EARLY NUMERACY PROFILES OF ARITHMETIC DISABILITY AND ARITHMETIC AND READING DISABILITY SUBTYPES

By

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Abstract

The present study investigated the kindergarten and grade 1 numeracy profiles of arithmetic disability (AD) and reading and arithmetic disability (RAD) subtypes. The results showed that children with RAD exhibited a different profile than children with AD in both kindergarten and in grade 1. In kindergarten, children with RAD knew fewer letters and numbers, were more developmentally delayed in their informal skills than AD children and had a memory span deficit. In grade 1, RAD children continued to be characterized by memory span and informal skill deficits. RAD children were also significantly deficient in mathematical problem solving and reading. The kindergarten predictors of grade 1 numeracy achievement were also investigated. The present study found support for the role of informal skills, working memory, spatial tasks and phoneme deletion in grade 1 numeracy achievement. Future research is needed to determine the predictive power of kindergarten skills to later numeracy skills.

TABLE OF CONTENTS

List of Tables

To Deda

I miss you

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Quantitative notions pervade nearly every aspect of life, especially in a technologically based society, yet we tend not to notice the role of numeracy skills in our daily thoughts, interactions, and experiences. Numeracy refers to calculation skills and mathematical reasoning. Specifically, arithmetic and mathematics are to numeracy what reading and writing are to literacy. Notions of numeracy are evident in obvious examples such as currency, counting and time, but also in less obvious aspects such as music, sports, literature, star-gazing, problem solving and decision making. Many aspects of our lives are based on quantitative ideas and opportunities, and those experiencing difficulties or disabilities in this area are at a significant disadvantage. It is estimated that numeracy dysfunctions[1] affect between 4-15% of the school aged population (Badian, 1999; Fleischner & Manheimer, 1997; Share, Moffitt, & Silva, 1988).

Despite this, numeracy dysfunctions tend to receive minimal research attention and little advancement has been made in the study of disorders of numeracy. This is in part likely due to the emergent status of the field. Mathematics disability (MD), mathematics difficulties, nonverbal learning disabilities, and arithmetic disability (AD) are among the most common terms used to describe numeracy dysfunctions. Although the defining characteristic among these groups tends to be below average achievement in arithmetic, researchers are not consistent in their selection criteria, which makes it difficult to draw conclusions and make inferences. For example, Siegel and Ryan (1989), Geary, Bow-Thomas and Yao (1992), and Jordan and Montani (1997) all use achievement scores to identify numeracy dysfunctions; however, Siegel and Ryan use a cut-off score at the 25th percentile, Jordan and Montani use the 30th percentile, and Geary, Bow-Thomas and Yao use the 45th percentile. Although the selection of cut-scores is admittedly arbitrary, it is difficult to argue that a cut-off score above the 40th percentile signifies a disability. As such, research findings in this area tend to be inconsistent and muddled. Regardless of the

[1] In this document, numeracy dysfunction refers to disorders of arithmetic and mathematical reasoning with or without concurrent reading difficulties. Specific disorders of arithmetic and mathematical reasoning will be referred to as arithmetic disability (AD).

terminology used or the specific variables under investigation, it is clear that researchers are interested in investigating those children with dysfunctions in numeracy skills. Current conceptualizations of learning disabilities (LD), based on over three decades of research, define LD as performance at or below the 25th percentile on standardized achievement measures (Lyon et al., 2001; Siegel, 1999).

One of the more promising findings to emerge from this area that may be important in resolving previous inconsistencies resulting from different selection criteria is the growing agreement among investigators that studies of disorders of numeracy must consider reading performance. Converging evidence exists to support the separation of students with numeracy dysfunctions into those with specific arithmetic disability (AD) and those with both reading and arithmetic disability (RAD). For example, Fuchs and Fuchs (2002) classified their sample into AD and RAD groups and found the RAD group to be significantly lower in mathematical problem solving than the AD group. Geary, Hoard and Hamson (1999) found significant differences between those with AD and RAD in counting skills and working memory, with differences favouring the AD group. Jordan, Hanich and Kaplan (2003) divided their sample into AD, RAD, reading disabled (RD), and normally achieving (NA) and found the AD and RAD groups did not differ from each other in calculation ability but the RAD group was significantly lower than the AD group in problem solving.

Additionally, there is research that these groups are identifiable across the lifespan and are stable over time. Shafrir and Siegel (1994) classified 331 adolescents and adults (age range 16 years to 72 years) into NA, AD, RD, and RAD groups. The authors found that each group differed significantly from the others on reading, spelling, memory and other cognitive measures. Silver, Pennet, Black, Fair, and Balise (1999) found that subtyping classifications for children ages 9 to 13 were moderately stable over 19 months. Specifically, approximately half of the sample of 80 children retained their initial status 19 months later. The authors found that the

RAD subtype was the most stable. However, this research is preliminary and the authors cautioned against making recommendations based on subtypes.

Although the stability and longitudinal course of subtypes is yet to be determined, children with numeracy difficulties with or without comorbid reading difficulties exhibit a number of deficits that differentiate them both from their normally achieving peers, as well as from each other. Badian (1999) studied 1,075 children over a period of 14 years to determine the persistent nature of AD, RAD, and RD subtypes. Birth history and preschool data were collected for each participant six months prior to entry into kindergarten. A number of important findings emerged from this study. Badian found that children classified as AD suffered more birth problems and illness than individuals with RD and RAD. In the preschool years, children with AD were significantly higher than the RAD and RD group in verbal IQ and language. AD, RAD and RD children were uniformly depressed and significantly worse than NA children on visual-motor skills. However, preschool visual motor skill was significantly correlated to arithmetic achievement at the end of grade 8 only in the AD group (Badian, 1999).

In school aged children, the deficits become more differentiated. In the first and second grades, children with RAD have been found to make frequent counting errors (Geary, 1990; Geary, Brown, & Samaranayake, 1991), to be developmentally delayed in their knowledge and understanding of counting (Geary et al., 1992; Geary et al., 1999), to have difficulty detecting errors made in counting (Geary et al., 1992; Geary et al., 1991; Geary et al. 1999), to use inefficient counting strategies (Geary, 1990; Geary et al., 1992; Geary et al., 1991), to execute and select counting strategies poorly (Geary, 1990; Geary et al., 1991), to have a high error rate in direct retrieval (Geary, 1990; Geary et al., 1991), to have unsystematic solution times for arithmetic facts (Geary, 1990), and to be unfamiliar with numerical representations (Geary et al., 1999). Additionally, Geary et al. (1999) found that children with RAD had significantly lower backward digit span than AD and NA children. In the early years, Geary et al. (1999)

hypothesized that number recognition and developmentally delayed counting knowledge may be distinguishing features of RAD children, although he cautioned the predictive utility of these measures. Additionally, Geary (1990; Geary et al., 1999) postulated that representation of addition facts in long-term memory may be abnormal in RAD children and that AD children may have specific deficits in the ability to manipulate information in working memory while engaged in numerical activities.

In later grades, RAD children seem to be the most impaired group on all measures of numeracy (Jordan & Montani, 1997; Russell & Ginsburg, 1984; Shafrir & Siegel, 1994), although the performance of AD children on some tasks is as depressed as the RAD group. Jordan and Montani (1997) found that third grade AD children were able to perform similarly to their NA peers on number fact and story problems when the problems were not timed. In timed conditions, the performance of the AD children was not differentiated from the RAD children. Similarly, Jordan et al. (2003) found that by the end of third grade, the AD group had an advantage over the RAD group in problem solving, although the groups did not differ on calculation fluency. Fuchs and Fuchs (2002) also found that fourth grade AD children were superior to RAD children in mathematical problem solving.

There is some evidence that visual-perceptual deficiencies, psychomotor deficits and tactile-perceptual deficits may differentiate AD children from RAD and NA children (Badian, 1999; Rourke, 1993; 2000). Rourke (1993; 2000) argues that the research on nonverbal learning disabilities (NLD) - a group with impaired numeracy skills and often compared to AD groups - provides evidence that children who exhibit specific patterns of reading, spelling and arithmetic achievement also demonstrate predictable patterns of neuropsychological abilities and deficits, which may prove useful for identification purposes. Specifically, in Rourke's research, those with NLD tend to have deficits in visual-spatial tasks and strengths in verbal skills. However, it should be mentioned that it is not clear that the NLD group represents a group with specific

arithmetic dysfunctions. Shafrir and Siegel (1994) and Badian (1999) also found that children with numeracy dysfunctions exhibited deficits on visual-spatial tasks. Previous research does not provide clear evidence.

In sum, although there is support for the differentiation of AD and RAD subtypes, this body of research is still in its infancy. The findings presented above indicate that RAD children are the most impaired subtype and there seems to be converging evidence that AD children display impaired calculation ability specifically under timed conditions. In fact, Geary (1993) has postulated that speed of processing and working memory or a combination of the two may be responsible for the deficits experienced in children with numeracy difficulties. However, at this point in time, there is nothing in the numeracy dysfunction literature akin to phonological awareness as the basis for RD, which has serious implications for early identification and intervention. Longitudinal data is needed to determine the defining characteristics of AD and RAD subtypes in the early years before a child experiences failure due to the disability. The absence of a core deficit in numeracy dysfunctions is a serious limitation in the field.

Core Deficit Contenders

Although a core deficit has yet to be determined in numeracy dysfunctions, a number of possible candidate systems have been implicated in the literature: informal mathematics skills, working memory, long-term retrieval and visual-perceptual skills.

Children bring to school an informal system of mathematical knowledge (Ginsburg, 1975; 1997). This informal system is thought to be a counting based-representation of numbers, as opposed to an abstract representation based on a written numeration system (Baroody, Gannon, Berent, & Ginsburg, 1984). Generally, informal skills are those that do not require the use of formal mathematical symbols and formulae taught in school and are often computed mentally. An example of an informal skill is the nonverbal calculation tasks used by Jordan and colleagues (Jordan, 1995; Jordan, Huttenlocher, & Levine, 1992; Jordan, Levine, &

Huttenlocher, 1994). In nonverbal calculation tasks, children are shown an initial array of objects that is then hidden by a cover. The child then watches the examiner either remove or add objects to the hidden array. The child's task is to reproduce the transformed array presumably by using an informal system of arithmetic. Other examples of informal mathematics include counting by 10s, or knowing that a family of four will require four place settings at the dinner table. The informal system develops spontaneously through interactions with the environment and is thought to be a requisite skill as children shift from the concrete world of objects to the abstract world of higher mathematical thinking and analysis. In other words, this informal system is thought to prepare children for the acquisition of formal mathematics (Baroody et al., 1984; Gersten & Chard, 1999; Jordan, 1995).

The hypothesis that informal skills foster the development of formal skills is not entirely supported by the evidence. For example, Jordan et al. (1992) found that kindergarten children of middle and low income families did not differ on nonverbal informal math tasks, such as nonverbal calculations, but did differ in formal math tasks, such as verbal story problems and number-fact calculations, with differences favouring the middle income children. This pattern of similar skill level in informal knowledge but different skill level in formal knowledge continued to be evident in the first grade even after formal instruction (Jordan et al., 1994), suggesting that informal skills may not distinctly map onto formal mathematics. Russell and Ginsburg (1984) found no deficiencies in informal math skills in a sample of grade 4 children with numeracy dysfunctions, suggesting that the difficulties in numeracy were not related to informal mathematics deficiencies. Jordan, Levine and Huttenlocher (1995) found differences in calculation ability in children with different patterns of cognitive functioning. Specifically, children with language impairments exhibited deficiencies on story problems but not on informal problems or number-fact problems. Children with low language and low spatial cognitive ability were impaired on informal problems and story problems but not on number-fact problems.

Children with low spatial ability did not differ from the nonimpaired group on any of the problem types. These findings (Jordan et al., 1995) indicate that impaired informal skills are not necessarily related to impaired formal skills, and that intact informal skills occur in the presence of impaired formal skills. Taken together, these findings show that groups of children can be comparable on informal skills yet exhibit significant differences in formal skills. Although such findings challenge the role informal skills play in the development of formal numeracy skills, appropriate data are required to sufficiently address the issue.

Working memory is one of the principal contenders for the cognitive process that is most important in numeracy operations. Working memory refers to the ability to "temporarily store and perform a set of cognitive operations on information that requires divided attention and the management of the limited capacity of short-term memory (Flanagan, Ortiz, Alfonso, & Mascolo, 2002, p. 37). An example of a working memory task is the backward digit span of the Wechsler Intelligence Scale for Children (WISC).

Working memory is important both in the calculation and the solution of arithmetic computations and word problems. Children with numeracy dysfunctions often perform arithmetic computations slowly and inaccurately (Jordan & Montani, 1997; Geary, 1993), impairment that has been attributed to limitations in working memory (Siegel & Linder, 1984; Siegel & Ryan, 1989). A number of studies have shown that children with numeracy dysfunctions showed impaired performance in working memory (McLean & Hitch, 1999; Passolunghi & Siegel, 2001; Siegel & Ryan, 1989; Wilson & Swanson, 2001). Working memory may also contribute to children's success in solving arithmetic word problems. Swanson and Cooney (1996) showed a positive relation between working memory and the solution of word problems. However, in their study with third and fourth grade children, Swanson and Cooney found that working memory and solution accuracy were only weakly correlated, and this correlation was not significant when the influence of reading comprehension ability was

controlled. Passolunghi and Siegel (2001) found that AD children were impaired on working memory tasks involving both verbal and numerical information, but were impaired only on numerical and not verbal span tasks, suggesting that the impairments of AD children may be due to limitations in attentional capacity. Geary et al. (1991) describe the results of a "short longitudinal" study involving 26 NA and 12 RAD first- or second-grade children tested at Time 1 and then 10 months later. The authors showed that at Time 2, the NA group had an increased reliance on working memory resources, a decreased reliance on counting to solve addition problems, and an increase in speed of counting and retrieving addition facts from long-term memory. The changes in the RAD group at Time 2 were not reliable. Additionally, Geary et al. found that the frequency of counting errors, the frequency of correct retrieval for number facts and working memory all predicted mathematical achievement. However, the same factors were also predictive of reading achievement. Thus, the role of working memory in numeracy skills is inconclusive.

Geary (1993; Geary et al., 1999) postulated a relationship between long-term representation and retrieval deficits and numeracy dysfunctions, although he noted that the development of long-term representations may be related to speed of processing as well as to computational accuracy, both of which may be related to working memory. Geary hypothesized that there may be a phonological component involved in representing and retrieving arithmetic facts from long term memory and that those with deficits in phonetic systems may experience difficulties representing or accessing information from long-term retrieval, including arithmetic fact retrieval. Jordan et al. (2003) did not find support for this hypothesis as they found that children with RD performed better than children with RAD on fact retrieval, whereas children with AD were not differentiated from children with RAD on fact retrieval. That the AD group was impaired on fact retrieval despite intact decoding skills is in contradiction to Geary's hypothesis.

Deficits in visual-perceptual skills have been implicated in numeracy dysfunctions (Badian, 1999; Rourke, 1993; 2000). Most of this research is from the neuropsychological literature, specifically within the study of nonverbal learning disabilities (NLD). However, as mentioned above, the research on NLD is not clear. Specifically, although many articles have been published on the topic of NLD, these articles are primarily review papers or theoretical perspectives and do not investigate hypotheses empirically. In an empirical study testing the discriminative validity of the NLD subtype, Harnadek and Rourke (1994) investigated 29 children with NLD, 27 children with reading and spelling disabilities and 27 control children. The participants were selected from a larger database of over 5 000 children. The NLD group was selected to have good verbal capacity (WISC VIQ > 79), difficulty with mechanical arithmetic (reading and spelling standard scores > arithmetic standard scores by at least 10 standard score points), visual-perceptual-organizational deficiencies (performance on these tasks at least one standard deviation below the mean and VIQ>PIQ by at least 10 points), psychomotor deficits (task performance at least one standard deviation below the mean), and tactile-perceptual deficits (task performance at least one standard deviation below the mean). Forty-two cases from the database fit the criteria. Of these 42 cases, 29 were identified as NLD, based on additional behavioural features. The reading and spelling disabled children were selected to have reading and spelling percentile scores no higher than the 14th percentile, as well as grade equivalent scores on standardized reading and spelling scores at least 1.8 years below their grade equivalent score on a standardized arithmetic test. The control group had no deficiencies. Performance on 15 neuropsychological variables was compared across the groups. The authors found that specific neuropsychological tests discriminated the NLD group from the other groups, and that reading and speech-sound tests best discriminated the reading and spelling disabled group from the NLD group. The authors concluded that those with NLD display unique neuropsychological profiles although cautioned that their results were preliminary and called for a replication of the

study. Although this study is used to support the unique NLD subtype, it is difficult to interpret this research as the descriptive statistics of the groups were not presented so it is not clear that the groups were in fact different. Further, the authors failed to discuss that of the 42 children selected to fit the NLD criteria, only 29 were identified as NLD. It seems problematic to conclude that the neuropsychological profile of the NLD children was specific to this group as 30% of the sample from the database that was not identified as NLD exhibited the same profile as those that were identified as NLD.

In sum, the profiles of the AD and RAD subtypes and their associated deficits remain inconclusive and there is little in the way of early identification practice for these children. Although a few candidate systems have been proposed to account for the difficulties experienced by children with numeracy dysfunctions, the data remain inconclusive. Longitudinal research into the early development of numeracy skills in children with numeracy dysfunctions is necessary to facilitate the practice of early identification and intervention.

The present study represents such an investigation. The study investigated the development and acquisition of numeracy skills in children from kindergarten to grade 1. The study was guided by two specific questions: (1) what are the early distinguishing features of AD and RAD subtypes; (2) which kindergarten skills are the best predictors of first grade numeracy success and failure?

Method

Participants and Materials

The participants of this study were 137 (71 boys and 66 girls) children who were part of a longitudinal study that began in their kindergarten year. These children represented all of the kindergarten children within a family of schools (n=5). The kindergarten full sample included 189 children (97 boys and 92 girls). The mean age of the kindergarten full sample was 70.23 months (SD= 3.38 months). By the end of grade 1, due to attrition, the sample consisted of 137

children. There were no differences on kindergarten measures between the longitudinal sample and the 52 children that were lost due to attrition. The mean age of the grade 1 sample was 83.18 months (SD= 3.54 months). The analyses in the present study are based on the 137 children in the longitudinal sample.

At the end of kindergarten, the participants were assessed on areas of numeracy, literacy, and cognitive processes that have been implicated in the literature as important to numeracy skills. A series of standardized and experimental tasks were administered.

Measures of Numeracy

Wide Range Achievement Test – 3: Computational Arithmetic subtest-Blue form (Wilkinson, 1993). This test is made up of an oral arithmetic and written arithmetic component. In the oral arithmetic component, children were asked basic computational questions and were required to count, judge the magnitude of numbers, or respond orally to verbal calculations. The oral arithmetic component can be thought of as a measure of informal mathematics skill. In the written arithmetic portion, children were presented the first five calculations of the subtest and were required to write their own response. Calculation questions were not read for the children. The written calculations component can be thought of as a measure of formal mathematics skill.

Number Identification. The numbers from 0 - 9 were presented randomly on a page for the child to identify.

Cognitive Processes

Wechsler Intelligence Scale for Children - III: Digit Span subtest (Wechsler, 1991). In this task children were asked to repeat strings of numbers presented orally (increasing in length). This task is made up of forward and backward digit span. In forward digit span, the children repeated the digits in the same order that they heard them. This can be considered a measure of memory span. In backward digit span, the child is required to repeat the digits in the reverse

order. The backward condition can be considered a working memory task. Forward and backward scores are combined to produce a scaled score.

Working memory for numbers: Kindergarten (Siegel & Ryan, 1989). This task involved counting yellow dots from a field of blue and yellow dots arranged in an irregular pattern on an index card. The child was asked to count the yellow dots aloud on each card and then recall the number counted for each set in the correct order. The number of yellow dots on each card varied between one and six.

Beery Test of Visual Motor Integration (Beery & Buktenica, 1989). In this task children were asked to copy basic two-dimensional shapes, ranging from simple to complex. The task measured fine-motor skills, perception of two-dimensional space and planning.

SATZ Recognition-Discrimination (Satz & Fletcher, 1982). The child discriminated which patterns were identical following the visual presentation of stimuli. This task measured the ability to recognize and discriminate abstract stimuli.

Measures of Literacy

Letter identification. In this task children were required to identify the names (not the sounds) of the 26 letters presented randomly on a page.

Phoneme deletion (Muter, Hulme & Snowling, 1997). In this task, the children were presented with a picture of a word and were asked to delete a phoneme (initial or final) from the word. For example, in the initial deletion task, the examiner said, "Bus without /b/ says ____", and in the final deletion task, the instructions were, "Bag without /g/ says _____."

The following tasks were used in grade 1 to assess the development and acquisition of numeracy skills:

Measures of Numeracy

Wide Range Achievement Test – 3: Computational Arithmetic subtest-Blue form (Wilkinson, 1993). Children were asked basic computational questions and were required to count, respond orally to verbal calculations, and to solve written calculation problems.

Woodcock-Johnson III: Calculation test - Research Edition (Woodcock, McGrew, Mather, 2001). In this task children performed various written mathematical calculations of increasing difficulty. Calculation questions were not read to the children. The Calculation subtest was added as it provided norms on calculation skills independent of oral arithmetic, unlike the WRAT Arithmetic subtest.

Woodcock-Johnson III: Applied Problems test - Research Edition (Woodcock et al., 2001). A measure of mathematical reasoning and problem solving in which the student performed mathematical problems of increasing difficulty. In this task, the examiner read the question to the child to eliminate the confound of reading ability.

Woodcock-Johnson III: Quantitative Concepts test (Woodcock et al., 2001). This task measured quantitative reasoning and mathematics knowledge. Quantitative Concepts is composed of two parts, Concepts and Number Series. In Concepts, the student demonstrated basic numeracy skills (e.g., counting) and identified math terms and formulae. In Number Series, the student demonstrated quantitative reasoning by identifying number patterns by determining the next number in the series (e.g., 6 7 8 __).

Cognitive Processes

Wechsler Intelligence Scale for Children - III: Digit Span subtest (Wechsler, 1991). In this task children repeated strings of numbers presented orally (increasing in length). The children repeated the digits in the same order that they heard them (forward) and in the reverse order (backward).

Working memory for numbers (Siegel & Ryan, 1989). This task involved counting yellow dots from a field of blue and yellow dots arranged in an irregular pattern on an index card. The child was asked to count aloud the yellow dots on each card and then recall the number counted for each set in the correct order. The number of yellow dots on each card varied from one to nine.

Woodcock-Johnson III: Block Rotation test (Woodcock et al., 2001). This task measured the child's ability to mentally manipulate three-dimensional objects. The child was presented with a stimulus object and then chose which 2 of 4 items represented the stimulus that has been rotated in 3D space.

Rapid Automatized Naming: *Speeded Number Naming* (RAN). In this task, children were required to name individual numbers (1-9) presented in random order on a 5 x 5 array. Each child's performance was recorded in seconds. This task was used to test the efficiency of lexical retrieval and is considered a measure of long-term retrieval and processing speed.

Measures of Literacy

Woodcock-Johnson III: Letter-Word Identification test - Research Edition (Woodcock et al., 2001). This task was made up of a word-reading list of increasing difficulty. Each child was required to read as many words as possible from the list. The task administration was discontinued when all items in a given level were failed.

Woodcock-Johnson III: Word Attack test-Form B (Woodcock et al., 2001). This task measured decoding ability through the reading of pseudowords. The child was required to decode as many words as possible from the list. The task administration was discontinued when all items in a given level were failed.

Wide Range Achievement Test –3: Spelling subtest-Blue form (Wilkinson, 1993). This test measured spelling achievement and was administered in small-group settings. This test is

made up of orally presented words of increasing difficulty of which the child was required to generate the correct spelling.

Research Design and Classification

Children were classified as AD, RAD or normally achieving (NA) based on their performance on the Arithmetic subtest of the WRAT and a measure of reading. In kindergarten, children were classified as AD if their performance on the WRAT Arithmetic subtest was at or below the 25th percentile and they had a score in the average range on the letter identification task. Average range was determined according to the full kindergarten sample. Children classified as RAD had a WRAT Arithmetic subtest score at or below the 25th percentile and were below average on the letter identification task. Children who performed at or above the 30th percentile on WRAT Arithmetic and had letter identification scores within the average range were classified as NA. Nineteen children were classified as AD, 11 were classified as RAD and 99 were classified as NA. According to this criteria, 8 children could not be classified and were not included in the analyses.

In grade 1, children were classified based on their performance on the WRAT Arithmetic subset and the WJ Letter-Word Identification test. AD was identified when WRAT Arithmetic scores were at or below the 25th percentile and WJ Letter-Word Identification scores were at or above the 30th percentile. Children were identified as RAD if both scores were below the 25th percentile. Children were identified as NA if both scores were above the 30th percentile. Twenty-five children were classified as AD, 9 were classified as RAD, and 101 were classified as NA. According to this criteria, 2 children could not be classified and were not included in the analyses.

Results

In order to make group comparison between NA, AD and RAD children, a series of one way analysis of variance (ANOVA) were conducted taking error rate into consideration.

Univariate analyses were selected rather than multivariate analyses as the research questions were more appropriately answered using ANOVAs (Huberty & Morris, 1989). Tukey HSD post hoc tests were conducted to examine significant differences identified in the ANOVA. Eta squared was used as a measure of effect size. The criteria for effect size are as follows: .01 (small), .06 (moderate), and .14 (large).

Kindergarten Results

Table 1 summarizes the performance of the NA, AD and RAD groups on the kindergarten tasks. The results of the ANOVA and Tukey HSD post hoc (alpha level .05) analyses on numeracy, cognitive processes and measures of reading are discussed below. To control for multiples ANOVAs, the Bonferroni correction factor was used. The corrected alpha required for statistical significance was p=.004.

Numeracy Measures. The results of the ANOVA indicated that there were significant group differences on overall WRAT3 Arithmetic performance, $F(2, 126) = 87.53$, $p<.0001$, $\eta^2 = .581$, as well as in the oral arithmetic portion, $F(2, 125) = 43.44$, $p<.0001$, $\eta^2 = .410$, and the written arithmetic portion, $F(2, 125) = 18.09$, $p<.0001$, $\eta^2 = .220$. On the overall WRAT3 Arithmetic test, the Tukey HSD post-hoc test indicated that the NA group performed significantly higher than the AD and RAD groups. The AD and RAD groups did not differ significantly. On the oral arithmetic portion of the Arithmetic test, the NA group performed significantly higher than the AD group, which performed significantly higher than the RAD group. On the written arithmetic portion of the Arithmetic test, the NA group performed significantly higher than both the AD and RAD groups. The AD and RAD groups did not differ significantly.

There were significant group differences on number identification, $F(2, 126) = 22.54$, $p<.0001$, $\eta^2 = .263$. The post hoc Tukey test revealed that there were no significant differences

between the NA and AD groups on the number identification test and that both the NA and AD groups identified significantly more numbers than the RAD group.

Cognitive Processes. Significant group differences were found on Digit Span Scaled Score, $F(2, 126) = 17.18$, $p<.0001$, $\eta^2 = .216$, forward digit span, $F(2, 126) = 12.42$, $p<.0001$, $\eta^2 = .166$, and backward digit span, $F(2, 126) = 14.29$, $p<.0001$, $\eta^2 = .186$. The post hoc test indicated that the NA group had a significantly higher scaled score than the AD and RAD groups. The AD and RAD groups did not differ significantly. On forward digit span, the NA group performed significantly higher than the RAD group, but not the AD group. The AD group also performed significantly higher than the RAD group on forward digit span. On backward digit span, the NA group performed significantly better than both the AD and RAD groups. The AD and RAD groups did not differ significantly on backward digit span.

The results of the ANOVA indicated that there were no significant group differences on working memory for numbers, $F(2, 126) = 4.04$, $p=.02$, $\eta^2 = .064$.

Significant group differences were found on the test of visual motor integration (VMI) , $F(2, 126) = 9.53$, $p<.0001$, $\eta^2 = .136$. The Tukey post hoc test indicated that the NA group performed significantly higher than the AD and RAD groups. There was no difference between the AD and RAD groups.

The results of the ANOVA indicated that significant group differences existed on SATZ recognition/discrimination, $F(2, 126) = 9.45$, $p<.0001$, $\eta^2 = .131$. Post hoc tests revealed that the NA group performed significantly higher than the AD and RAD groups. There was no post hoc difference between the AD and RAD groups.

Measures of Reading. Significant group differences existed on letter identification, $F(2, 126) = 158.89$, $p<.0001$, $\eta^2 = .717$. Post hoc Tukey tests indicated that the NA and AD groups identified significantly more letters than the RAD group, although there were no differences between the NA and AD groups on letter identification.

There were significant group differences on phoneme deletion initial, $F(2, 126) = 18.07$, $p=.0001$, $\eta^2 = .230$, and phoneme deletion final, $F(2, 126) = 7.30$, $p=.001$, $\eta^2 = .108$. On phoneme deletion initial, the post hoc Tukey test revealed that the NA group performed significantly higher than both the AD and RAD groups. There was no difference between the AD and RAD groups on phoneme deletion initial. The pattern of results was similar on phoneme deletion final; the NA group performed significantly higher than both the AD and RAD groups, and there was no difference between the AD and RAD groups.

Summary. In kindergarten, the NA children performed significantly better than the AD and RAD groups on WRAT3 Arithmetic, oral arithmetic, written arithmetic, overall Digit Span, backward digit span, VMI, SATZ recognition/discrimination, and both phoneme deletion initial and final. There were no differences between the NA, AD, and RAD groups on working memory for numbers. The NA and AD groups did not differ significantly on number identification, forward digit span, or letter identification, although the NA and AD groups performed significantly higher than the RAD group on these measures. There were no significant differences between the AD and RAD groups on WRAT3 Arithmetic, written arithmetic, Digit Span, backward digit span, VMI, SATZ recognition/discrimination, and phoneme deletion initial and final. The AD group preformed significantly better than the RAD group on oral arithmetic, number identification, forward digit span, and letter identification.

Grade 1 Results

Table 2 summarizes the performance of the NA, AD and RAD groups on the grade 1 tasks. The results of the ANOVA and Tukey HSD post hoc (alpha level .05) analyses on numeracy, cognitive processes and measures of reading are discussed below. To control for multiples ANOVAs, the Bonferroni correction factor was applied and the corrected alpha required for statistical significance was $p=.003$.

Measures of Numeracy. The results of the ANOVA indicated that there were significant group differences on WRAT3 Arithmetic, $F(2, 132) = 90.99, p<.0001, \eta^2 = .585$. The Tukey HSD post-hoc test indicated that the NA group performed significantly higher than the AD and RAD groups. The AD and RAD groups did not differ significantly.

On WJIII Calculation there were significant group differences, $F(2, 131) = 18.99$, $p<.0001, \eta^2 = .230$. The post hoc test indicated that the NA group had significantly higher scores than the AD and RAD groups. There was no post hoc difference between the AD and RAD groups on calculation skill.

On the measure of mathematical problem solving, WJIII Applied Problems, significant group differences existed, $F(2, 132) = 29.24, p<.0001, \eta^2 = .317$. The Tukey post hoc test revealed that the NA group performed significantly higher than both the AD and RAD groups. The AD group had significantly better developed mathematical problem solving skills than RAD group.

Significant group differences existed on overall WJII Quantitative Concepts performance, $F(2, 132) = 25.42, p<.0001, \eta^2 = .270$. Quantitative Concepts is composed of two subtests; Quantitative Concepts is a measure of knowledge of mathematic formulae and principles, and Number Series is a measure of quantitative reasoning. There were significant group differences on both Quantitative Concepts, $F(2, 132) = 25.50, p<.0001, \eta^2 = .273$, and Number Series, $F(2, 132) = 11.72, p<.0001, \eta^2 = .147$. The post hoc test revealed that the NA group performed significantly higher than the AD and RAD groups on overall Quantitative Concepts performance, as well as on the Concepts and Number Series subtests. The AD group performed significantly better than the RAD group on the overall Quantitative Concepts test, as well as on the Quantitative Concepts subtest. There was no significant difference between the AD and RAD groups on the Number Series subtest.

Cognitive Processes. The results of the ANOVA indicated that there were significant group differences on Digit Span Scaled Score, $F(2, 132) = 12.01$, $p<.0001$, $\eta^2 = .151$, forward digit span, $F(2, 132) = 6.11$, $p=.003$, $\eta^2 = .087$, and backward digit span, $F(2, 132) = 10.21$, $p<.0001$, $\eta^2 = .129$. On overall Digit Span, the post hoc test indicated that the NA group had a significantly higher scaled score than the AD and RAD groups. The AD and RAD groups did not differ significantly. On forward digit span, the NA and AD groups performed significantly higher than the RAD group, but did not differ significantly from each other. On backward digit span, the NA group performed significantly better than both the AD and RAD groups. The AD and RAD groups did not differ significantly on backward digit span.

There were significant group differences on working memory for numbers, $F(2, 132) = 13.22$, $p<.0001$, $\eta^2 = .163$. The Tukey post hoc test indicated that the NA group performed significantly higher than the AD and RAD groups on the working memory for numbers test. There were no significant differences between the AD and RAD groups on the working memory for numbers test.

The ANOVA results indicated that there were no significant group differences on WJIII Block Rotation, $F(2, 132) = 2.63$, $p>.05$, $\eta^2 = .040$.

Significant group differences were found on speeded number naming, $F(2, 131) = 7.34$, $p=.001$, $\eta^2 = .103$. The post hoc test indicated that the NA group performed significantly faster than the AD and RAD groups. The AD and RAD groups did not differ significantly.

Measures of Reading. There were significant group differences on WJIII Word Identification, $F(2, 132) = 81.03$, $p<.0001$, $\eta^2 = .567$. The post hoc Tukey test indicated that the NA group performed significantly higher than the AD and RAD groups. The AD group obtained a significantly higher score than the RAD group.

On the measure of decoding, WJIII Word Attack, significant group differences existed, $F(2, 132) = 37.15$, $p<.0001$, $\eta^2 = .377$. The post hoc test revealed that the NA group had

significantly higher scores than the AD and RAD groups. The AD group also had significantly higher scores than the RAD group.

The ANOVA revealed significant group differences on WRAT3 Spelling, $F(2, 128) = 26.15$, $p < .00o1$, $\eta^2 = .287$. Post hoc Tukey tests indicated that the NA group was significantly better than the AD and RAD groups in spelling. The AD group was significantly better than the RAD group.

Summary. In grade one, the NA children performed significantly better than the AD and RAD groups on all measures of numeracy and reading, as well as overall Digit Span, backward digit span, working memory for numbers, and speeded number naming. The NA and AD groups performed similarly on forward digit span, which was significantly higher than the performance of the RAD group. There were no differences between the NA, AD and RAD groups on WJIII Block Rotation. The AD and RAD groups performed similarly on WRAT3 Arithmetic, WJIII Calculation, Number Series, overall Digit Span, backward digit span, working memory for numbers, and speeded number naming. The AD group performed significantly better than the RAD group on overall Quantitative Concepts as well as the Quantitative Concepts subtest, Applied Problems, forward digit span, and on all measures of reading.

Prediction of Numeracy Ability

In order to examine the contribution of kindergarten variables to performance on grade one numeracy ability, a series of regression analyses were conducted on NA and the numeracy dysfunction group. The AD and RAD groups were combined for the regression analyses due to small sample sizes. Oral arithmetic, written arithmetic, backward digit span, VMI, SATZ, and phoneme deletion initial were used as predictor variables as these variables significantly differed in the NA and numeracy dysfunction groups. One regression model examined the prediction of first grade calculation skills and the other model examined the prediction of first grade mathematical problem solving ability. All assumptions for regression were met.

Model 1. For the calculation skills regressions, grade 1 WJIII Calculation was the dependent variable. Oral arithmetic, written arithmetic, backward digit span, VMI, SATZ, and phoneme deletion initial were entered as explanatory variables. In the NA group, this model accounted for a significant amount of variance, $F(6, 93) = 2.43$, $p=.03$, $R^2=.136$. In the numeracy dysfunction group, this model also accounted for a significant amount of variance, $F(6,26) = 7.18$, $p<.0001$, $R^2=.624$. To determine the importance of these components to the overall model, the variance was partitioned using the Pratt Index (Thomas, Hughes & Zumbo, 1998). The results of the Relative Pratt Index are presented in Table 3. Of the 13.6% of variance accounted for by the model in the NA group, oral arithmetic accounted for 40% of the variance, written arithmetic accounted for 18.4%, backward digit span accounted for 23.2%, VMI accounted for 21.2%, SATZ accounted for 2.7% and phoneme deletion initial did not account for any variance. Based on the Pratt Index, oral arithmetic, backward digit span, VMI, written calculation were, in relative order, the most important explanatory variables in the model. The contribution of SATZ and phoneme deletion were found to be "unimportant" according to the criteria set by Thomas (1992).

A different pattern of variable importance emerged in the numeracy dysfunction group. Of the 62.4% of variance accounted for by the model in the numeracy dysfunction group, oral arithmetic accounted for 46.8% of the variance, backward digit span accounted for 14.6%, VMI accounted for 38.7%, and phoneme deletion initial accounted for 12.7% of the overall variance. Written arithmetic and SATZ did not account for any of the variance. Based on the Pratt Index, oral arithmetic, VMI, backward digit span, and phoneme deletion initial were, in relative order, the most important explanatory variables in the numeracy dysfunction model. The contribution of written arithmetic and SATZ were found to be unimportant.

Model 2. For the mathematical problem solving skills regressions, grade 1 WJIII Applied Problems was the dependent variable. As above, oral arithmetic, written arithmetic, backward

digit span, VMI, SATZ, and phoneme deletion initial were entered as explanatory variables. This model was significant in both the NA group, $F(6, 94) = 7.56, p<.0001, R^2=.326$, and in the numeracy dysfunction group, $F(6, 26) = 6.80, p<.0001, R^2=.611$. As above, the Pratt Index was used to determine variable importance. The results of the Relative Pratt Index are presented in Table 3. Of the 61.1% of variance accounted for by the model in the NA group, oral arithmetic accounted for 36.9% of the variance, written arithmetic accounted for 50.2%, backward digit span accounted for 2.7%, and phoneme deletion accounted for 9.8% of the overall variance. VMI and SATZ did not account for any variance. Based on the Pratt Index, the most important explanatory variables in the NA model were, in relative order, written arithmetic, oral arithmetic, and phoneme deletion initial. Backward digit span, VMI, and SATZ were found to be unimportant to the model.

Of the 61.1% of variance accounted for in the numeracy dysfunction model, oral arithmetic accounted for 53.6% of the variance, VMI accounted for 41.8%, and SATZ accounted for 13.3% of the overall variance. Written arithmetic, backward digit span and phoneme deletion did not contribute to the model. Oral arithmetic, VMI and SATZ were found to be, in relative order, the most important explanatory variables in the numeracy dysfunction model. The contribution of written arithmetic, backward digit span and phoneme deletion initial were found to be unimportant.

Summary. Regression analyses with the normally achieving and numeracy dysfunction groups were conducted to examine the contribution of oral arithmetic, written arithmetic, backward digit span, VMI, SATZ and phoneme deletion to first grade calculation skills and mathematical problem solving ability. In the normally achieving group, the explanatory variables accounted for 13.6% of the variance in first grade calculation skills. Oral arithmetic, backward digit span, VMI and written arithmetic were, in relative order, the most important variables in the model. In the numeracy dysfunction group, the explanatory variables accounted for 67.3% of the

variance in first grade calculation skills. Oral arithmetic, VMI, backward digit span, and phoneme deletion were the most important variables in the model.

The explanatory variables accounted for a significant amount of variance in first grade mathematical problem solving ability in both the normally achieving (R^2=.326) and numeracy dysfunction (R^2=.611) groups. In the normally achieving group, written arithmetic was the most important variable in the model, followed by oral arithmetic and phoneme deletion initial. In the numeracy dysfunction groups, oral arithmetic was the most important variable in the model, followed by VMI and SATZ.

Discussion

The present study sought to determine the early distinguishing features of AD and RAD subtypes. The findings of this study demonstrated that AD and RAD subtypes could be identified in both kindergarten and first grade and that the subtypes displayed different deficit profiles in numeracy, literacy and cognitive processes. In kindergarten, both AD and RAD groups were deficient in oral and written arithmetic, as compared to the NA group, although the AD group performed significantly higher than the RAD group on oral arithmetic. The AD group also performed significantly higher than the RAD group on number identification. This finding is consistent with those of Geary et al. (1999) who suggested that in the early years, RAD children's number recognition and counting knowledge may be distinguishing features of this subtype.

The numeracy dysfunction groups were also differentiated from the NA group on backward digit span, although the AD group performed similarly to the NA group on forward digit span. There were no differences between the groups on the working memory for numbers task. These results are somewhat inconsistent with previous research. For example, Siegel and Ryan (1989) found that AD children differed significantly from RD children on working memory tasks specific to numerical information. Our results suggest that differences in working

memory for numbers do not exist in kindergarten. Passolunghi and Siegel (2001) found that AD children were impaired on working memory tasks that contained both verbal and numerical information, but were impaired on span tasks only if they contained numerical information. In the current study, RAD children but not AD children were impaired on numerical span tasks. Geary et al. (1999) found no differences between NA, AD, and RAD groups on forward digit span but found that the RAD group performed significantly lower than the other groups on backward digit span. In the present study, forward digit span, a measure of memory span, was significantly lower in the RAD group, while backward digit span, a measure of working memory, was significantly lower in both the RAD and AD groups. The findings from the current study suggest that RAD children may have a more limited short-term memory capacity, which would affect working memory performance in a different way than in the AD group, whose memory span was not different from the NA group. Thus, the low performance on backward digit span by the AD group may be due to more specific deficits, whereas the RAD group may experience difficulty due to a limited capacity system. This area should be investigated further. The AD and RAD groups also performed more poorly than the NA children on visual motor integration (VMI), and SATZ recognition-discrimination, which is consistent with previous research (Badian, 1999; Shafrir & Siegel, 1994).

The unique kindergarten profile of RAD children seems to be deficient letter and number recognition as well as deficiencies in memory span and oral arithmetic. In overall arithmetic achievement, working memory, visual-motor skills, recognition-discrimination skills and phonological awareness, there appear to be no differences between AD and RAD kindergarten children.

In first grade, there continued to be differences between the AD and RAD subtypes, although there were more similarities than differences. In measures of numeracy, RAD children performed significantly lower than AD children on Quantitative Concepts, which is a measure of

basic numeracy skills such as counting and identifying age appropriate numeracy concepts and formulae. That the RAD group was significantly poorer in this task indicates that they have insufficient mathematical background knowledge. This may be due to a lack of exposure or to a deficit in the ability to store and retrieve such information. Geary (1993; Geary et al., 1999) suggested that children with numeracy dysfunctions may have long-term retrieval deficits. Interestingly, there was no difference between the AD and RAD groups on Number Series, which is a measure of mathematical reasoning. The lack of difference suggests that at least in the first grade, numerical reasoning ability is not especially deficient in RAD children. Thus, poorer performance on numeracy achievement would seem to be related to their limited background knowledge. The RAD children were also significantly lower than the AD children on mathematical problem solving. This is consistent with previous research which has shown that RAD children are more impaired than AD children on mathematical problem solving ability (e.g., Fuchs & Fuchs, 2002; Jordan et al., 2003). This is likely due to this group's immature calculation skills, as measured by the Calculation test, as well as the group's underdeveloped knowledge of mathematical terms and formulae, as measured by the Quantitative Concepts subtest. It is also interesting to note that the AD group performed within the average range on both the Calculations and Applied Problems tests. This is consistent with the findings of Jordan and Montani (1997) who found that in untimed conditions, children with AD were able to perform simple arithmetic calculations within the average range. As the present study did not include a speeded measure of calculation skill, it is not possible to determine whether timed conditions would affect calculation skills in this group. This should be further investigated. However, this finding suggests that AD children may have developmentally appropriate calculation and application skills. Whether these abilities persist beyond grade 1 remains to be determined.

In grade 1, RAD children continued to be characterized by both memory span and working memory deficits, whereas the AD group was characterized only by working memory deficits. There were no differences between the normally achieving and impaired groups on Block Rotation, a measure of spatial thinking. This finding was unexpected given previous literature that has found deficiencies in spatial tasks in children with numeracy dysfunctions (e.g., Rourke, 1993; 2000, Shafrir & Siegel, 1994). The numeracy dysfunction groups were also found to be deficient on speeded number naming, a measure of long-term retrieval efficacy and speed of processing. Geary (1993; Geary et al., 1999) suggested that both long-term retrieval skills and speed of processing may be a contributing factor to numeracy dysfunctions. The results of the present study are consistent with this hypothesis, although further research is needed.

On all measures of reading, the AD group performed significantly lower than the NA group and significantly higher than the RAD group. This finding is not unexpected given that the AD group was selected to have reading achievement scores within the average range.

In grade 1, the profile of RAD children seems to be poor background knowledge of mathematical concepts, greater impairment in mathematical problem solving skills than the AD group, poor performance on measures of literacy, as well as a memory span deficit. Both impaired groups are equally deficient in arithmetic achievement, mathematical reasoning, working memory and speed of processing.

The other purpose of the present study was to investigate the kindergarten skills that best predicted first grade numeracy achievement. The results of the current study indicated that the pattern of predictability was different for normally achieving and numeracy dysfunction groups in both calculation skills and in mathematical problem solving. The kindergarten variables oral arithmetic, written arithmetic, backward digit span, VMI, SATZ and phoneme deletion initial were used as explanatory variables as they differentiated the numeracy dysfunction and NA

groups in the present study, and have been implicated in numeracy dysfunctions in previous studies.

In the calculation skills regression, the explanatory variables accounted for 13.6% of the variance in the NA group and 62.4% in the numeracy dysfunction group. This suggests that the variables that were important for the impaired groups were not necessarily important for the NA group. When the variance was partitioned to explore variable importance, we found that in the NA group, oral arithmetic was the most important variable in the model, accounting for 40% of the 13.6% accounted for by the overall model. Backward digit span, VMI and written arithmetic were also found to be important to the NA model. In the impaired group, oral arithmetic was also the most important variable in the model, followed by VMI, backward digit span and phoneme deletion initial. That oral arithmetic was the most important variable in both groups is consistent with the hypothesis that informal skills are important to the development of formal arithmetic skills (e.g., Baroody et al., 1984; Gersten & Chard, 1999; Jordan, 1995). However, this should be investigated longitudinally as the role of informal skills in later years is unclear. The finding that phoneme deletion was an important variable in the numeracy dysfunction group is consistent with the hypothesis proposed by Geary (1993; Geary et al., 1999) that phonological awareness may play a role in numeracy dysfunctions. However, Geary hypothesized that a phonological deficit may account for the deficits experienced in the RAD group. As the regression analyses in the present study were not specific to numeracy dysfunction subtype (due to small sample sizes), we are unable to support the position that phonological deficits are related to numeracy deficits specifically within the RAD group.

In the mathematical problem solving regression, the explanatory variables accounted for 32.6% of variance in the NA group and 61.1% in the numeracy dysfunction group. Written arithmetic was found to be the most important variable in the NA model, followed by oral arithmetic and phoneme deletion. In the impaired group, oral arithmetic was the most important

variable, followed by VMI and SATZ. These findings suggest that the NA and impaired groups use different skills to solve mathematical problems, which is not unexpected given that the impaired groups are by definition impaired in some aspect of calculation skills. In the NA model, therefore, written calculation skill is the most important variable in explaining problem solving skills. In other words, variables such as working memory (backward digit span) and planning (visual motor integration) become less important to the solution of mathematical problems if a child has sufficient calculation skills. In the impaired group, however, oral arithmetic skills were still the most important variable, followed by VMI and SATZ. This finding suggests that children with numeracy dysfunction use different systems to solve word problems.

Conclusion

The present study investigated the development of numeracy skills in children from kindergarten to first grade. As well, kindergarten predictors of grade 1 numeracy achievement were investigated. The results of the present study show that children with RAD exhibit a different profile than children with AD in both kindergarten and in grade 1. In kindergarten, children with RAD know fewer letters and numbers, are more developmentally delayed in their informal skills than AD children and have a memory span deficit. Both AD and RAD children were impaired on oral arithmetic, written arithmetic, working memory, VMI, SATZ and phoneme deletion. In grade 1, RAD children continued to be characterized by memory span deficits and informal skills and were also significantly deficient in mathematical problem solving and reading. Both AD and RAD groups were impaired in Quantitative Concepts, Number Series, working memory and processing speed. Whether and to what extent these profiles persist over time remains to be determined.

Additionally, the results of the present study suggest that although both AD and RAD groups are deficient in numeracy skills, the reasons for impairment may be different for each group. The deficiencies in the RAD group seem to be due to a lack of developmentally

appropriate background and informal knowledge, which is exacerbated by limited short-term memory and working memory systems. The AD group, on the other hand, seems to have mild impairments in background knowledge, but are able to perform calculation and application tasks at an appropriate level in untimed conditions. For those involved in the education of children, the findings from the present study support the need for repeated and explicit instruction in mathematical concepts, terms and formulae, even as early as kindergarten. RAD children may require additional assistance in developing the skills required for calculation performance and application. AD children may require additional assistance in developing calculation fluency. Whether these profiles will persist beyond grade 1 is not known.

The present study adds to the growing body of research that supports the separation of numeracy impaired children into those with and without concurrent impairments in reading. Additionally, the present study found support for the role of informal skills, working memory, spatial tasks and phoneme deletion in grade 1 numeracy achievement. Future research is needed to determine the predictive power of kindergarten skills to later numeracy skills.

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Table 1

Mean Performance of NA, AD, and RAD Groups on Kindergarten Measures

Kindergarten Measure	**NA (n=99) M (SD)**	**AD (n=19) M (SD)**	**RAD (n=11) M (SD)**
WRAT3 Arithmetic percentile	69.30 (22.53)[a]	18.37 (6.05)[b]	7.27 (5.93)[b]
Oral Arithmetic* (max 15)	12.33 (1.73)[a]	9.47 (2.22)[b]	7.64 (2.54)[c]
Written Arithmetic* (max 5)	1.96 (1.51)[a]	0.37 (0.60)[b]	0.09 (0.30)[b]
Number Identification* (max 10)	9.88 (0.84)[a]	9.79 (0.54)[a]	7.36 (2.20)[b]
Digit Span Scaled Score	9.93 (2.76)[a]	7.58 (3.08)[b]	5.36 (2.34)[b]
Forward Digit Span*	6.74 (1.85)[a]	5.74 (1.56)[a]	4.09 (1.45)[b]
Backward Digit Span*	2.67 (1.03)[a]	1.53 (1.47)[b]	1.27 (1.19)[b]
Working Memory* (max 9)	3.54 (2.54)[a]	2.16 (1.46)[a]	2.09 (1.87)[a]
VMI Percentile*	63.48 (29.35)[a]	37.16 (24.50)[b]	37.73 (29.27)[b]
SATZ* (max 15)	12.62 (2.23)[a]	10.95 (3.42)[b]	9.55 (3.56)[b]
Letter Identification* (max 26)	24.04 (2.19)[a]	23.42 (2.69)[a]	8.45 (6.01)[b]
Phoneme Deletion Initial* (max 8)	4.89 (3.42)[a]	1.58 (2.01)[b]	0.18 (0.60)[b]
Phoneme Deletion Final* (max 8)	3.87 (3.23)[a]	1.63 (2.73)[b]	1.09 (2.07)[b]

Note. * = number correct; WRAT 3=Wide Range Achievement Test (3rd Ed.); VMI=Beery Test of Visual Motor Integration; SATZ=SATZ Recognition-Discrimination (Satz & Fletcher, 1982); Superscripts that are the same do not differ significantly.

Table 2

Mean Performance of NA, AD, and RAD Groups on Grade 1 Measures

Grade One	**NA (n=101) M (SD)**	**AD (n=25) M (SD)**	**RAD (n=9) M (SD)**
WRAT3 Arithmetic percentile	63.39 (21.40)[a]	16.88 (6.73)[b]	6.44 (5.88)[b]
WJIII Calculation percentile	67.54 (24.09)[a]	45.48 (23.26)[b]	26.00 (12.50)[b]
WJIII Concepts percentile	65.99 (24.90)[a]	39.92 (23.53)[b]	17.44 (11.85)[c]
Quantitative Concepts*	14.61 (1.86)[a]	12.88 (2.24)[b]	10.22 (2.39)[c]
Number Series*	9.29 (1.94)[a]	7.96 (1.49)[b]	6.67 (2.00)[b]
WJIII Applied Problems percentile	65.41 (26.14)[a]	37.40 (17.25)[b]	13.33 (11.34)[c]
Digit Span Scaled Score	11.23 (2.99)[a]	9.20 (2.90)[b]	6.89 (3.02)[b]
Forward Digit Span*	7.51 (2.05)[a]	7.04 (2.09)[a]	5.11 (1.05)[b]
Backward Digit Span*	3.51 (1.19)[a]	2.48 (1.19)[b]	2.22 (1.86)[b]
Working Memory* (max 12)	4.85 (2.09)[a]	3.32 (1.87)[b]	1.89 (1.17)[b]
WJIII Block Rotation percentile	61.69 (29.29)[a]	62.28 (32.38)[a]	38.11 (30.67)[a]
Speeded Number Naming (sec)	14.98 (3.21)[a]	18.75 (13.24)[b]	22.22 (8.59)[b]
WJIII Word Identification percentile	82.60 (15.85)[a]	62.80 (18.70)[b]	15.22 (7.29)[c]
WJIII Word Attack percentile	83.87 (15.49)[a]	57.40 (29.20)[b]	37.33 (27.24)[c]
WRAT3 Spelling percentile	72.21 (21.74)[a]	50.00 (17.68)[b]	27.89 (21.13)[c]

Note. * = number correct; WRAT 3=Wide Range Achievement Test (3rd Ed.); WJIII = Woodcock-Johnson Tests of Achievement (3rd Ed.). Superscripts that are the same do not differ significantly.

Table 3

Pratt Index Scores

	Beta Weight	Simple Correlation	Pratt Index
Model 1 - Calculation Skills			
Normally Achieving Group R^2 =.136			
Oral Arithmetic	.193	.282	.400
Written Arithmetic	.109	.229	.184
Backward Digit Span	.137	.230	.232
VMI	.144	.200	.212
SATZ	.024	.153	.027
Phoneme Deletion Initial	-.076	.099	-.056
Numeracy Dysfunction Group R^2 =.624			
Oral Arithmetic	.434	.673	.468
Written Arithmetic	-.132	.328	-.069
Backward Digit Span	.171	.532	.146
VMI	.409	.591	.387
SATZ	-.112	.333	-.060
Phoneme Deletion Initial	.209	.378	.127
Model 2 - Mathematical Problem Solving Skills			
Normally Achieving Group R^2 =.326			
Oral Arithmetic	.259	.465	.369
Written Arithmetic	.331	.494	.502
Backward Digit Span	.040	.216	.027
VMI	-.090	.021	-.006
SATZ	.023	.118	.008
Phoneme Deletion Initial	.094	.341	.098
Numeracy Dysfunction Group R^2 =.611			
Oral Arithmetic	.495	.662	.536
Written Arithmetic	-.114	.306	-.057
Backward Digit Span	-.045	.456	-.034
VMI	.408	.626	.418
SATZ	.168	.485	.133
Phoneme Deletion Initial	.010	.220	.004

Note. To calculate the Pratt Index, the beta–weight is multiplied by the simple correlation and this number is divided by the R^2 value. An Index score less than 1/(2 x number of predictor variables) is classified as "unimportant" (Thomas, 1992).