Chapter

Predictors of Early Numeracy: Applied Measures in Two Childcare Contexts

Belinda Blevins-Knabe, Jacob Esplin, Ann M. Berghout Austin and Shawnee M. Hendershot

Abstract

The purpose of the current research was: (1) To assess differences in early numeracy, phonological awareness, receptive language, executive functioning, and working memory for children in two childcare settings (family and center); (2) To determine whether applied measures of phonological awareness and executive functioning could serve as predictors of numeracy performance. Children (N = 89) ranging in age from 39 to 75 months were recruited from state-licensed childcare centers and family childcare homes. Teacher ratings of executive functioning were significantly related to early number skills, phonological awareness, and receptive language, but none of the parent ratings were significantly related to the child scores. The overall model did not differ between center and family childcare children. Phonological awareness was a significant predictor of number skills for both younger and older children. Receptive language skills were the best predictor of early numeracy performance for younger children and the best predictor for older children was phonological working memory measured by a non-words repetition task. These results suggest a connection between children's numeracy skills and a developmental change from receptive language skills to phonological working memory skills.

Keywords: childcare, early numeracy, executive functioning, phonological awareness, working memory

1. Introduction

A strong case exists for the need to understand the relationships between the factors that influence and are influenced by children's understanding of mathematics. Children's mathematics skills at school entry predict future mathematics skills [1], and overall school achievement [2, 3]. It is well known, in fact, that early mathematics skills are usually more powerful than early reading skills in predicting later school success [1, 2, 4]. Perhaps this is because developing skills in mathematics helps children learn certain problem solving and reasoning skills essential for success in other academic areas [5].

In addition to children's mathematics skills linguistic skills play a significant role in their academic success [6–7]. Currently, the connections between mathematics and linguistic skills are not well understood either by researchers or other significant adults in preschool children's lives. For example, parents downplay the role of early mathematics skills and emphasize the importance of preschool children's linguistic skills over their mathematics skills [8] as do family home care providers, [9] and teachers of preschool children [10].

Executive functioning is another influence on children's academic performance, including mathematics and reading [11, 12]. Executive functioning skills are those that direct problem solving and help regulate behavior and are more predictive of academic success than intelligence tests [13].

Given the importance of children's early mathematics skills to their later mathematics achievement [5] and the strong likelihood that early childhood educators can positively influence young children's mathematical development [10] we were interested in examining the predictive relationship of linguistic skills and executive functioning on young children's mathematics performance. Because in the early years much of the research has focused on young children's number skills we will do the same, while recognizing that mathematics includes more than numeracy.

2. Predictors of early numeracy performance

2.1 Phonological awareness

Children's recognition of and facility in using the units of sound that compose language, for example syllables and root words, is called phonological awareness. Phonological awareness is predictive of both children's reading performance [14] and early mathematical performance [15, 16]. How well phonological awareness predicts later mathematical performance varies with task difficulty. For example, both Krajewski and Schnieder [6] and Michalczyk et al. [17] report that phonological awareness directly influenced children's learning of the sequence of number words, but Cirino [18] found it only indirectly influenced more advanced use of number words and small sum addition. In contrast, other researchers have found that phonological awareness is not a better predictor of children's mathematics achievement than other linguistic skills, working memory skills, or counting skills [19, 20]. Given the variability in the research literature the nature and strength of the relationship between phonological awareness and number skills is still in question.

2.2 Executive functioning

The processes and skills that are often classified under the executive functioning umbrella include (a) working memory, (b) ability to shift attention, and (c) ability to focus attention (inhibition control) when planning, solving problems, and acting out goal-directed thoughts [21–23]. Clements et al. [21] suggest that early mathematics influences executive functioning and executive functioning influences early mathematics. If this is the case activities that promote acquisition of early number skills are likely also to promote executive functioning and vice versa.

2.3 Working memory

Working memory is one of the components of executive functioning. However, it is of particular interest because there is evidence that different types of working memory have specific connections to young children's mathematics performance. Rasmussen and Bisanz [24] separated working memory into 3 components and demonstrated that visual and spatial working memory predicted performance on nonverbal arithmetic problems for preschool children. For children in first grade phonological (verbal) working memory was the best predictor of performance on verbal arithmetic problems. In some cases, researchers have included both measures of phonological awareness and working memory and found that each has a unique relationship with number skills. Kleemans, Segers, and Verhoeven [25] found that general intelligence, phonological awareness and grammatical ability were correlated with the operations of addition and subtraction while the working memory measures, including repeating words and sentences and reproducing a visual representation with blocks, were related to subtraction.

On the other hand, some researchers have found no effects or limited effects of phonological awareness on mathematics ability when working memory measures were included. Passolunghi et al. [19] found that working memory and counting predicted first-grade children's performance on a mathematics achievement test, but measures of phonological awareness were not significant predictors.

3. The current study

Much of the current research indicates that both phonological awareness and executive functioning measures, including working memory, predict young children's performance on number tasks. If we can demonstrate that one or both support young children's number skills we can make recommendations about appropriate curriculum and home activities. Therefore, one purpose of the current study was to identify the best predictors of early numeracy performance when parent- and teacher-rated executive function, phonological (verbal) working memory, linguistic skills (receptive language), and phonological awareness are included.

We included a measure of receptive language, which assesses children's understanding of the meaning of language rather than their ability to produce it, because it is possible that children's understanding of the meaning of language is more influential on their number skills than their use and recognition of language sounds (phonological awareness). Although Austin et al. [26] found receptive language predicted children's early number skills they also found this result was likely due to the influence of phonological awareness. In this study we included measures of executive functioning to provide a more stringent test of the influence of phonological awareness.

Many of the measures we used in this study were based on regularly occurring activities in the preschool classroom and home environments. The BRIEF-P [22] is composed of ratings by parents and teachers and was used to assess executive functioning. Executive functioning skills may be enhanced through practice [11, 21] making it even more authentic to assess them in the home and childcare environments where most practice likely takes place. Due to the many connections between phonological (verbal) working memory and mathematical performance [19, 24] we also included a second measure of phonological working memory, the repetition of words and non-words [27].

The PALS (Phonological Literacy Screening) [28] has multiple tasks covering literacy skills that are often taught in preschool settings. If this more ecological measure of phonological awareness is related to young children's early number skills then it would provide the type of information that could assist educators in creating a streamlined curriculum where mutually supportive concepts are taught [29].

Another purpose of the study was to examine the influence of type of caregiving environment. Many children are in out-of-home care, either center care or family childcare. Significant differences have been found between care types regarding school readiness scores (e.g., [26]), caregiver behavior, and the caregiving environment (e.g., [30]). It is unclear whether skills develop differently for children in separate types of childcare. As a result, we wanted to know if the relationships among the measures in this study would differ between setting since their caregiving environments may provide different support for learning number skills.

Our research questions were as follows:

1. Do scores on early numeracy, phonological awareness, receptive language, executive functioning, and phonological working memory differ in this study between children in center care and from those in family childcare?

2. Which of the applied measures (phonological awareness, executive functioning, or phonological working memory) is the best predictor of performance on number tasks? Does the predictor change when looking at different age groups?

4. Method

Demographic information for the child, family, and caregiver was collected. Child information included age, gender, and ethnicity. Family information included partnered status of primary caregiver/parent, age of parent(s), number of children in family, whether the family received state funding/services, parental education, family income, hours worked per week per parent, and primary language spoken in the home. Caregiver information included type of childcare (family or center), years in business, program size, enrollment, and whether the program was non-profit.

4.1 Participants

4.1.1 Children

Eighty-nine children (n = 42 females), 39 to 75 months (M = 54.9, SD = 8) in age, participated in the study. Mean age did not differ significantly between boys (M = 55.43, SD = 8.14) and girls (M = 54.24, SD = 8.00), or between childcare center (M = 55.60, SD = 6.90) and family childcare (M = 53.73, SD = 9.66). Fifty-five children (62%, n = 26 females) came from three state-licensed childcare centers; 34 children (38%, n = 16 females) from eight state-licensed family childcare programs. Seventy-six children (85%) were Caucasian, reflecting the homogeneity of the region. Eight parents (9%) described their child's ethnicity as Latino/Hispanic, Asian/Pacific Islander, or 'other.' Five parents (6%) declined to report child ethnicity. Seventy-eight children (88%) spoke English as a first language.

4.1.2 Parents

The education level of both parents was higher for center care families (Mothers center care: M = 1.94, SD = 99, Mothers home care: M = 0.78, SD = 0.19, $t(73)$ = 4.9, p = 0.001; Fathers center care: M = 2.09, SD = 1.07, Fathers home care: M = 1, SD = 0.23, $t(60)$ = 3.73, p = 0.001), and fathers of center care children (M = 38.42, SD = 8.04) were older than fathers of family care children (M = 32.47, SD = 5.49, t (41) = 2.67, p = 0.05). Parents of children in family care programs worked more hours, per week, on average however the difference was not significant. Yearly family income did not differ between center and family care families and ranged between $30,000 and $50,000.

4.1.3 Caregivers

Thirty center and family childcare programs were approached about participating in the study: 77% agreed to participate. The children that met participation criteria were from the three childcare centers and eight of the 20 family childcare programs. The three childcare centers that participated averaged almost 30 years (range: 2–81 years) in operation, the average capacity was 90 children (range: 45–173), and the average career ladder level was 6.33 (range: 0–10), 10 being the highest possible, with level determined by training participation. One center was accredited by the National Association for the Education of Young Children (NAEYC).

The 8 family childcare programs that participated averaged 12.25 years (range: 4–24 years) in operation and the average career ladder level was 8.5 (range: 6–10). Three programs were accredited by the National Association for Family Child Care (NAFCC).

4.2 Measures

4.2.1 Parent and caregiver measures

Behavior Rating Inventory of Executive Function-Preschool Version (***BRIEF-P***): The BRIEF-P [22], is an age- and gender-normed clinical measure designed to be completed by the child's parent/guardian and/or out-of-home caregiver, with 63 questions distilling to five subscales: Inhibit, Emotional Control, Shift, Working Memory, and Planning and Organizing. Each subscale has a summary score, with higher scores indicating more concerns about behavior. Gioia et al. [22] reported internal consistency for the composite score (parents: 0.95; caregivers: 0.97), correlation between parents and caregivers ($r = 0.17$, $p < 0.01$), and test-retest reliability (parents: 0.90; caregivers: 0.88).

4.2.2 Individually administered child measures

Phonological Awareness Literacy Screening, Pre-K (***PALS***): PALS [28] is an assessment of phonological awareness in eight areas: name writing, upper-case and lower-case alphabet recognition, letter sounds, beginning sound awareness, print and word awareness, rhyme awareness, and nursery rhyme awareness. Cronbach's alphas range from 0.75 to 0.93.

Peabody Picture Vocabulary Test-Third Edition (***PPVT-III***): The PPVT-III [31] measures receptive vocabulary abilities for children as young as 2 years 6 months old. Children are shown four pictures simultaneously and asked which picture best represents a certain word. Reported split-half reliability is 0.94.

Test of Early Mathematics Ability, Third Edition, Form B (***TEMA-3***): The TEMA-3 [32] is an assessment of children's verbal and nonverbal numerical knowledge (age: 36–107 months), with items for young children (e.g., nonverbal problem solving, counting small numbers of objects, cardinality, etc.) and for older children (e.g., writing single-digit numerals, simple word problems, magnitude comparisons, etc.). Reliability (0.80–0.90) and criterion validity correlations with other norm-referenced mathematics scales (0.54–0.91) have been reported.

Phonological Working Memory: Two direct, verbal assessments of children's phonological working memory were used, each with five one-, two-, and three-syllable words, for a total of fifteen real words and fifteen non-words [27]. Hereafter, the real words measure will be referred to as the real words repetition task and the made-up words measure will be referred to as the non-words repetition task.

First the real words repetition task was presented, then the non-words repetition task. The assessor told the child 'I will say a word and I would like you to repeat it.' If the child had a problem with immature articulation, this was taken into consideration. The reliability for this study was 0.80.

4.2.3 Assessment protocol

Three graduate students individually assessed children at the child's out-of-home care program. Training meetings were held to discuss assessment administration and to recognize test fatigue. The same graduate student administered all assessments with a particular child in two sessions within a one-week time frame. The order of exposure to assessments was randomized based on child preference (in order to maximize cooperation, the child was asked whether they wanted to do numbers or letters first).

5. Results

The results are organized by research question. Because our outcomes variables were raw and not age normed, age was a covariate in our models. For descriptive statistics for child measures by gender and childcare type, see **Table 1**. For correlations between variables, see **Table 2**.

	Childcare centers (n = 55)			**Family childcare (n = 34)**		
Variable	**Boys (n = 29)**	**Girls (n = 26)**	**Overall**	**Boys (n = 18)**	**Girls (n = 16)**	**Overall**
TEMA-3 (standard)						
M	100.46	104.31	102.31	98.94	91.19	95.18
SD	13.19	12.58	12.92	17.88	12.29	15.69
PPVT-III (standard)						
M	110.04	104.81	107.52[a]	105.12	98.56	101.94[a]
SD	16.53	11.05	20.62	10.09	13.90	12.35
PALS (total raw)						
M	66.89	75.31	71.02[a]	63.78	42.56	53.79[a]
SD	34.14	34.07	34.04	41.26	35.19	39.44
Verbal Working Memory (raw)						
M	28.61	28.42	28.52[b]	26.17	27.56	26.82[b]
SD	1.52	1.58	1.54	3.94	1.86	3.18
BRIEF-P Planning & Organizing/Working Memory (raw)						
M	32.48	30.35	31.47[b]	42.85	35.75	39.44[b]
SD	8.13	5.15	6.91	12.27	6.80	10.50

[a]Means *differ at* p *0.05.*
[b]Means *differ at* p *0.01.*

Table 1.
Descriptive statistics for child measures by gender and childcare type.

DOI: http://dx.doi.org/10.5772/intechopen.81065

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. Child age	—																			
2. Gender	−0.08	—																		
3. Center or home	−0.11	−0.00	—																	
4. Marital status	0.10	0.04	−0.26*	—																
5. Mother age	0.23	0.02	−0.28*	0.25	—															
6. Mother workweek	−0.17	−0.01	0.10	−0.15	−0.13	—														
7. Father age	0.23	−0.02	−0.39*	0.10	0.87***	−0.09	—													
8. Father workweek	0.11	0.23	0.21	−0.03	0.09	−0.07	−0.02	—												
9. # Siblings	0.03	−.09	−.14	0.19	0.42**	−0.01	0.48**	−0.14	—											
10. Subsidy	−0.04	−.09	0.15	−0.58***	−0.25	−0.16	−0.22	−0.26	−0.08	—										
11. Mother education	0.13	−.08	−0.50***	0.20	0.35**	−0.13	0.31*	−0.10	0.01	−0.48***	—									
12. Father education	0.13	−.02	−0.43***	0.21	0.58***	−0.03	0.53***	0.05	0.28*	−0.38**	0.71**	—								
13. Income	−0.01	0.11	−0.20	0.68***	0.51**	0.16	0.58**	0.15	0.41**	−0.72***	0.45**	0.53**	—							
14. TEMA	0.72***	−0.05	−0.18	−0.04	0.19	−0.14	0.20	0.25	0.07	0.01	0.20	0.36**	−0.00	—						
15. PPVT	0.55***	−0.21	−0.21	−0.01	0.20	−0.01	0.19	0.02	−0.10	−0.10	0.38**	0.41**	0.02	0.70***	—					
16. PALS	0.49***	−0.04	−0.23*	−0.04	0.13	−0.07	0.13	0.22	−0.08	−0.08	0.25*	0.33*	−0.01	0.73***	0.64***	—				
17. Verbal WM	0.27*	0.09	−0.34**	−0.05	0.40**	0.03	0.52***	−0.06	0.23*	0.23*	0.19	0.29*	0.06	0.44***	0.43***	0.42***	—			

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
18. Teacher BP WM	−.10	−0.19	0.39***	−0.22	−0.07	0.17	−0.07	0.04	−0.16	−0.16	−0.39**	−0.28*	−0.15	−0.22	−0.06	−0.13	−0.09	—		
19. Teacher BP PO	−0.19	−0.16	0.38**	−0.25*	−0.27	0.22	−0.25	0.06	−0.18	0.19	−0.42***	−0.38**	−0.21	−0.29*	−0.08	−0.18	−0.19	0.82***	—	
20. Teacher BP P&O/WM	−0.15	−0.21	0.42***	−0.19	−0.22	0.17	−0.27	0.05	−0.20	.024	−0.43**	−0.37*	−0.17	−0.29**	−0.09	−0.20	−0.27*	0.86***	0.94***	—

*p *0.05*

**p *0.01*

***p *0.001.*
Note: Raw scores used.

Table 2.
Correlations between variables.

5.1 Question 1: Do Children's scores differ by care type on early numeracy, phonological awareness, receptive language, EF, and WM measures?

Teacher BRIEF-P, but not parent scores, were significantly related to the TEMA-3, PPVT-III, and PALS; therefore, parent BRIEF-P scores will not be discussed further. Correlations between phonological working memory and the BRIEF-P working memory subscale were not significant, suggesting the measures assess two separate aspects of memory.

A 2 (Gender) X 2 (Caregiving Type) ANOVA was run to determine significant differences in children's scores on all measures. The main effect of gender was significant for PPVT-III standardized scores, $F(1, 87) = 3.92$, $p = 0.05$, with boys' scores significantly higher. The main effect of caregiving type was significant for: PALS, $F(1, 86) = 5.16$, $p = 0.03$; PPVT-III, $F(1, 87) = 4.13$, $p = 0.05$; phonological working memory, $F(1, 87) = 10.79$, $p \leq 0.001$; and BRIEF-P Working Memory/Planning & Organizing, $F(1, 79) = 14.39$, $p \leq 0.001$, with childcare center scores significantly higher for PALS, PPVT-III, and phonological working memory. BRIEF-P scores were significantly higher for children in family childcare, with higher values indicating more concerns. The interaction (Gender X Caregiving Type) was not significant for any of the measures. No significant differences were found between English-First-Language children and ESL children ($n = 3$) for any of the measures used.

5.2 Question 2: Which of the applied measures (phonological awareness, executive functioning, or phonological working memory) is the best predictor of numerical performance? Does the predictor change when looking at different age groups?

Since the BRIEF-P Working Memory and Planning and Organizing subscales were highly correlated, the two scales were combined according to the BRIEF-P protocol. For clarity of communication, we will refer to this combination as BRIEF-P Working Memory/Planning & Organizing subscales. Raw scores were used for all variables and age was corrected within the models.

5.2.1 Predictors of early numeracy performance

Regression analyses using the enter method were performed to determine which linguistic and working memory measures predicted TEMA-3 performance and to determine if care type was a significant predictor (see **Table 3** for regression results). All four models indicated a significant effect: Model 1, including age, care type, BRIEF-P Working Memory/Planning & Organizing subscales, and real words repetition task; Model 2, which substituted non-words repetition task for the real words repetition task; Model 3, which added PPVT-III; and Model 4 which included PALS. The best fit was Model 4 and accounted for 76% of the variance in TEMA-3 performance, with age ($t[71] = 4.60$, $p < 0.001$), PPVT-III ($t[71] = 2.45$, $p < 0.05$), and PALS ($t[71] = 4.95$, $p < 0.001$) as significant predictors.

5.2.2 Differences between age groups

We separated our sample into two groups by age (see **Table 4** for regression results). The younger group ranged in age from 39 to 55 months ($n = 44$, $M = 48.14$, $SD = 4.75$); the older group ranged in age from 56 to 75 months ($n = 44$, $M = 61.59$, $SD = 4.00$). Regressions were performed to explore differences between outcome variables for the two age groups. Using the enter method we found Model 1 and

Variable	B	SEB	β	R^2	adjusted R^2	F for change in R2
Model 1				0.57	0.55	32.74*
Age	0.76	0.09	0.68*			
Teacher WM/PO	−0.16	0.08	−0.17**			
RWRT	1.12	0.61	0.14			
Model 2				0.58	0.56	34.44*
Age	0.72	0.09	0.63*			
Teacher WM/PO	−0.16	0.08	−0.16**			
Non-Words Repetition Task	1.01	0.42	0.19**			
Model 3				0.68	0.66	39.33*
Age	0.50	0.09	0.44*			
Teacher WM/PO	−0.17	0.07	−0.17**			
Non-Words Repetition Task	0.45	0.39	0.08			
PPVT	0.17	0.04	0.40**			
Model 4				0.76	0.75	46.41*
Age	0.39	0.08	0.34*			
Teacher WM/PO	−0.10	0.06	−0.10			
Non-Words Repetition Task	0.28	0.35	0.05			
PPVT	0.09	0.04	0.20**			
PALS	0.10	0.02	0.42*			

*$p < 0.001$.
**$p < 0.05$.

Table 3.
Regression analyses with all ages combined for variables predicting the TEMA.

Model 2, which included the executive functioning measures, was only significant for the older group. Model 3, which added the PPVT-III, was significant for both groups. Model 4 added the PALS total score and provided the best fit for both age groups.

6. Discussion

Our first research question was: Do scores on early numeracy, phonological awareness, receptive language, EF, and working memory differ between children in center care and those in family childcare? The answer to this question was yes. The center care children performed better on the PALS, PPVT, and Phonological Working Memory and scored significantly lower on the BRIEF-P, a measure where higher values indicate more problems. This result is typical of other studies conducted in the United States. Such differences have been attributed to the limited number of materials found in family childcare and to differences in the quality of caregiver behaviors [30]. In this study the difference in scores might also be attributed to the higher level of education for center care parents.

Our second question was: Do applied measures of phonological awareness, executive functioning, and phonological working memory predict early numeracy performance? The best predictors of early numeracy performance when both age groups were combined were the linguistic measures of receptive vocabulary and

Variable	B	SEB	β	R^2	Adjusted R^2	F for change in R2
Younger age group (age M = 48 months, range 39–55 months)						
Model 1				0.06	0.01	1.10
BRIEF-P WM/PO	−0.14	0.11	−0.21			
RWRT	0.36	1.04	0.06			
Model 2				0.10	0.05	1.90
BRIEF-P WM/PO	−0.12	0.11	−0.19			
Non-Words Repetition Task	0.71	0.56	0.21			
Model 3				0.53	0.49	12.95***
BRIEF-P WM/PO	−0.15	0.08	−0.24			
Non-Words Repetition Task	−0.08	0.43	−0.02			
PPVT	0.21	0.04	0.69***			
Model 4				0.65	0.61	15.69***
BRIEF-P WM/PO	−0.10	0.07	−0.16			
Non-Words Repetition Task	−0.16	0.38	−0.05			
PPVT	0.126	0.041	0.41**			
PALS	0.09	0.03	0.46**			
Older age group (age M = 61.59 months, range 56–75 months)						
Model 1				0.24	0.19	5.7**
BRIEF-P WM/PO	−0.19	0.16	−0.17			
Non-Words Repetition Task	3.02	0.94	0.46**			
Model 2				0.28	0.24	7.11**
BRIEF-P WM/PO	−0.12	0.16	−0.11			
Non-Words Repetition Task	3.11	0.86	0.51**			
Model 3				0.42	0.38	8.83***
BRIEF-P WM/PO	−0.16	0.14	−0.14			
Non-Words Repetition Task	2.08	0.85	0.34*			
PPVT	0.21	0.07	0.42**			
Model 4				0.61	0.56	13.30***
BRIEF-P WM/PO	−0.04	0.13	0.03			
Non-Words Repetition Task	1.53	0.75	0.25*			
PPVT	0.09	0.06	0.17			
PALS	0.13	0.03	0.52***			

*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

Table 4.
Regression analyses with separate age groups for variables predicting the TEMA.

phonological awareness. Further insight into the relationships between the predictor measures and children's numeracy performance is informed by the analyses that looked at the two age groups separately. As would be expected, younger children scored lower on the TEMA, PPVT, and PALS than the older children. Using numeracy performance (TEMA) as the outcome variable only the PPVT and PALS accounted for a significant proportion of the variance for younger children. However, for the older children, who were passing more advanced numeracy items on the TEMA, the PPVT was no longer significant, but instead the PALS and the non-words repetition measure were significant. This suggests that receptive language is more influential for lower level number tasks, but not more advanced tasks. Examples of lower level number tasks on the TEMA were nonverbal items, counting small numbers of objects, and answering questions about cardinality for small numbers. Higher level number tasks involved using number symbols, solving simple addition problems, and comparing numbers to make decisions about size. It appears that as children get older and are able to succeed on more advanced number tasks receptive language accounts for less variance while phonological awareness (PALS) and phonological working memory (non-words repetition task) account for more variance.

Of the three measures of phonological working memory only the non-real words repetition task was predictive of older children's numeracy performance. The real words repetition task, non-words repetition task and the Teacher-rated BRIEF-P subscale of Working Memory were not significantly correlated suggesting that they each tapped different characteristics of phonological working memory. This variation is not surprising given that the BRIEF-P rating is based on the teacher's impression across the weeks and months of working with the child while both the real words repetition and the non-words repetition tasks are on-the-spot measurements based on the child's accuracy at that moment. It is also the case that the non-words repetition task is carefully designed to include certain combinations of language sounds rather than actual words and that is not the case for the Brief-P subscale of working memory.

The non-words repetition task is frequently used to assess language acquisition, and to diagnose and understand the characteristics of language impairment because it measures both phonological working memory and several other phonological components that underlie the learning of words [33]. Success on the non-word repetition task requires children to identify the units of speech (phonemes) that compose words and depends on recognizing the lawful combinations of language sounds. A bi-directional relationship between receptive vocabulary and the non-words repetition task exists with the skills measured by the non-words repetition task supporting vocabulary growth up to age 5. By age 5 children's vocabularies have reached sufficient size to support the skills of identification of language units, processing and combining language sounds that the non-words repetition task measures [33].

Our results are consistent with the literature on the relationship between receptive vocabulary and the non-words repetition task. The shift from the PPVT predicting younger children's number skills to the non-word repetition task predicting older children's number skills occurs at about the same time that receptive vocabulary more strongly supports the skills measured by the non-words repetition task. One possible explanation is that the concept of a unit is common to both phonological working memory and number skills. As children are improving in their identification and use of language units their number skills, which are also based on understanding units [34], are also improving. Another possible explanation is that a larger vocabulary contains more advanced words, which supports both phonological working memory and number skills. Although the PPVT does not include many words that are specific to number it is possible that as children's vocabularies grow that more number words are included. Purpura and Logan [35] found that a number specific vocabulary predicts young children's number performance. It is not possible to select from these explanations, or other possibilities based on our research. Further research is needed to examine the relevance of the connection between the non-word repetition task and children's number skills.

7. Implications for curriculum

We agree with Krajewski and Schneider [6] that phonological awareness and early number skills should be taught together early in the preschool years in order to reinforce skill development. An added bonus, as noted by Krajewski and Schneider, is that phonological awareness skills are also necessary to the development of reading so early exposure facilitates the development of two key skill domains. Additionally, it appears from the work of Chu et al. [36] that both numeracy and preliteracy skills, such as recognition of the alphabet in preschool, predict achievement in numeracy and reading by the end of kindergarten. A strong case is emerging for the importance of learning about numeracy in preschool in order to support the development of both numeracy and reading.

With respect to executive functioning, especially phonological working memory, we agree with Clark et al. [11] and Clements et al. [21] that intentional training and practice, presented in a developmentally appropriate way, could scaffold children's development of the executive functioning skills that are specifically geared to learning number skills. Phonological working memory involves remembering the units of language. As children become more proficient with phonological awareness moving to an emphasis on explicit identification of the units of language is appropriate.

7.1 Influence of type of childcare setting

Type of childcare setting is a demographic characteristic not often included in research on children's number skills. While there were significant differences between program types for children's scores, there were no differences in the predictors for type of childcare setting. The same patterns held for both center and family childcare children. This particular finding has never before been reported in the literature, to our knowledge and suggests that the same types of training and curriculum are likely to be effective for children in both settings.

7.2 Applied measures

Many studies use laboratory measures for phonological awareness and executive functioning. Our work demonstrates that applied measures of phonological awareness and executive functioning which are composed of activities that could be observed or implemented by teachers serve as predictors of early numeracy performance. Both the PALS and BRIEF-P are measures that can be used by teachers, and our discussion of curriculum implications above indicates how the information gained from these measures could help teachers plan both curriculum and intervention. The measure of phonological working memory, the non-words repetition task, is one that can also be readily understood by teachers and used as the basis for classroom activities.

8. Limitations

There are several limitations to this study. First, the sample was cross sectional in nature. It would be beneficial to study the same children over a period of time to see the impacts that developmental changes in phonological working memory, executive functioning, receptive vocabulary, and phonological awareness have on number skills and vice versa.

Another limitation is the fact that the childcare center children were drawn from just three centers, limiting the independence and variability of this subsample. The family childcare sample was a bit more variable with children recruited from eight family care programs. However, in the region of the country in which this study took place family care programs are more plentiful than childcare centers. Many parents have a strong personal preference for family childcare over childcare centers, believing that it is preferable to find a family childcare provider whose values align with those of the family. Conducting similar research in another region is an important step in replicating our results.

A final limitation might have been our sample size and lack of statistical power to detect small effects. We might not have had sufficient statistical power to detect smaller relationships.

9. Conclusions

Best practices for encouraging the development of preschool mathematics are still emerging. The National Mathematics Advisory Panel [29] expressed concern that some preschools and childcare programs emphasize isolated, unconnected skills that do not support early mathematics development as well as other strategies. They argue for a developmental approach with curriculum progressing logically from less sophisticated topics into more sophisticated ones. Understanding the relationships between early mathematics development and other cognitive domains can improve our understanding of how young children develop foundational mathematical skills; likely identifying areas that use similar strategies [21].

Our work contributes to understanding the connections between young children's number skills, their linguistic skills, and executive functioning. The PALS, a measure of phonological awareness, predicted both the younger and older children's number skills. It was significant in all combinations of predictors and for both age groups. This result replicated the work of others who have reported the effect of phonological awareness on children's number skills [6, 17, 18].

Additionally, our results demonstrate that receptive language is a closely related influence on younger children's number skills. However, this pattern changed for older children and one of the components of executive functioning, phonological working memory, was more influential than receptive language on their number skills. The predictive relationship between the non-words repetition task and older children's number skills indicates that similar skills are involved. One likely candidate is the concept of a unit.

Although the children attending family childcare scored lower on many measures there was no evidence that the relationships between phonological awareness, executive functioning, and number skills differed so the same curricular approaches should work for both. Curricular support for building children's vocabulary and discrimination of language sounds could provide the foundation needed for the further development of phonological memory [33] and number skills. In addition, curriculum for older preschool children could focus on acquisition of units of language and as well as units for counting and for measuring.

The successful use of applied measures in this study provides a promising pathway for future research examining the connections between young children's number skills, linguistic skills, and executive functioning. In addition, the use of behaviors that can be easily observed by teachers makes it easier to provide useful guidance for improving education for early childhood teachers and parents.

Acknowledgements

We thank the Utah State University Agriculture Experiment Station for their support. Thanks to the parents, children, and providers who participated in this study, to Krista Gurko and Alexander Fronk who assisted with data collection, Roxane Pfister for assistance with data analysis.

Author details

Belinda Blevins-Knabe[1], Jacob Esplin[2], Ann M. Berghout Austin[2]* and Shawnee M. Hendershot[3]

1 University of Arkansas at Little Rock, Little Rock, USA

2 Utah State University, Logan, USA

3 Pittsburg State University, Pittsburg, USA

*Address all correspondence to: ann.austin@usu.edu

References

[1] Watts TW, Duncan GJ, Siegler RS, Davis-Kean PE. What's past is prologue: Relations between early mathematics knowledge and high school achievement. Educational Researcher. 2014;**43**(7):352-360. DOI: 10.3102/0013189X14553660

[2] Duncan GJ, Dowsett CJ, Claessens A, Magnuson K, Huston AC, Klebanov P, et al. School readiness and later achievement. Developmental Psychology. 2007;**43**(6):1428-1446. DOI: 10.1037/0012-1649.43.6.1428

[3] Ritchie SJ, Bates TC. Enduring links from childhood mathematics and reading achievement to adult socioeconomic status. Psychological Science. 2013;**24**(7):1301-1308. DOI: 10.1177/0956797612466268

[4] Curby TW, Rimm-Kaufman SE, Ponitz CC. Teacher-child interactions and children's achievement trajectories across kindergarten and first grade. Journal of Educational Psychology. 2009;**101**(4):912-925. DOI: 10.1037/a0016647

[5] Clements DH, Sarama J. Learning and Teaching Early Math: The Learning Trajectories Approach. 2nd ed. New York, NY: Routledge, Taylor & Francis; 2014. 380 p. DOI: 10.4324/9780203520574

[6] Krajewski K, Schneider W. Exploring the impact of phonological awareness, visual-spatial working memory, and preschool quantity—Number competencies on mathematics achievement in elementary school: Findings from a 3-year longitudinal study. Journal of Experimental Child Psychology. 2009;**103**(4):516-531. DOI: 10.1016/j.jecp.2009.03.009

[7] Wade M, Jenkins JM, Venkadasalam VP, Binnoon-Erez N, Ganea PA. The role of maternal responsiveness and linguistic input in pre-academic skill development: A longitudinal analysis of pathways. Cognitive Development. 2009;**45**:125-140. DOI: 10.1016/j.cogdev.2018.01.005

[8] Lukie IK, Skwarchuk S, LeFevre J, Sowinski C. The role of child interests and collaborative parent–child interactions in fostering numeracy and literacy development in Canadian homes. Early Childhood Education Journal. 2014;**42**(4):251-259. DOI: 10.1007/s10643-013-0604-7

[9] Blevins-Knabe B, Austin AB, Musun L, Eddy A, Jones RM. Family home care providers' and parents' beliefs and practices concerning mathematics with young children. Early Child Development and Care. 2000;**16**:541-558. DOI: 10.1080/0300443001650104

[10] Ginsburg H, Lee J, Boyd J. Mathematics education for young children: What it is and how to promote it. Social Policy Report. 2008;**22**(1):3-24. Available from: www.srcd.org/documents/publications/spr/22-1_early_childhood_math.pdf. [Accessed: 2018-07-30]

[11] Clark CC, Pritchard VE, Woodward LJ. Preschool executive functioning abilities predict early mathematics achievement. Developmental Psychology. 2010;**46**(5):1176-1191. DOI: 10.1037/a0019672

[12] Segers E, Damhuis CP, van de Sande E, Verhoeven L. Role of executive functioning and home environment in early reading development. Learning and Individual Differences. 2016;**49**:251-259. DOI: 10.1016/j.lindif.2016.07.004

[13] Bardikoff N, Sabbagh M. The differentiation of executive functioning

across development: Insights from developmental cognitive neuroscience. In: Budwig N, Turiel E, Zelazo PD, editors. New Perspectives on Human Development New York. NY, US: Cambridge University Press; 2017. pp. 47-66. DOI: 10.1017/CBO9781316282755.005

[14] Whitehurst GJ, Lonigan CJ. Child development and emergent literacy. Child Development. 1998;**69**:848-872. DOI: 10.2307/1132208

[15] Kleemans T, Segers E, Verhoeven L. Cognitive and linguistic precursors to numeracy in kindergarten: Evidence from first and second language learners. Learning and Individual Differences. 2011;**21**(5):555-561. DOI: 10.1016/j.lindif.2011.07.008

[16] Skibbe LE, Hindman AH, Connor CM, Housey M, Morrison FJ. Relative contributions of prekindergarten and kindergarten to children's literacy and mathematics skills. Early Education and Development. 2013;**24**(5):687-703. DOI: 10.1080/10409289.2012.712888

[17] Michalczyk K, Krajewski K, Preβler A, Hasselhorn M. The relationships between quantity-number competencies, working memory, and phonological awareness in 5- and 6-year-olds. The British Journal of Developmental Psychology. 2013;**31**(4):408-424. DOI: 10.1111/bjdp.12016

[18] Cirino PT. The interrelationships of mathematical precursors in kindergarten. Journal of Experimental Child Psychology. 2011;**108**(4):713-733. DOI: 10.1016/j.jecp.2010.11.004

[19] Passolunghi MC, Vercelloni B, Schadee H. The precursors of mathematics learning: Working memory, phonological ability and numerical competence. Cognitive Development. 2007;**22**:165-184. DOI: 10.1016/j.cogdev.2006.09.001

[20] Purpura DJ, Hume LE, Sims DM, Lonigan CJ. Early literacy and early numeracy: The value of including early literacy skills in the prediction of numeracy development. Journal of Experimental Child Psychology. 2011;**110**(4):647-658. DOI: 10.1016/j.jecp.2011.07.004

[21] Clements DH, Sarama J, Germeroth C. Learning executive function and early mathematics: Directions of causal relations. Early Child Research Quarterly. 2016;**36**:79-90. DOI: 10.1016/j.ecresq.2015.12.009

[22] Gioia GA, Espy KA, Isquith PK. BRIEF-P: Behavior Rating Inventory of Executive Function-Preschool Version [kit]. Lutz, FL: Psychological Assessment Resources; 2003

[23] Miyake A, Friedman NP, Emerson MJ, Witzki AH, Howerter A. The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. Cognitive Psychology. 2000;**41**:49-100. DOI: 10.1006/cogp.1999.073

[24] Rasmussen C, Bisanz J. Representation and working memory in early arithmetic. Journal of Experimental Child Psychology. 2005;**91**(2):137-157. DOI: 10.1016/j.jecp.2005.01.004

[25] Kleemans T, Segers E, Verhoeven L. Relations between home numeracy experiences and basic calculation skills of children with and without specific language impairment. Early Child Research Quarterly. 2013;**28**(2):415-423. DOI: 10.1016/j.ecresq.2012.10.004

[26] Austin AMB, Blevins-Knabe B, Ota C, Row T, Lindauer SLK. Mediators of preschoolers' early mathematics concepts. Early Child Development and Care. 2011;**181**(9):1181-1198. DOI: 10.1080/03004430.2010.520711

[27] Gathercole SE, Adams AM. Phonological working memory in very young children. Developmental Psychology. 1993;**29**(4):770-778. DOI: 10.1037/0012-1649.29.4.770

[28] Ivernizzi M, Sullivan A, Meier J, Swank L. Pre-K teacher's Manual: PALS Phonological Awareness Literacy Screening; 2004

[29] National Mathematics Advisory Panel. Foundations for Success: The Final Report of the National Mathematics Advisory Panel. Washington, DC: US Department of Education; 2008

[30] Kontos S. Family day care: The 'other' form of care. In: Spodeck B, Saracho O, editors. Yearbook in Early Childhood Education. Vol. 3. . Issues in Child. New York, NY: Teachers College Press; 1992. pp. 107-124

[31] Dunn LM, Dunn LM. Peabody Picture Vocabulary Test. Circle Pines, MN: American Guidance Service; 1997

[32] Ginsburg HP, Baroody AJ. The Test of Early Mathematics Ability. 3rd ed. Austin, TX: PRO Ed; 2003

[33] Coady JA, Evans JL. Uses and interpretations of non-word repetition tasks in children with and without specific language impairments (SLI). International Journal of Language & Communication Disorders. 2008;**43**(1): 1-40. DOI: 10.1080/13682820601116485

[34] Sophian C. The Origins of Mathematical Knowledge in Childhood. New York: Lawrence Erlbaum Associates; 2008. 196 p

[35] Purpura DJ, Logan JR. The nonlinear relations of the approximate number system and mathematical language to early mathematics development. Developmental Psychology. 2015; **51**(12):1717-1724. DOI: 10.1037/ dev0000055

[36] Chu FW, van Marle K, Geary DC. Predicting children's reading and mathematics achievement from early quantitative knowledge and domain-general cognitive abilities. Frontiers in Psychology. 2016;**7**. DOI: 10.3389/ fpsyg.2016.00775 [Accessed:2018-07-30]