controlling for covariates. In contrast, neither time spent in math activities nor number talk in the lab were associated with math skills in either correlational analyses, $r(79) = .12$, $p = .298$ and $r(79) = .11$, $p = .345$ respectively, or regression analyses.

7. Discussion

The goal of the current study was to understand how existing measures of math input relate to parents' engagement in math activities with their children at home, the number talk observed during these activities, and how this may vary across different types of families. Parents who spent more time in math activities also tended to use more number talk, both at home and in the lab, and report engaging in more math activities at home. In addition, math anxiety and math beliefs did not significantly relate to whether number talk was used during math-related or non-math-related activities. However, parents with higher education levels were more likely to use number talk than parents with lower education levels during activities not related to math. Significant gender differences were only seen in non-math-related activities, where parents were more likely to use number talk with boys compared to girls. Within math-related activities, however, girls were actually marginally more likely to hear number talk.

7.1. Measures of home math input

The observed time spent in math activities in the home was significantly related to the parent-reported math activities, demonstrating that parent-child interactions during these home observations were representative of what activities parents report they engage in with their children more generally. This suggests that our brief home observations via videoconference and parental report of math activities reflect similar aspects of children's opportunities to learn math at home.

In contrast, parent number talk at home was not significantly related to their number talk in the lab. This lack of an association points to the importance of considering the activities and the context during which parental number talk is being observed. In the lab context, parents and children were presented with a fixed set of toys that they had not necessarily played with at home, and so their talk may have differed in some systematic way. For example, they might have spent more time discussing features of the toys, exploring how to play with them or what to do. This is not to suggest that number talk in the lab is not a meaningful measure, as lab number talk did in fact correlate with time spent in math activities at home, but rather indicates that parent-child conversations in these more structured contexts may reflect a different underlying process than talk that occurs at home when playing with familiar toys. Understanding the differences in talk in these contexts is critical given that past research has examined number talk both at home (e.g., Levine et al., 2010; Susperreguy & Davis-Kean, 2016) and in lab settings (e.g., Elliott et al., 2017) and found relations to children's math abilities in both cases. These findings further suggest that it may be beneficial to use more than one measure to study parent number talk in conjunction with children's math abilities to better capture how math learning can be influenced. Additionally, it is critical to note that only home number talk and the survey measure of the math activities showed some evidence of relations with children's math skills, although these associations were rather weak. These tenuous associations are consistent with the mixed pattern of findings documented in past work (c.f., Elliott & Bachman, 2018a). As such, we argue that these analyses underscore the importance of parental math input as well as the need for more methodological work to explain these complex associations.

7.2. Math activities and number talk

We also found that parents were substantially more likely to use number words during math-related activities than non-math-related activities. Given that many of the activities coded as math-related had explicit links to number, such as board games, where players move their token a designated number of spaces, or playing with a cash register, where discussions of money presented numerous opportunities to talk about number and quantities, this may not be particularly surprising. These findings also align with previous studies that demonstrate that the types of activities that parents and children engage in may influence number talk (Mutaf Yildiz et al., 2018). However, the current study did not examine subcategories of math activities given the relative infrequency of each in this sample. Moreover, because we only examined whether number talk occurred, our findings cannot speak to variations in the amount or types of number talk that occur in different activities. Future research should examine the factors that predict parents' use and variations of number talk in specific math-related activities, such as puzzles and board games, given past research suggesting that the amount of number talk used across activities that are all related to math varies considerably (Daubert et al., 2018; Ramani et al., 2015).

Although number talk was more likely to occur in math-related activities, considerable talk did occur in the contexts of activities that were not explicitly math-related as well. This is consistent with past work showing that parents vary in their number talk during neutral activities such as eating (Susperreguy & Davis-Kean, 2016) or shared book reading (Anderson et al., 2004). However, it is unknown how number talk in the context of these different types of activities might differentially relate to children's learning. Although the extant evidence suggests that number talk occurring within math-related activities (e.g., Ramani et al., 2015) and other activities (e.g., Susperreguy & Davis-Kean, 2016) are both related to children's math skills, no study has directly compared how these differing types of input relate to children's math skills. Some research suggests that children may learn more from certain types of number talk, such as talk about numbers of objects that are physically present, large number words, or more advanced math concepts (Elliott et al., 2017; Gunderson & Levine, 2011; Ramani et al., 2015), and so if math-related activities elicit different types of number talk, we might expect different outcomes for children. Given the patterns of associations with children's math achievement shown here, one might expect that number talk, regardless of the context, would be predictive of math outcomes, as number talk at home but not time in math activities predicted math achievement. However, more work formally testing this hypothesis is needed.

7.3. Parental beliefs and number talk

In this study, we found no links between parental beliefs about math, including their math anxiety as well as their beliefs about how important math skills are for children starting kindergarten. On the one hand, this is somewhat surprising given that previous studies have documented positive associations between parents' beliefs about math and their engagement with the home numeracy environment (e.g., Blevins-Knabe et al., 2000; LeFevre, Polyzoi, Skwarchuk, Fast, & Sowinski, 2010; Missall et al., 2014; Sonnenschein et al., 2012). However, it is possible that the influence of these beliefs may not extend to parental talk, as suggested by the null associations between beliefs about math and number talk documented by Elliott and colleagues (2017). Alternatively, most studies examining parental math attitudes measure how much individuals enjoy math, and so it is possible that math anxiety, as measured in this study, operates differently from simply not liking math. To date only a handful of studies have examined relations between math anxiety and parenting, but this evidence suggests that extreme negative attitudes about math negatively predict parents' practices to support math with their young children (authors, in press) and may in fact shape the ways that parents interact with their children when teaching their children math (i.e., helping with math homework; Maloney, Ramirez, Gunderson, Levine, & Beilock, 2015). How these attitudes might in turn relate to parent number talk is less clear.

7.4. Family demographics and number talk

Although we initially found differences in the number talk used by parents with low and high levels of education, further analyses revealed that these differences were only seen in the context of activities that were not related to math. These findings offer an additional level of nuance to the growing body of research suggesting that parents with lower levels of income or education engage in math stimulation differently than their peers (Elliott & Bachman, 2018b). Specifically, past work documenting SES differences in parental number talk (e.g., Levine et al., 2010) may reflect the fact that these families also engage in activities to support math learning less frequently (DeFlorio & Beliakoff, 2015; Levine et al., 2012; Ramani & Siegler, 2008) and thus have fewer opportunities to discuss math concepts with their young children. However, these results suggest that when engaging in math activities, parents of high- and low-SES are equally likely to use number words, although it remains unknown whether these interactions differ qualitatively. Furthermore, parents in this sample were highly educated on average, and so parents with less than a Bachelor's degree were combined into a single group. Future research is needed to examine whether this pattern is seen among parents with lower levels of education as well, such as whether similar interactions would be seen among parents who did not finish high school or completed only high school.

Additionally, gender biases in children's exposure to number talk favoring boys were seen only when parents were interacting with activities that were explicitly not math-related. However, many studies have documented gender differences in both parental math activities in the HNE (Hart et al., 2016) as well as parental number talk (Chang et al., 2011). These past findings may be attributable to this interaction, as boys may receive more number talk at home *because* of these disparities in access to math-related activities. If so, more work is needed to understand how math-related activities can be encouraged for parents of girls (and parents with lower levels of educational attainment) to narrow differences in number talk exposure as a result.

7.5. Limitations and future directions

The current study builds upon the existing literature by providing insights into how various measures of math-related learning opportunities at home operate across families. However, some limitations need to be considered. First, home observations encompassed only a total duration of thirty minutes, and the lab observations were merely ten minutes long. Future research could examine more and longer observations, both in the lab and at home, to allow for a longer observation time and activities that may require more time (e.g., playing board games that take longer and require adding scores in the end). Recording parent-child interactions at home also offered several affordances, such as allowing dyads to interact with their own toys in a more comfortable setting, but recording video calls also presented numerous challenges, particularly in terms of video quality. Researchers did not interrupt parents to request that they adjust the camera, and so in many cases parents and children were not visible if they moved or were blocked by other objects in the room. In these and other cases where visual data were not clear (e.g., poor internet connectivity or lighting), coders relied on context clues and parent-child conversations to code behaviors. Even though independent coders were reliable, issues of the validity of these codes for dyads' actual behaviors remain.

Related to this concern, parents in this study were aware that their behaviors were being video recorded, and so it is likely that these observations differed from typical interactions in systematic ways (e.g., if parents were uncomfortable being recorded). Although no parents in this sample expressed concerns regarding recordings, parents may have nonetheless altered their behaviors during these sessions. In this study we also focused exclusively on parents' use of number words and thus have a very narrow view of the types of math conversations that may be occurring at home. We also only examined occurrences of number talk and therefore do not know much about the quality of the number talk or occurrences of conversations about a broader range of mathematical concepts. Many past studies have examined a wider range of math concepts, including spatial talk, sequencing, operations, and elicitations (e.g., Hojnoski et al., 2014; Pruden, Levine, & Huttenlocher, 2011; Susperreguy & Davis-Kean, 2016). By focusing exclusively on parents' use of number words, we may miss interesting and important patterns of how math talk more generally is used by different parents across different activities.

Additionally, the study focused on one parent only, and it is possible that parents' behaviors may also be related to the presence of other adults to help raise the child, their educational attainment and other characteristics. More generally, this sample was fairly homogenous in terms of education and race, and so it is unclear how these findings would extend to a more diverse and socioeconomically disadvantaged sample.

8. Conclusions

The current study indicates fairly high levels of engagement in math learning at home and demonstrates an agreement between parent-report and home observation measure of in-home play activities with their children. Further, this study is the first to compare number talk within math-related and non-math-related activities and shows that number talk is more likely to occur in the context of math-related activities at home yet still is somewhat frequent in other types of activities. Our results also indicate that educational and gender differences in number talk documented in past work are unique to non-math-related activities. Finally, only home number talk and the survey measure of math activities in the home showed some evidence of relations with children's math skills, suggesting that differentiating between the ways that parents provide support for their children's math learning is important for developmental research. Specifically, considering both the amount of math-related input as well as the context of that input is critical for future work examining differences in children's opportunities to learn math at home and how they actually impact children's math skills.

Author contributions

Jyothirmayi Thippana: Conceptualization, methodology, data curation, writing – original draft. **Leanne Elliott:** Conceptualization, formal analysis, investigation, writing – original draft. **Sarah Gehman:** Data curation, writing – review and editing. **Klaus Libertus:** Methodology, writing – review and editing. **Melissa Libertus:** Writing – review and editing, supervision, funding acquisition.

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