Count on reading: Phonological awareness' role in the literacy and numeracy of preschoolers

Ellie Clin, Lindsay Heggie, and Lesly Wade-Woolley (*Queen's University, Kingston, ON*)

Introduction

The development of reading and math skills are highly related in children, often to the extent that a disability in one domain is accompanied by a disability in the other (see e.g. Rouselle & Noël, 2007). Based on the assumption that the interrelation of skills in reading and in math stems from abilities in a common area, Hecht, Torgesen, Wagner, and Rashotte (2001) have proposed a model to account for this relationship. With the strong empirical evidence for the importance of phonological awareness (PA) in reading development (e.g. Adams, 1990) and the knowledge that phonological systems are often engaged during counting and solving arithmetic and computation problems (see Hecht et al., 2001), they proposed that a child's phonological awareness may contribute to mathematic development as it does for reading. Indeed, for students in grades 2 through 5, three types of phonological skills (phonological memory, rate of access, and PA) predicted math computation skills; the first two skills (phonological memory and rate of access) were developmentally limited in that they predicted math growth in computation skills between grades 2 and 3, while PA's predictive power continued between grades 3 and 4 as well as grades 4 and 5.

Developing math abilities in younger children have also been studied. Children as young as 2.5 years have shown a reliable ability to calculate small numbers nonverbally; children aged 3 years show differences in this nonverbal mathematical ability that are strongly related to differences in intelligence (Huttenlocher, Jordan, & Levine, 1994). This nonverbal mathematical ability is hypothesized to develop some time between infant abilities in mathematical approximation and school-age acquisition of symbols (Huttenlocher et al., 1994).

These hypotheses have found support in the literature (e.g. Simmons, Singleton, & Horne, 2007). However, in their study of five and six-year-olds, Simmons et al. used the British Ability Scales Number Skills Test (BAS Number; Elliott et al., 1983), which makes heavy demands on verbal ability. The task consists of 34 orally presented problems with accompanying pictures. For example, there are simple arithmetic problems ("Each horse needs four new shoes. How many horseshoes must the farmer get altogether?") and size matching questions ("Can you show me the bucket that goes with the little spade?"). Given the heavy language demands inherent in the BAS, it is not surprising that PA, a language skill, was shown to be a significant predictor of performance on the math outcome measure. However, the verbal nature of the math task makes it difficult to determine whether the phonological component would maintain a predictive relationship to early math were a lesser language-oriented math measure involved. In other words, the influence of PA and its contribution to developing mathematical ability may have been confounded by the sole use of orally presented, verbal math problems. For a relationship between phonological awareness and developing math skills to hold, we should see a similar effect of PA on math when these skills are assessed by measures less constrained by verbal ability.

The present study seeks to examine phonological skills' contribution to developing numeracy while children are transitioning between the stages proposed by Huttenlocher et al. regarding the developmental nature of this language-based ability, as well as to investigate the relationship between reading and mathematical ability at this stage. Using kindergarten students who had been exposed to formal education for approximately half a school year, we examined the degree to which phonological awareness accounts for mathematical skills when tested with measures that were less reliant on verbal skills.

Central Questions

Are early reading abilities and early numeracy abilities related?

Does phonological awareness predict early reading ability?

Does phonological awareness predict early numeracy ability, using measures of mathematics ability less reliant on verbal skills?

Method

Participants

Forty-five children (M_{age} = 67.2 months; 26 female, 19 male) enrolled half-time in both Kindergarten and daycare in Eastern Ontario participated in this study. No screening measures were used; participation was based on parental consent and verbal assent of the participant prior to each session.

Materials

General ability measures

Matrix Analogies Test (MAT; Naglieri, 1985). To test their ability in nonverbal reasoning, children were shown a large picture of geometrical shapes and patterns with one section missing, as well as five or six small pictures to act as possible fills for the missing section of the large picture. Children were instructed to look at the picture and point to which of the options should be put into the missing section.

Peabody Picture Vocabulary Test (PPVT; Dunn & Dunn, 1997). To test general language ability, children were shown a page containing four equal quadrants, each filled with a drawn picture. Children were asked to point to the one picture which best represented a word provided by the experimenter (e.g. "Point to crying").

Comprehensive Test of Phonological Processing: Non-word Repetition (CTOPP; Wagner, Torgesen, & Rashotte, 1999). As a test of short-term memory, children were instructed to listen carefully to made-up words played on a CD player over a pair of headphones, and to repeat back the made-up word exactly as they had heard it. Children's responses were recorded on an audio digital recorder for scoring.

Phonological awareness measures

Comprehensive Test of Phonological Processing: Blending Words (CTOPP; Wagner, Torgesen, & Rashotte, 1999). Over headphones, children listened to separate phonemes or syllables and were asked to combine the phonemes or syllables they heard into one word (e.g. /i/ /t/ makes 'it').

Phoneme Deletion (Wood & Terrell, 1998). On one occasion, children listened to the experimenter say a word and were then asked to repeat the word without the initial phoneme (e.g. "told" becomes "old"). On another occasion, children repeated the experimenter's spoken word without the final phoneme (e.g. "made" becomes "may").

Comprehensive Test of Phonological Processing: Sound Matching (CTOPP; Wagner, Torgesen, & Rashotte, 1999). In each set, the participant was asked to identify which word in a series of three best matched the target word (for example, "Which word starts with the same sound as pan: pig, hat, or cone?"). There were ten trials for initial sounds and ten for final sounds.

Early reading measures

Woodcock Reading Mastery Tests: Word Identification (WID; Woodcock, 1998). Beginning at an age-appropriate level, children were presented with small sets of words of increasing difficulty on a page and asked to read them aloud in no set time limit.

Wide Range Achievement Test (WRAT-3; Wilkinson, 1993). Children were asked to read the names of letters and words of increasing difficulty on a page aloud in no set time limit. The first 15 items were uppercase letters that the participant was asked to name.

Early numeracy measures

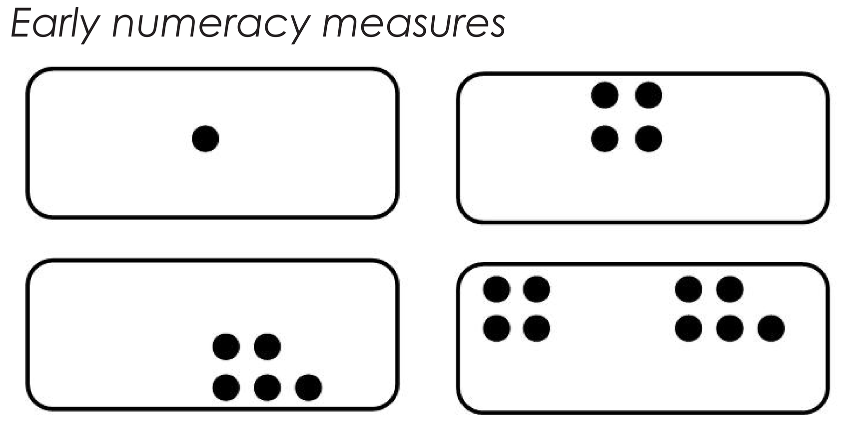

Figure 1. Quantity Array items.

Quantity Array (Clarke & Shinn, 2004). Children were shown 3 pages of 12 boxes each, wherein every box contained a number of dots. With a time limit of one minute, children were asked to say the number of dots in each box for as many boxes as they could.

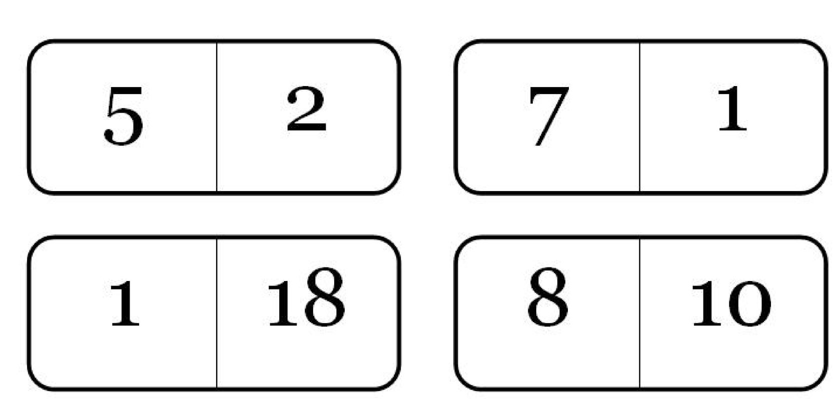

Figure 2. Quantitiy Discrimination items.

Quantity Discrimination (Clarke & Shinn, 2004). Children were shown 3 pages of 21 boxes, each containing two Arabic numerals. Children were asked to say or point to the number in each box that was biggest for as many of the boxes as they could within one minute.

Results

Table 1

Descriptive Statistics: Scores on reading and math measures.

	Min	Max	*M*	*SD*
WRAT	7	26	16.12	3.83
Word Identification	0	46	8.72	12.42
Letter Sounds	3	26	17.47	6.69
Quantity Discrimination	4	38	19.19	8.31
Quantity Array	8	18	12.47	2.89

Note. n=43 and all of the above are raw scores.

Age (in months) and sex were not significant correlates of performance on either the math or reading measures. Two outliers were identified on the basis of very high scores (one on math and reading measures; the other on nonverbal reasoning (MAT) score) and were not included in the analyses (*n*=43).

In order to determine whether developing reading and math skills were related, a series of zero order correlations between the two math measures (Quantity Array and Quantity Discrimination) and the three reading measures (WRAT, WordID, and Letter Sounds) were run (see Table 2). Results showed significant correlations between both Quantity Array and Quantity Discrimination and the three reading measures.

Table 2

Correlations between reading and math measures.

	WordID	WRAT	Letter Sounds	Quant Disc
WordID	-			
WRAT	.794***	-		
Letter Sounds	.507**	.701***	-	
Quant Disc	.333*	.363*	.308*	-
Quant Array	.359*	.428**	.308*	.580***

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

Math and reading composites were created based on strong correlations between measures. In addition, a phonological awareness composite was made, composed of scores on Phoneme Blending, Phoneme Deletion (initial and final), and Sound Matching tasks. (See Table 3.)

Table 3

Measures of Phonological Awareness.

	Phoneme Blending	Phoneme Deletion
Phoneme Blending	-	
Phoneme Deletion	.571***	-
Sound Matching	.566***	.565*

Note. *** denotes *p*<.001

Our measures of short-term memory, nonverbal reasoning, and general language ability did not significantly correlate with our reading or math measures (see Table 4) and were thus not included as control measures.

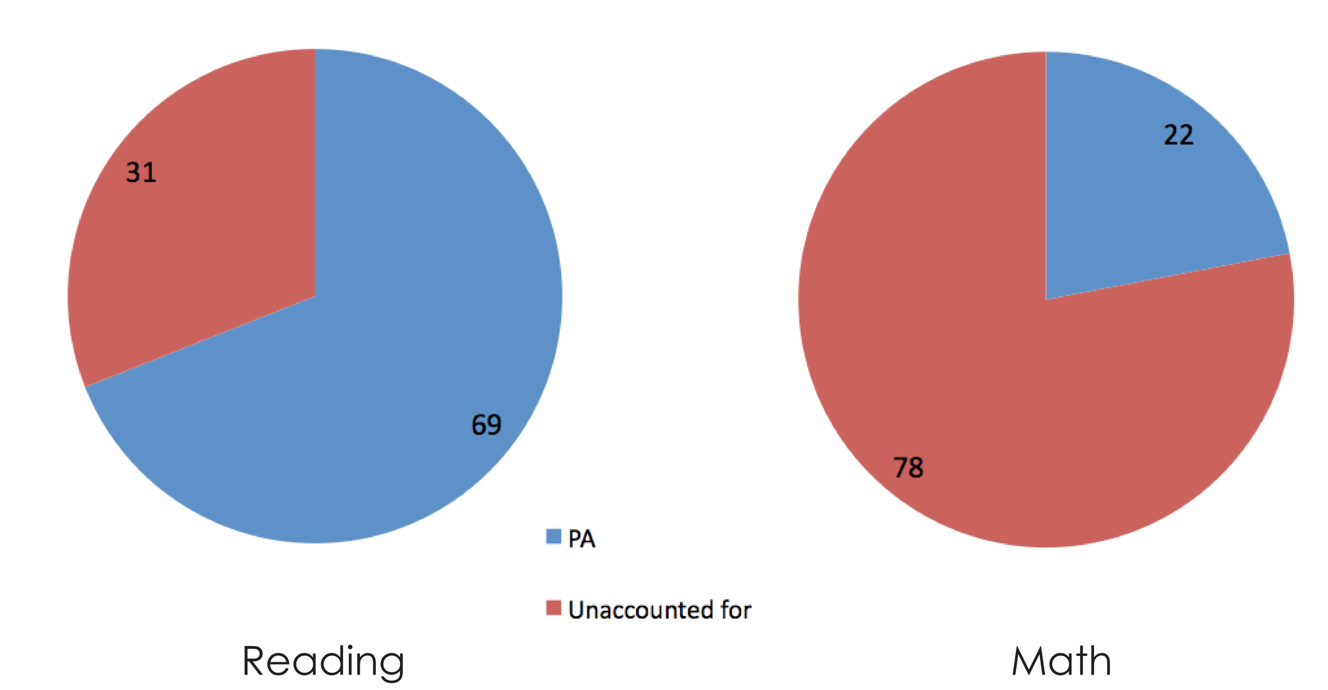

Figure 3. Percentage of reading and math skills accounted for by PA.

Table 4

Control measures not correlated with reading or math measures.

	WordID	WRAT	Letter Sounds	Quantity Discrim	Quantity Array
PPVT	-.033	.67	.061	.137	-.016
MAT	-.012	-.004	.046	.065	.149

Note: all of the above are raw scores.

A zero order correlation was run in order to investigate to what degree abilities in phonological awareness account for early reading and early math abilities. PA was found to be a significant correlate of both reading and math abilities, but accounted for different percentages of the variance for each skill set (Table 5).

Table 5

PA's influence on early reading and math skills.

	PA Composite	Reading Composite	Math Composite
PA Composite	-		
Reading Composite	.831***	-	
Math Composite	.467**	.445**	-

Note. PA Composite = Phoneme Blending, Phoneme Deletion (initial + final), Sound Matching; Reading Composite = WordID, WRAT, Letter Sounds; Math Composite = Quantity Discrimination and Quantity Array. ** denotes *p*<.01 and *** denotes *p*<.001

Thus, PA accounts for 69% of the variance in reading and 22% of the variance in math (see Figure 3).

Discussion

Our findings support past research in two ways. First, our data replicates previous findings showing that phonological awareness (PA) significantly predicts a large amount of variance (in our study, 69%) in reading ability at this age. Second, it was found that early reading abilities and early math abilities are related (reading and math measures correlated significantly between 31%-79%). Further, our findings suggest that PA plays a significant role in predicting early math skills, even when these skills are assessed using nonverbal measures. While PA does predict a significant amount of variance in reading and math, the amount of variance predicted in early reading surpasses the variance predicted in early math.

Overall our findings are consistent with current theories of phonological awareness' involvement in early math and reading skills, but there are theoretical and practical limitations to this study. Primarily, none of our control variables significantly correlated with math or reading skills. Data would further have been improved if a second time point for assessment and additional mathematics measures had been included.

In addition to PA's influence, variables other than reading and pre-reading skills (e.g. number sense) also significantly contribute to the prediction of children's early math abilities (Jordan, 2007). Current research suggests that children who experience difficulties in both math and reading are at a particular disadvantage for successful growth in math skills, compared to children who only experience difficulty in one area. Phonological awareness may account for significant variance in mathematical ability, but difficulties in PA are not sufficient to necessitate a mathematical disability, as is often the case for a reading disability (Jordan, 2007).

Phonological awareness' influence maintained the predictive relationship to early math evidenced by Simmons, Singleton, and Horne (2007) with math measures that were less dependent on verbal components. Future research investigating the role of language skills in math development should use math assessments which do not rely heavily on language-based operations, particularly with respect to children who experience difficulties in both reading and math.

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