Parent Ratings of Preschoolers' Numeracy Skills are Predictive of Direct Assessments

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Declarations of interest: none

This work was supported by the Clifford B. Kinley Trust [grant number 208424]

Abstract

The current study examines whether parent ratings of children's numeracy skills are skill- and domain-specific to inform how to best utilize parent ratings in research. Children in the sample ($N=129$) ranged from 3.07 to 5.95 years old and 52.3% were male. Most (81%) of the children were White. Parents were asked to rate their children's counting, simple arithmetic, and numeral identification skills. Children were directly assessed on these skills, as well as their broad numeracy abilities, and other cognitive skills (e.g., expressive vocabulary, executive function). Parent ratings of their children's numeracy skills varied in terms of how skill-specific they were. However, aggregated parent ratings predicted directly assessed broad numeracy abilities, more so than other cognitive skills, providing evidence for discriminant validity. Findings inform how parent ratings may be used in research, especially in cases where children cannot be directly assessed, such as when large-scale parent surveys are used.

Keywords: parent ratings; numeracy skills; preschool

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1. Introduction

For parents, understanding where their children's numeracy abilities lie is essential for providing a high quality home numeracy environment (HNE; Zippert & Ramani, 2017)—a context related to preschool children's developing mathematical abilities (Anders et al., 2012; LeFevre et al., 2009; Napoli & Purpura, 2018; Niklas & Schneider, 2014; Skwarchuk, 2009; Skwarchuk et al., 2014, 2016; Thompson et al., 2017). Previous findings suggest that parent engagement in mathematics activities may be informed by their beliefs regarding their children's abilities (Blevins-Knabe & Musun-Miller, 1996); thus, age-appropriate and high-quality behaviors are contingent on parents understanding their children's numeracy skills. However, little research has addressed the alignment between parent ratings of their preschoolers' specific numeracy skills and direct assessments of these skills. Better understanding parent ratings of their children's numeracy skills may inform measurement of children's numeracy skills in research. Depending on how skill- or domain-specific (i.e., whether parents are rating children's specific versus broad numeracy skills, or general cognitive skills) these ratings are, parent ratings may be utilized as a reasonable substitute for certain direct child assessments when direct assessment data cannot otherwise be collected. Therefore, the goal of this study was to understand whether, and under which circumstances, parent ratings of children's specific numeracy skills may serve as a reasonable substitute for direct assessments. In particular, we examined convergent validity with direct assessments of respective specific numeracy skills as well as broad numeracy skills, and discriminant validity with direct assessments of other cognitive skills.

1.1 Importance of Parent Understanding of Children's Abilities

Clarifying how fine-grained parent ratings of their children's numeracy skills are informs researchers' understanding of the quality of children's home numeracy environment. Findings have long demonstrated that parents' understanding of their children's cognitive abilities is a critical factor related to parent-child learning interactions, as parents can only effectively scaffold their children's learning if they are able to accurately assess their children's skills (Huang et al., 2005; Hunt, 1961; Hunt & Paraskevopoulos, 1980; Miller, 1988). Parents who overestimate their children's skills may overwhelm children with distressing situations and parents who underestimate their children's skills may not adequately challenge or interest children (Hunt & Paraskevopoulos, 1980; Stoiber, 1992). To scaffold children's learning, parents must understand their children's abilities to determine what their children will be able to do with parental support, and what skills are beyond their children's reach (Gauvain, 2001; Vygotsky, 1978; Yelland & Masters, 2007). The extent to which parents understand their children's specific numeracy abilities may determine how skill-specific or broad their home numeracy activities will be.

1.2 Parent Ratings of Children's Numeracy Abilities

Research focusing on parents' understanding of their children's specific numeracy skills is rather scarce. Fluck, Linnell, and Holgate (2005) examined parent ratings of their children's understanding of counting and cardinality, whereas Zippert and Ramani (2017) examined parent ratings of a broader range of number skills. In the latter study (Zippert & Ramani, 2017), parent ratings of these skills were aggregated into conventional numeracy (i.e., rote counting, counting principles, numeral identification), advanced numeracy (i.e.,

symbolic magnitude comparison, symbolic arithmetic), and non-symbolic numeracy measures (i.e., non-symbolic magnitude comparison, non-symbolic addition), to examine parent accuracy of rating children's skills in these three broader areas. Their results indicated that across different numeracy skills, when parents made a prediction about whether their children would get items correct or incorrect (versus indicating uncertainty), parents were quite accurate. However, rates of accuracy varied across numeracy domains. When parents provided ratings of their children's abilities, they were most accurate in estimating their children's non-symbolic numeracy skills, followed by conventional numeracy skills.

In both studies, when parents of preschoolers made errors in estimating their children's numeracy skills, they typically overestimated their children's abilities (Fluck et al., 2005; Zippert & Ramani, 2017). Specifically, Fluck and colleagues (2005) found that mothers were unaware of the discrepancy between children's ability to count and their subsequent understanding of cardinality. Instead, they assumed that if their child could count, their child also had cardinal understanding. The authors suggested that mothers may not have seen many instances of their children exhibiting behaviors that were inconsistent with understanding cardinality. Findings from these studies suggest that parents may not be engaging children in HNE activities that are appropriate for their current abilities; based on their overestimation of their children's skills, parents may be engaging children in activities that are too difficult.

With regards to parents' confidence in rating their children's numeracy abilities, Zippert and Ramani (2017) found that parents reported being most unsure about how their children would perform on items related to advanced numeracy, compared to

conventional numeracy and non-symbolic number skills. Considering that parents in this study reported engaging their children in more conventional number-related experiences than advanced number-related activities (Zippert & Ramani, 2017), these findings are in line with Fluck and colleagues' (2005) explanation regarding the link between parents' more limited experiences with certain children's math skills and their more limited knowledge about these respective skills. Given that parents from Zippert and Ramani's (2017) study reported having fewer experiences with their children's advanced numeracy skills to draw their estimations from, they were more likely to indicate that they were uncertain about these skills.

1.3 Specificity of Parents' Numeracy Ratings

Overall, parents are less likely to engage in numeracy activities at home, relative to other learning-related activities (e.g., Blevins-Knabe et al., 2000; LeFevre et al., 2009). This suggests that parents may often be unfamiliar with their children's numeracy abilities. Hence, research should attend to a more nuanced understanding of parents' knowledge of their children's numeracy abilities. It is possible that when parents are asked to rate their children's specific numeracy abilities, they may base their ratings on their understanding of their children's broad numeracy abilities. Fluck and colleagues (2005) provide some evidence for this, as they found that parents may apply their knowledge of their children's numeracy skills in one area to another (i.e., equating counting to having cardinal understanding). However, no studies have directly addressed this hypothesis. Therefore, the current study adds to this scarce body of literature and addresses the specificity of parent ratings of children's numeracy skills by examining its convergent validity with direct assessments of respective skills and direct assessment of

broad numeracy skills (American Educational Research Association et al., 2014). Given the extent to which parents have been able to predict children's numeracy skills accurately in previous studies (Zippert & Ramani, 2017), we believe that it is unlikely that parent ratings of children's numeracy abilities are so broad that they are tapping into children's other cognitive abilities (e.g., literacy, executive functioning [EF]). However, the present study will examine whether parent ratings exhibit discriminant validity, as they should be more related to children's directly assessed math skills than directly assessed skills in other areas (American Educational Research Association et al., 2014).

We do this to better understand whether and when parent ratings may be used in lieu of direct assessment scores. Better understanding how to utilize parent ratings is valuable, given that parent ratings of their children's abilities are commonly used in research (Fenson et al., 2007; Gioia et al., 2003; Gresham & Elliott, 1990)—likely because these data are easy to collect. There are also challenges with directly assessing young children due to their attention spans and wariness of strangers (Vacc & Ritter, 1995). Furthermore, we expand on previous studies (Fluck et al., 2005; Zippert & Ramani, 2017) by using a larger sample size and extend the age range of our sample slightly beyond those included in the extant literature, so that our findings are more generalizable.

1.4 Parent Ratings as a Commonly Used Measure

Parent ratings are often used in place of direct measures of child skills across various cognitive and behavioral domains, and these parent ratings have frequently been found to be valid and reliable (Ezpeleta et al., 2015; Gresham et al., 2011; Rescorla et al., 2005). Parent ratings have also been used in large-scale longitudinal studies (e.g., the

Early Childhood Longitudinal Study), which many researchers rely on in their secondary data analyses. Given the frequency in which parent ratings are already used, it is worthwhile to examine whether they may be used as a reasonable substitute for direct assessments in particular instances, such as when direct assessments cannot be collected.

For example, new methods of efficient, large-scale, online data collection are becoming more commonly used (e.g., Amazon's Mechanical Turk [MTurk]; Buhrmester et al., 2018; Schleider & Weisz, 2015). However, child direct assessment data cannot be collected using these methods. MTurk, for example, pays workers to complete tasks (e.g., fill out surveys) and allows for rapid, low-cost data collection from diverse populations (Paolacci et al., 2010). However, researchers are not able to directly assess children through such means. It is valuable to determine how parents rate their children's specific numeracy abilities, to better understand how these ratings may be best used in research, as these findings may have implications for many researchers collecting large-scale survey data. Parent ratings of children's skills should not be used as a replacement for direct child assessment data in all cases. Rather, their use should be considered in instances where direct child assessment data cannot otherwise be collected, and only if parent ratings can be demonstrated to distinctly measure mathematics skills, which we test in the present study.

1.5 Present Study

In this study, we aimed to understand how fine-grained parent ratings of their children's numeracy skills (i.e., verbal counting, simple arithmetic, numeral identification) are, to better understand the circumstances in which parent ratings may

serve as a reasonable proxy for direct assessments. Specifically, we tested the following hypotheses (H):

1. Parent ratings of their children's specific numeracy skills will be related to direct assessments of these respective skills.
2. Overall, parent ratings of their children's specific numeracy skills will be better aligned with a direct assessment of children's *broad* numeracy abilities than to direct assessments of specific numeracy skills.
3. A latent variable comprised of parent ratings of children's specific numeracy skills will be predictive of direct assessments of children's broad numeracy abilities.
4. Parent ratings of children's numeracy abilities will be specific to numeracy and not be indicative of their overall cognitive abilities, such that aggregated parent ratings of children's numeracy skills will remain predictive of children's directly assessed broad numeracy abilities, even when including direct assessments of vocabulary and executive functioning (EF) in the same model.

2. Method

2.1 Participants

Participants were recruited from 18 preschools and childcare centers in the Midwestern United States. Parents of 129 preschool children provided consent for their child to be assessed and filled out a demographic questionnaire. Children included in the sample ranged from 3.07 to 5.95 years old ($M=4.62$) and 69 (52.3%) were male. Most (81%) of the children in the sample were White, 4.8% were Latino, 4.8% Asian, 2.4% African American, and 7% another race/ethnicity or multiracial. In terms of education,

26.4% of parents had a high school degree or fewer years of schooling, 27.1% had some college or an Associate's degree, and 46.5% had a Bachelor's or graduate degree.

Demographic characteristics of the sample are included in Table 1.

2.2 Measures

2.2.1 Parent questionnaire

Parents were asked to complete a background questionnaire. They reported demographics as well as ratings of their child's specific numeracy abilities. To determine parent ratings of their children's verbal counting abilities, parents were asked, "How high can your child count?" To determine parent ratings of children's numeral identification skills, parents were presented with numerals 1 through 15 and asked to circle all of the numerals that their child could identify. However, for these analyses, only items that corresponded with direct assessments of children's numeral identification ability (i.e., 1, 2, 3, 7, 8, 10, 12, 14, 15) were used; together, items showed high internal consistency ($\alpha=.93$). Parents were also asked to respond "yes" or "no" to the prompt, "My child can calculate simple sums (e.g., $1 + 1 = ___$, $1 + 2 = ___$)." Distribution of all key study variables are included in Table 1.

These three tasks were selected as they represent a broad range of skills in children's early math development (Purpura et al., 2013). In particular, numeral knowledge—which includes numeral identification—is an important predictor in the transition between early and later mathematics skills (Merkley & Ansari, 2016).

Additionally, basic counting has been found to be highly correlated with advanced counting (Nguyen et al., 2016; Purpura & Lonigan, 2015). Based on previous studies that have found that parents do not have an accurate understanding of children's cardinality

(Fluck et al., 2005), the present study did not include a measure of cardinality.

2.2.2 Direct child assessments

Trained assessors directly collected data on children's verbal counting, simple arithmetic, and numeral identification skills. These items were adapted from previous studies (Purpura & Lonigan, 2015). Children were also assessed on their broad early numeracy, expressive vocabulary, and EF skills.

2.2.2.1 Verbal counting

For verbal counting, children were prompted with, "I want you to count as high as you can starting with the number one. Go ahead." Children were stopped when they made an error or when they reached 100. The greatest number they counted to without making an error was recorded as their score.

2.2.2.2 Simple arithmetic

Children were shown five addition problems ($\alpha=.78$) that were printed on individual sheets of paper, and the equation was also verbally read (e.g., the assessor asked, "What is one plus two?" while pointing to " $1 + 2 = __\$ "). All addition problems were for sums less than five. Responses to each question were scored as either "incorrect"=0 or "correct"=1, and scores were summed.

2.2.2.3 Numeral identification

Assessors showed children cards with numerals printed on them and asked, "What is the name of this number?" Numbers assessed included: 1, 2, 3, 7, 8, 10, 12, 14, and 15 ($\alpha=.87$). If children said the names of individual numbers for double-digit numerals (e.g., "one and five" instead of "fifteen"), the assessor asked, "Do you know what they're called together?" Children received one point for each correct response and scores were

summed for a maximum of nine possible points. A side-by-side comparison of parent-rated and directly assessed numeracy skills is included in Table 2 and the specific parent rating items are presented in the Appendix.

2.2.2.4 Broad numeracy abilities

The Preschool Early Numeracy Skills Screener – Brief Version (PENS-B; Purpura et al., 2015) was used to assess children on their broad numeracy abilities ($\alpha=.88$ for the current sample). The assessment is comprised of 24 items that evaluate a broad range of early numeracy skills. The PENS-B takes approximately five minutes to administer and requires the assessment manual and scoring sheet (i.e., manipulatives are not used in the assessment). Specific skills that are assessed include: set comparison, numeral comparison, one-to-one correspondence, number order, numeral identification, ordinality, number combinations, and story problems. All 24 items of the PENS-B were administered, and children received one point for each correct response. However, a ceiling rule was applied during analyses and points were not counted after three consecutive incorrect responses (Purpura et al., 2015). Children's PENS-B scores were calculated by summing their correct responses. Scores ranged from 0 to 24 ($M=12.48$; $SD=5.90$). Previous work (Purpura et al., 2015) has indicated that the PENS-B has high internal consistency ($\alpha=.93$) and is correlated with the Test of Early Mathematics Ability – 3rd Edition (TEMA-3; $r=.73$; Ginsburg & Baroody, 2003).

2.2.2.5 Expressive vocabulary

A measure for expressive vocabulary was included in our analyses because most language measures are highly correlated with mathematics measures (Collins & Laski, 2019; Harvey & Miller, 2017). Children's expressive vocabulary was measured using the

Clinical Evaluation of Language Fundamentals®-Preschool-2 (CELF®-Preschool-2; Semel et al., 2004). This specific measure was included because of its efficiency. The assessment includes 20 items that require children to name pictures (“What is this?”) and actions (“What is he doing?”). Items are scored on a range from 0 to 2, where 0=incorrect, and items are either worth one or two points. For items worth two points, children may receive one point for a partially correct answer. The assessment is stopped when children respond incorrectly to seven consecutive questions. Total scores observed for the scale ranged from 2 to 38 ($M=21.41$; $SD=8.06$).

2.2.2.6 Executive Function

Children’s EF, which includes cognitive processes such as inhibitory control, working memory, and cognitive flexibility (Garon, Bryson, & Smith, 2008), was also included in our analyses, as it has been found to be related to math skills (Best et al., 2011; Harvey & Miller, 2017; Lefevre et al., 2013). EF was assessed using the Sun/Moon Stroop task (Archibald & Kerns, 1999), as this particular measure of EF has been found to be related to children’s mathematics skills (Purpura, Schmitt, et al., 2017). For the Sun/Moon, children are shown a page with 30 pictures of suns and moons and asked to name the pictures as quickly as possible. If children respond incorrectly for a picture, they cannot move on to the next picture until they say the correct name. If children get to the last picture and still have time left, they begin at the top of the page again. The total number of pictures that children name in 45 seconds is recorded. Children then complete an “opposites task” (i.e., saying “sun” for pictures of moons and “moon” for pictures of suns). The score for the opposites task was used in the analyses. Scores for the current sample ranged from 9 to 54 ($M=30.78$; $SD=8.38$).

2.3 Analytic Plan

Analyses were conducted in STATA version 15. To test H1, and examine whether parent ratings of children's numeracy skills (i.e., verbal counting, simple arithmetic, numeral identification) were related to direct assessments of each respective skill, bivariate correlations between corresponding skills were run. Next, to address the relation between parent ratings and corresponding direct assessment scores for each skill, we used path models and controlled for children's age, gender, and parent education. Parent education was included as a proxy for socioeconomic status, as it has previously been found to be associated with parents' accuracy in predicting their children's abilities (Hunt & Paraskevopoulos, 1980). Moreover, for each individual numeral identification item, percent agreement between parent ratings of their children's ability to identify each specific numeral and children's direct assessment results were also calculated.

To address H2, and test whether parent ratings were better aligned with direct assessments of broad numeracy abilities relative to specific numeracy skills, three sets of correlated correlations (Meng et al., 1992) were used. Correlations used to test H1 were compared to correlations between parent ratings of each skill and direct assessments of broad numeracy ability. Lee and Preacher's (2013) program was used to test the equality of the two correlations for each specific skill. For each set of correlations, the same sample was used (i.e., participants had to have data for the parent-rated skill, directly assessed specific skill, and directly assessed broad numeracy skill).

Next, to test H3, and examine whether aggregated parent ratings of their children's numeracy abilities were predictive of children's broad numeracy abilities, we

used structural equation modeling (SEM). In Model 1, we conducted a confirmatory factor analysis (CFA) to determine whether parent ratings of their children's ability to verbally count, calculate simple arithmetic, and identify numerals loaded onto one factor representing broad numeracy abilities. In Model 2, we addressed whether this latent variable for parent ratings of their children's overall numeracy skills predicted children's PENS-B scores, controlling for children's age, gender, and parent education.

Finally, to address H4, and determine whether parent ratings of children's numeracy skills were specific to numeracy and not a measure of children's other cognitive abilities, we examined whether the latent variable for parent ratings of children's overall numeracy skills predicted children's PENS-B scores more so than direct assessments of children's vocabulary and EF scores. We controlled for demographic characteristics such as children's age, gender, and parent education. Including these two non-mathematics measures in our model provided the most conservative test of discriminant validity because EF and literacy have been shown to be highly related to children's math development (Best et al., 2011; Collins & Laski, 2019; Harvey & Miller, 2017; Lefevre et al., 2013). To account for potential relations between these cognitive skills, we correlated our error terms.

Given that some children did not complete direct assessments ($n=8$) and some parents were missing items on the questionnaire ($n=29$), sample sizes for correlational analyses (i.e., H1, H2) varied. Missing data analyses were conducted with each of the outcome variables in our path models used to address H1 (i.e., directly assessed verbal counting, simple arithmetic, numeral identification). Child age was the only covariate significantly related to the missingness of all three direct assessment scores, including

counting, $r(129)=-0.31$, $p<.001$, simple arithmetic, $r(129)=-0.29$, $p=.001$, and numeral identification, $r(129)=-0.30$, $p=.001$. Older children were less likely to be missing direct assessment scores for numeracy. Additionally, parents' highest level of education was significantly related to the missingness of directly assessed simple arithmetic scores, $r(129)=-0.19$, $p=.029$, indicating that children whose parents were more educated were less likely to be missing this variable. Full information maximum likelihood was used to account for missing data in path models.

For H3 and H4, missing data analyses indicated that age was the only covariate significantly related to missingness of all outcome variables (i.e., PENS-B, expressive vocabulary, EF), such that older children were less likely to be missing these direct assessment scores. Missing PENS-B scores were also related to parent-rated numeral identification scores, $r(121)=-0.20$, $p=.026$, while missing expressive vocabulary direct assessments scores were also related to parent-rated numeral identification, $r(121)=-0.19$, $p=.040$, and directly assessed EF scores, $r(122)=-0.24$, $p=.009$. Finally, missing EF direct assessment scores were also related to parent-rated numeral identification, $r(121)=-0.29$, $p=.001$, and verbal counting, $r(120)=-0.19$, $p=.041$, parents' education, $r(129)=-0.24$, $p=.007$, and children's expressive vocabulary direct assessment scores, $r(123)=-0.24$, $p=.008$. Full information maximum likelihood was used to account for missing data for these models.

3. Results

3.1 H1: Relation Between Parent Ratings of Numeracy Skills and Children's Direct Assessments

Bivariate analyses indicated that parent ratings of children's numeracy skills were

correlated with children's respective direct assessment scores, though the strength of these relationships varied (see Table 3).

Results from path models indicated that, after controlling for children's age and gender and parents' education, parent ratings of verbal counting, simple arithmetic, and numeral identification, all predicted direct assessments of the specific skill (Table 4). In terms of the percent alignment between parent ratings and direct assessment of children's ability to identify specific numerals, parents were most able to predict their child's ability to identify numeral 1 and they were least able to predict their child's ability to identify numerals 10 and 14 (1: 82%; 2: 81%; 3: 78%; 7: 77%; 8: 76%; 10: 72%; 12: 77%; 14: 72%; 15: 75%).

3.2 H2: Specificity of Parent Ratings of Children's Numeracy Skills

Bivariate correlations between parent ratings of children's numeracy skills and direct assessments of children's broad numeracy skills, along with correlated correlation z-scores, are presented in Table 3 and summarized below. The correlated correlations test for whether the correlations between parent ratings and directly assessed specific numeracy skills (from 3.1) and the correlations between parent ratings and directly assessed broad numeracy skills are significantly different from one another.

3.2.1 Counting

The correlation between parent-rated and directly assessed verbal counting was weaker than the correlation between parent-rated counting and directly assessed broad numeracy skills. The test for equality indicated that these correlations were significantly different from one another.

3.2.2 Simple arithmetic

Similarly, the correlation between parent-rated and directly assessed simple arithmetic was weaker than the correlation between parent ratings of simple arithmetic and directly assessed broad numeracy skills. However, the test for equality indicated that these correlations were not significantly different from one another.

3.2.3 Numeral identification

Finally, the correlation between parent-rated and directly assessed numeral identification was stronger than the correlation between parent-rated numeral identification and directly assessed broad numeracy skills. The test for equality indicated that these correlations were not significantly different from one another.

Overall, these findings indicated that there are different patterns of relations between parent ratings and direct assessments of specific numeracy skills and broad numeracy skills. Parent ratings of children's verbal counting was more representative of children's broad numeracy abilities, providing support for H2. However, for parent ratings of simple arithmetic and numeral identification, the correlations between parent ratings and direct assessments of the respective skill and broad numeracy skills did not significantly differ. Overall, it does not seem as though parent ratings are skill-specific.

A complete correlation table including all parent ratings and directly assessed skills is included in Table 5. These findings demonstrate the lack of specificity in parent ratings and the potential biases in parents' conceptions of their children's numeracy skills. Findings indicate that parent-rated verbal counting is moderately to strongly correlated with how parents rate other numeracy skills. Further, parent ratings of specific numeracy skills (i.e., verbal counting, simple arithmetic) appear to be more strongly correlated with non-corresponding directly assessed numeracy skills than corresponding

skills.

3.3 H3: Relation Between Aggregated Parent Ratings of Children's Numeracy Skills and Direct Assessments of Children's Broad Numeracy Skills

3.3.1 Measurement model for parent ratings of children's numeracy scores

Fit statistics for Model 1, the measurement model for the latent variable for parent ratings of children's numeracy scores, indicated good fit based on Hu and Bentler's (1999) criteria that models with good fit have a RMSEA < .06, SRMR < .08, CFI > .95, and a non-significant χ^2 . χ^2 analyses indicated that the model was fully saturated. Standardized factor loadings for each of the individual numeracy items ranged from .51 to .83 and all were statistically significant, $p < .001$. Findings are displayed in Figure 1. The correlations between parent-rated verbal counting and other parent-rated numeracy skills (Table 5) may serve to explain the high factor loading for verbal counting onto the latent variable.

3.3.2 Parent ratings predicting broad numeracy

Model 2 (Figure 2), which addressed whether the latent variable for parent ratings of children's numeracy predicted direct assessments of broad numeracy skills, after controlling for child and parent demographic characteristics, also indicated good fit. The path from parent ratings to children's PENS-B scores was positive and significant, $\beta = .71$, $p < .001$.

3.4 H4: Aggregated Parent Ratings' Domain-Specificity to Numeracy

Finally, Model 3, which added direct assessments of children's vocabulary and EF to the previous model, indicated even better fit (Figure 3). Parent ratings of children's numeracy skills continued to significantly and positively predict PENS-B scores, $\beta = .71$, $p < .001$, even after including direct assessments of other domains. Age was the only

demographic control that significantly accounted for variance in direct assessments of broad numeracy, $\beta=.21$, $p<.01$ (not displayed in figure).

Although parent ratings of children's numeracy skills also predicted expressive vocabulary, $\beta=.34$, $p<.01$, and EF, $\beta=.33$, $p<.01$, there is clear evidence that parent ratings are substantially more related to PENS-B than other direct assessments. To take this a step further and test whether the coefficient for the path between parent ratings and PENS-B was significantly different from the coefficients for the paths between parent ratings and expressive vocabulary, and parent ratings and EF, we ran two additional models. We first constrained the path between parent ratings and PENS-B to be equal to the path between parent ratings and expressive vocabulary in one model, then we constrained the path between parent ratings and PENS-B to be equal to the path between parent ratings and EF in another model. In both subsequent models, fit indices indicated poorer fitting models than Model 3, providing evidence for discriminant validity. Additionally, correlations displayed in Table 5 also indicated that parent ratings of each specific skill were more strongly correlated with children's PENS-B scores than their expressive vocabulary and EF scores, providing further support for discriminant validity.

4. Discussion

The current study addressed the relations between parent ratings of children's specific numeracy abilities and direct assessments of children's specific and broad numeracy skills. Results indicated that parent ratings of their children's numeracy skills were not skill-specific, and in some cases were targeting children's broader numeracy abilities. However, findings show that parents' understanding of their children's numeracy skills are more specific to numeracy than other cognitive abilities. This is a

promising finding, given that on average parents of young children do not spend much time engaging their children in numeracy activities (Cannon & Ginsburg, 2008) and parents may not be able to differentiate between numeracy skills (Fluck et al., 2005; Zippert & Ramani, 2017). These findings have implications for how to best utilize parent ratings in research. Findings suggest that parent ratings of their children's specific numeracy abilities may be used together as a measure of children's global numeracy abilities in instances where direct assessment data cannot be collected, such as when only parent surveys are administered.

4.1 A Closer Look at Parent Ratings of Specific Numeracy Skills

Findings from the current study align with previous work indicating that parents may not be quite as familiar with their children's specific numeracy skills (Fluck et al., 2005; Zippert & Ramani, 2017). Thus, parent ratings of their children's mathematics skills can be useful in situations where researchers and practitioners would benefit from knowing about children's broad numeracy ability, as parent ratings are not very granular. One factor that may contribute to this lack of granularity may be that the items given to parents were designed to be easier for parents to rate and recall their children's abilities (Table 2). Future work should address whether or not parents can rate their children's abilities using more specific and descriptive items. For example, instead of asking parents whether or not their child can perform simple sums, researchers can examine whether parents can reliably report on their child's ability to perform specific simple sums (Zippert & Ramani, 2017). Similarly, parents can be given more descriptive instructions that mirror the direct assessments that they were given in this study (e.g., specifying "how high can your child count *without making any mistakes?*"). Providing more detailed

requests for parent ratings would offer a better understanding as to whether parent ratings can be used in a more fine-grained way and serve as a reasonable substitute for direct assessments of specific numeracy skills in the future.

The present study builds on previous findings (Fluck et al., 2005) to examine additional numeracy skills and offers a closer examination of parent ratings of children's numeracy skills (Zippert & Ramani, 2017). For example, the current study addressed parent ratings of their children's verbal counting, numeral identification, and simple arithmetic—three different numeracy skills. This contrasts from Zippert and Ramani's (2017) study, which examined parent accuracy by aggregating their ratings into broad skills such as conventional numeracy, advanced numeracy, and non-symbolic numeracy. Findings from the current study indicate that alignment between parent ratings of specific numeracy skills and direct assessments of corresponding skills and broad numeracy abilities vary, indicating that aggregating specific numeracy skills into broad categories omits a certain level of detail. In particular, parent ratings of the conventional numeracy skills measured in the present study (i.e., counting, numeral identification) varied in terms of whether they were more or less highly correlated with direct assessments of children's specific numeracy skill or broad numeracy skills. By examining parent ratings of individual numeracy skills and not aggregating these skills into broader categories, we were able to examine parent ratings of children's specific numeracy abilities with more detail.

4.2 Parent Ratings as a Reasonable Substitute for Direct Assessments

In addition to providing a closer examination of parent ratings of children's numeracy skills, another unique contribution of the present study is that we aimed to

inform measurement. In previous work, researchers may have decided against using parent ratings when unable to collect direct assessment data because the validity of parent reports of children's abilities was unknown or was not as rigorously tested. Our finding that parent ratings of their children's numeracy skills appear to be a valid substitute for direct assessments of overall numeracy, when combined, has implications for the methods researchers use to collect data on children's abilities going forward. However, parent ratings should not be used as a replacement for all direct child assessments; rather, they may be used as a reasonable measure of children's broad mathematics skills, and not broader cognitive ability, in instances where children are not able to be assessed. Further, parent ratings may be a beneficial substitute for direct assessments in situations where placing children in broad preliminary mathematical ability groups may be beneficial until further monitoring can be provided (e.g., text-message-based interventions, beginning of the school year) but direct-assessment is not necessarily practical. However future research should directly address the effectiveness of using parent ratings to initially group children. Additionally, future work should test whether current findings replicate for other direct assessments (Clements et al., 2008; Ginsburg & Baroody, 2003) of children's numeracy skills.

4.3 Supporting Parents' Increased Understanding of Children's Skills

Despite the measurement implications this study may have, researchers must continue examining how to support parents in better understanding their children's specific numeracy abilities. Accurate judgments of children's abilities allow for appropriate scaffolding of children's learning (Hunt & Paraskevopoulos, 1980; Miller, 1988; Vygotsky, 1978). Though parents in the current study may have an understanding

of their children's broad numeracy abilities, these ratings are not fine-grained, or specific to individual numeracy skills. This suggests that parents may not be appropriately addressing the different aspects of children's numeracy development, which is in line with previous findings that parents' accuracy in rating children's numeracy skills varies across skills (Zippert & Ramani, 2017).

Previous work examining the accuracy of parent ratings of children's numeracy skills has suggested that inaccuracies may be due to parents' lack of exposure to their children's specific numeracy skills (Fluck et al., 2005; Zippert & Ramani, 2017). Additionally, parents may draw inaccurate conclusions based on the skills that they do observe. For example, Fluck et al., (2015) speculated that parents assumed that their children understood cardinal value based on their children's ability to count. The finding from the current study that parent ratings of verbal counting loaded highly on the latent variable for parent ratings (see Figure 1) may indicate that parents make assumptions about children's skills based on verbal counting. Verbal counting may be the primary mathematical activity in which parents engage in with their children.

To support parents' understanding of children's various numeracy abilities and children's subsequent numeracy development, researchers and interventionists should focus on exposing parents to the range of numeracy skills that exist, as well as various activities that promote these different components. For example, having storybooks that include age-appropriate mathematical language and concepts for children (e.g., Purpura, Napoli, et al., 2017)—along with how the concepts build upon each other, suggestions for activities to practice with children, and tips for knowing if their children understand the concept—may broaden parents' understanding of which mathematics skills are

appropriate to introduce to their children. Further, parents should have an understanding of the developmental trajectories of children's numeracy skill development so they know how to support particular numeracy skills at certain developmental time periods. This can be done through family-school partnerships, specifically parent-educator communication about children's learning and development in mathematics, or communications regarding developmentally appropriate mathematics activities to engage children in at home (Lin et al., 2019). Finally, children's teachers as well as interventionists should focus on helping parents interpret their children's behaviors in response to these activities. These strategies would assist parents in scaffolding the various aspects of children's numeracy development.

4.4 Limitations and Future Directions

Although findings from this study have broad implications, a few limitations should be acknowledged. Given that the present study examined parent ratings of three numeracy skills (i.e., parent ratings of verbal counting, simple arithmetic, and numeral identification), future work should attend to far more numeracy skills like other studies have (Zippert & Ramani, 2017), and examine their relations to direct assessments of corresponding skills and broad numeracy abilities. Relatedly, considering that the latent variable for parent ratings of children's overall numeracy abilities included three directly observed variables, researchers should address whether parent ratings of other numeracy skills, and different combinations of these skills, may be a stronger predictor of directly assessed overall numeracy skills.

In addition to the limitations with parent ratings of numeracy skills, there are additional considerations to note. For example, the generalizability of these findings is

limited as the sample included in this study was relatively small and homogenous. Future work should replicate these analyses and include larger sample sizes and more diversity to address these issues and validate study findings. Further, data were collected concurrently. A longitudinal framework would determine whether parent ratings of their children's numeracy skills predicts children's numeracy outcomes at a later time point and the directionality of this relation. Additionally, addressing whether parent ratings could be used to measure changes as a result of intervention would also be useful. Further, we included one direct assessment of expressive vocabulary and EF in our final model. The inclusion of alternative direct assessments of literacy, EF, or additional cognitive abilities may strengthen the validity of the current findings.

Moreover, although this work has implications for the HNE, future work should collect data on children's HNE and examine how parent ratings of their children's numeracy abilities and children's direct assessments may be related. Similarly, those interested in better understanding the context surrounding children's HNE and how it relates to parent ratings of their children's numeracy skills, may be interested in collecting additional parent data to address these factors. Understanding parents' beliefs/expectations about math development or math anxiety may better explain how parent ratings of children's math abilities may or may not be related to children's HNE.

4.5 Implications

Our goal in this study was to assess the alignment and specificity of parent ratings of children's numeracy skills with child direct assessment scores. Findings provide initial evidence that parents have an understanding of where their children's numeracy skills lie, but this understanding is broad. It would be worthwhile for future work to address

whether parent ratings of their children's specific skills in other cognitive domains (e.g., literacy, EF) are skill- and domain-specific, and whether they can similarly be aggregated to produce a valid measure of the broader cognitive domain. These findings would further inform the use of online data collection methods in child development research.

5. Conclusion

Parents are not really able to distinguish between their preschoolers' number skills and are likely better off being surveyed in a broader way regarding their children's number skill development. Given that researchers may face several challenges in collecting direct assessments of children's cognitive abilities, these findings have implications for how researchers may use parent ratings to study children's math abilities. Our results demonstrate that parent ratings of their children's numeracy skills can be used as a valid measure of their children's broad numeracy abilities, when aggregated. However, considering the importance of parents' understanding of their children's numeracy abilities for providing an optimal HNE, more effort should focus on supporting parents in better understanding their children's numeracy abilities. These findings lay the foundation for future work to address whether parent ratings of children's skills in other domains can be similarly used, and if combining parent ratings of other numeracy skills may be more strongly related to direct assessments of children's overall numeracy skills.

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Table 1

Demographic characteristics and distribution of key study variables

	<i>n</i>	<i>M or %</i>	<i>SD</i>	Observed Range
Demographic Characteristics				
Child age	129	4.62	0.54	3.07 - 5.95
Child male	69	52.27%		
Child race/ethnicity	126			
White	102	80.95%		
Hispanic/Latino	6	4.76%		
Asian	6	4.76%		
Black/African American	3	2.38%		
Other/Multiracial	9	7.14%		
Respondent relationship to child	129			
Mother	109	84.50%		
Father	14	10.85%		
Other	6	4.65%		
Respondent level of education	129			
Some high school	4	3.10%		
High school diploma or equivalent	30	23.26%		
Some college	23	17.83%		
Associate's degree	12	9.30%		
Bachelor's degree	25	19.38%		
Graduate/postgraduate degree	35	27.13%		
Parent Ratings				
Verbal counting	120	30.17	23.69	5 - 100
Simple arithmetic ^a	55	47.83%		
Numerical identification	121	5.65	3.25	0 - 9
Direct Assessments				
Verbal counting	124	20.27	17.51	1 - 100
Simple arithmetic	120	1.46	1.65	0 - 5
Numerical identification	121	5.72	2.69	0 - 9
Broad numeracy	124	12.48	5.90	0 - 24
Expressive vocabulary	123	21.41	8.06	2 - 38
Executive function	122	30.78	8.38	9 - 54

Note: ^a *n* and % for those reporting "yes"

Table 2

Descriptions of corresponding parent ratings and child assessments

	Parent Ratings	Direct Assessments
Verbal counting	Asked "How high can your child count?" Child's score was recorded as the number parents indicated; however, if the number was greater than 100, the score was recorded as 100.	Prompted with, "I want you to count as high as you can starting with the number one. Go ahead." Children were stopped when they made an error/when they reached 100. The greatest number they counted to without making an error was recorded as their score.
Simple arithmetic	Asked to respond "yes"/"no" to "My child can calculate simple sums (e.g., $1 + 1 = ___$, $1 + 2 = ___$)." A score of 1 was given if they responded yes and a score of 0 was given if they responded no.	Shown five addition problems with sums less than five, printed on individual sheets of paper; the equation was also verbally read (e.g., the assessor asked, "What is one plus two?" while pointing to " $1 + 2 = ___$ "). Correct answers were given one point and scores were summed.
Numeral identification	Presented with numerals 1 to 15 and asked to circle all of the numerals that their child could identify. Items that corresponded with direct assessments were used (i.e., 1, 2, 3, 7, 8, 10, 12, 14, 15). One point was given for each of the 9 numerals indicated as "known" by parents for a total score of 0 to 9.	Shown cards with numerals printed on them (1, 2, 3, 7, 8, 10, 12, 14, 15) and asked, "What is the name of this number?"

Table 3

Relations between parent ratings of children's specific numeracy abilities and children's directly assessed domain-specific and broad numeracy skills

	Direct Assessments		Correlated Correlations (z)
	Domain-specific numeracy skill	Broad numeracy skill	
Parent rated verbal counting (n=113)	0.31**	0.53***	-2.56*
Parent rated simple arithmetic (n=104)	0.42***	0.56***	-1.67
Parent rated numeral identification (n=111)	0.56***	0.46***	1.66

Note: Both sets of correlations are calculated with the same sample

* $p < .05$, ** $p < .01$, *** $p < .001$ (2-tailed)

Table 4

Path coefficients for parent ratings of children's specific numeracy skills predicting directly assessed corresponding skills

	Direct Assessment					
	Counting		Simple arithmetic		Identifying numerals	
	β	SE	β	SE	β	SE
Parent ratings	0.23*	0.09	0.37***	0.08	0.52***	0.07
Child male	-0.32	0.09	-0.03	0.08	0.01	0.07
Child age	0.13	0.09	0.18*	0.08	0.19**	0.07
Respondent education	0.13	0.09	0.14	0.08	0.17**	0.07
Observations	132		132		132	

* $p < .05$, ** $p < .01$, *** $p < .001$

Table 5

Relations between parent ratings and direct assessments

	Parent Ratings			Direct Assessments				
	Verbal counting	Simple arithmetic	Numeral identification	Verbal counting	Simple arithmetic	Numeral identification	General numeracy (PENS-B)	Expressive vocabulary
Parent Ratings								
Verbal counting	-							
Simple arithmetic	0.52***	-						
Numeral identification	0.40***	0.31***	-					
Direct Assessments								
Verbal counting	0.31***	0.45***	0.27**	-				
Simple arithmetic	0.41***	0.42***	0.11	0.20*	-			
Numeral identification	0.51***	0.53***	0.56***	0.46***	0.39***	-		
General numeracy (PENS-B)	0.53***	0.57***	0.47***	0.45***	0.48***	0.75***	-	
Expressive vocabulary	0.21*	0.31**	0.26**	0.29**	0.25**	0.32***	0.53***	-
Executive function	0.34***	0.27**	0.22*	0.26**	0.30***	0.49***	0.54***	0.15

* $p < .05$, ** $p < .01$, *** $p < .001$

Model 1:

Figure 1. Measurement model for overall parent ratings of children's numeracy. Standardized coefficients shown. * $p < .05$; ** $p < .01$; *** $p < .001$

Model 2:

Figure 2. Parent ratings of children's numeracy predicting direct assessments. Standardized coefficients shown. * $p < .05$; ** $p < .01$; *** $p < .001$

Model 3:

Figure 3. Overall parent ratings of children's numeracy predicting direct assessments of children's cognitive skills. All demographic controls (i.e., age, male, parent education) collapsed in figure. Standardized coefficients shown. * $p < .05$; ** $p < .01$; *** $p < .001$

Appendix

Survey Questions

1. How high can your child count? _____

2. My child can identify the following numerals (**circle all that apply**):

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
---	---	---	---	---	---	---	---	---	----	----	----	----	----	----

3. My child can calculate simple sums (e.g., $1+1=$, $1+2=$): yes_____ no_____