Published in final edited form as:

Learn Disabil Res Pract. 2008 August ; 23(3): 125–136. doi:10.1111/j.1540-5826.2008.00270.x.

Phonological Awareness and Rapid Naming Skills of Children with Reading Disabilities and Children with Reading Disabilities Who Are At Risk for Mathematics Difficulties

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Abstract

Limited research has examined the skills of children with a reading disability (RD) and children with RD and a mathematics disability (MD). Even less research has examined the phonological awareness (PA) and rapid automatized naming (RAN) skills in these two groups of children and how these skills relate to reading and math achievement. Additionally, various classification criteria are frequently implemented to classify children with MD. The purpose of this study, therefore, was to examine the PA and RAN skills in children who met different criteria for RD only and children with RD who are at-risk for mathematics difficulties (MDR). Participants were 114 second or third grade students with RD from public elementary schools in three large metropolitan areas. Students were classified as at-risk for mathematics difficulties utilizing a 25th percentile cutoff and a 15th percentile cutoff as assessed by the KeyMath-Revised Test (Connolly, 1988). A series of PA and RAN measures were administered along with a range of reading and mathematics measures. Hierarchical regression analyses indicated that children with RD only evidenced a different pattern of results compared to children with RD + MDR. Additionally, using a more stringent criterion to classify children at-risk for mathematics difficulties resulted in a differential pattern of results when compared to a less stringent classification criterion.

Students with reading disabilities (RD) constitute between 17% and 20% of the school-age population (Robinson, Menchetti, & Torgesen, 2002), while 4% to 7 % of students are estimated to manifest math disabilities (MD; Fuchs, Fuchs, & Prentice, 2004). During the

last two decades, there has been an abundance of research that has focused on the understanding of reading difficulties/disabilities (RD). Research focused on the understanding of the core deficits associated with MD, however, has received less attention (Fuchs et al., 2004; Gertsen, Jordan, & Flojo, 2005). Studies attempting to broaden the scope of MD research to include research questions that pertain to co-occurring reading and mathematics difficulties (RD + MD) are important because many school-identified students with learning disabilities have achievement deficits in both reading and mathematics (Fleischner & Manheimer, 1997). For example, research has reported that 56% of elementary and junior high school children with RD exhibit concomitant mathematics difficulties, and 43% of the children identified with MD also exhibited deficits in reading achievement (Badian, 1983; Knopik, Alarcon, & DeFries, 1997). It is important, therefore, for research to attempt to identify core deficits in children with RD + MD and determine whether those deficits differ when compared to children with RD only.

A large corpus of research has indicated that the primary deficit in children with RD is in phonological awareness (PA; e.g., Catts, Fey, Zhang, & Tomblin, 2001; Morris et al., 1998; Olson et al., 1989; Stanovich, 1988; Vellutino et al., 1996). Phonological awareness is often defined as the ability to manipulate the individual phonemes of oral language (Elbro & Peterson, 2004). Students who are not able to identify and manipulate the phonic elements of speech will not be able to map those sounds onto specific orthographic patterns. Without established grapheme/phoneme correspondences, children do not have the skills necessary for the decoding of unfamiliar words.

In addition to a deficit in PA, recent research also has indicated that a subset of children with RD evidence deficits in rapid automatized naming (RAN) skills, either separately or in combination with deficits in PA (Wolf et al., 2002). A deficit in RAN skills, therefore, represents a difficulty in efficiently and automatically retrieving stored phonological representations. Although related, PA and naming speed tasks have been shown to contribute both shared and independent variance to real word and nonword identification (Bowers & Swanson, 1991; Manis, Doi, & Bhadha, 2000).

Research on MD recently has been criticized for being too theoretical, with too little emphasis on empirical research (Gertsen et al., 2005), and for failing to adequately control for reading ability (Fuchs et al., 2004). With respect to the first criticism, limited research has sought to examine the potential underlying mechanisms that govern the development of mathematics skills. It has been speculated that the skills important for successful reading, PA and RAN skills, are also important for the development of successful mathematics skills. In order to perform computational problems, a child must accurately and efficiently access operators that are represented by stored phonological representations. Deficits in PA or the speed at which phonological representations are retrieved would, therefore, affect the development of proficient mathematics skills (Hecht, Torgesen, Wagner, & Rashotte, 2001).

Support for the suggestion that the same skills that are important for reading also are important for mathematics comes from Bryant and his associates (Bryant, MacLean, Bradley, & Crossland, 1990) who found significant correlations (r range: .33–.58) between PA skills (i.e., rhyme oddity, alliteration oddity, joint rhyme/alliteration choice, initial

phoneme deletion, final phoneme deletion, and phoneme tapping) at 4 and 5 years of age and later arithmetic performance at 6 years of age. Bryant et al. (1990) also noted that scores on alliteration oddity (4 years 7 months) and phoneme tapping tasks (5 years 11 months) were predictive of later growth in arithmetic skills. In addition to these findings, Hecht and associates (2001) found evidence of PA skills influencing growth in general math computation skills. These researchers reported that second-grade levels of PA explained 10% of the unique variance in fifth grade levels of general math computation skills. In contrast, early mathematics ability was not found to significantly predict later levels of PA. Based on these findings, the authors suggested that the phonological processing skills that influence growth in reading performance also contribute to growth in general math computational skills. Findings such as these indicate that processes previously found to be important for reading achievement (i.e., PA) are also important in for mathematics achievement.

Further support for the suggestion that the same skills that are important for reading achievement are also important for mathematics achievement comes from research examining the role that RAN skills play in reading and mathematics performance. With respect to reading, the extant literature indicates that RAN skills consistently predict reading achievement (e.g., Catts, Gillispie, Leonard, Kail, & Miller, 2002; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004). In contrast, the nature of the relationship between math achievement and RAN skills is less researched and less well known. There is evidence in the literature, however, to suggest that RAN tasks are related to math achievement. For example, Clarke and Shinn (2004) developed a number fluency identification task that required children to orally identify as many numbers as they could that were presented in a random order in one minute. In a group of typically developing children, this identification task was found to highly correlate with a standardized measure of applied mathematics at the beginning of the first grade ($r = .65$) and at the end of the first grade ($r = .63$). In addition, Chard et al. (2005) found that letter naming fluency, rapid color naming, and rapid picture naming measured in kindergarten significantly predicted mathematics achievement assessed at the beginning of the first grade in a study designed to assess the effectiveness of measures developed to screen students for mathematics difficulties.

Mathematics Disability and Reading Disability

The previously cited criticism that many studies have not controlled for reading ability is of particular importance because research suggests that children with RD + MD may be more similar to children with RD only than children with MD only. Studies examining the response to mathematics-based interventions have shown that children with RD + MD respond more slowly to intervention efforts than children with MD only, RD only, or typically achieving children (Fuchs et al., 2004; Jordan, Hanich, & Kaplan, 2003). While studies like these indicate that children with RD + MD are different from children with MD only and RD only, other studies suggest that MD and RD + MD represent different disabilities and that the difference between RD and RD + MD groups is in severity and not in nature. Support for this suggestion comes from Fletcher (2005) who outlines a series of studies indicating that while children with RD + MD evidenced significantly lower performance on measures of sustained attention, concept formation, PA, rapid naming, vocabulary, and visual-motor abilities than children with RD, the overall pattern of

performance did not differ significantly between the two groups. The RD + MD group profile pattern, however, did differ significantly from the MD only group. Results such as these have led some to suggest that the math difficulties associated with MD and with RD + MD represent different disabilities and that RD + MD is a language based learning disability that shares a common etiology with RD rather than a disability with mathematics skills (Fletcher, 2005).

Purposes and Hypotheses

Previous research has suggested that children with RD + MD differ from children with RD only in performance levels, but not in performance patterns. Limited studies, however, have investigated the role of PA and RAN speed in understanding the linkages between reading and mathematics achievement in children with RD only and RD + MD. An objective of this study, therefore, was to investigate the role of PA and RAN in reading and math achievement in early elementary school age students with RD and with RD who were at-risk for mathematics difficulties (MDR). Because we used more than one cutoff level, and because we used a composite score on a standardized mathematics assessment that was administered at only one time point, we choose to use the term “at-risk for mathematics difficulties” rather than math disability. While it is believed that the findings concerning the students in this study can be generalized to children with a classification of MD, there is a possibility that the research definition of MDR used classified students into the RD + MDR group who did not evidence MD. The research questions that guided the first objective of the study were: (1) How was PA and RAN related to children’s mathematics achievement? (2) How did these abilities impact mathematics performance, as compared to reading, by children with RD and RD + MDR?

Because research concerning MD often utilizes various criteria to identify children with MD (Fuchs et al., 2004) another objective of this study was to examine the consequences of employing different cutoff levels to classify children as at-risk for mathematical difficulties. Because classifications of MD are not stable over time (Geary, Hamson, & Hoard, 2000), it has been argued that using higher cutoff levels will result in identifying children who are at risk for developing more severe math difficulties and will yield a more inclusive group of children with mathematics difficulties (Gersten et al., 2005). Research concerning MD is still in its infancy, however, and it is not clear whether children who demonstrate serious mathematics difficulties are conceptually and meaningfully different from children who meet less stringent criteria. Children who meet more stringent criteria may represent a group of children who possess serious deficits in underlying mechanisms responsible for mathematics operations. Children meeting less stringent criteria may represent groups of children who are struggling to grasp mathematics skills because of educational experience or performance issues on standardized tests related to test anxiety, inadequate test administration, or individual performance fluctuations (e.g., exhaustion). Using less stringent criteria to classify children with MD consequently may capture both groups of students, while more stringent criteria may only identify those students who evidence actual deficits associated with MD. Examining these potentially fundamentally different children as a combined group could produce misleading results. Associated with the second objective of this study, therefore, were the research questions: (1) Does using a more stringent criterion

for classification of MDR result in differential relations between PA and RAN skills and reading and mathematics achievement? (2) Does classifying children with MDR using a different cutoff criterion influence interpretations concerning the relationship between RD only and RD + MDR groups?

Method

Participants

Data presented here come from a larger study interested in examining the effectiveness of different reading intervention programs with children with RD. The original study was a 2 (ethnicity) X 2 (gender) X 2 (SES) X 4 (time point) mixed factorial design. For a complete description see Morris, et al., (2007). Participants in the current study were 114 second and third grade students from public elementary schools referred by their teachers due to difficulties in learning to read. Referred students exhibited difficulty with decoding and word identification skills and did not evidence the fluent oral reading skills necessary to gain meaning from connected text. All students, therefore, exhibited difficulty with basic decoding skills and had not made the developmental shift to either fluent oral reading or reading for meaning.

Children were excluded if English was not their first language, they had repeated a grade, had a Kaufman-Brief Intelligence Test (K-BIT; Kaufman & Kaufman, 1990) Composite Score below 70, and/or had a history of psychotic disorder or other serious psychiatric or neurological disease. Children were independently evaluated for reading disabilities and included in a large, three-site (Atlanta, Boston, Toronto) treatment intervention program focused on the improvement of reading skills. In order to meet the criteria for RD, students met either Low Achievement (LA) and/or Ability Achievement Regression Corrected Discrepancy (AA-D) definitions. Individuals with a K-BIT IQ Composite score greater than 70 and whose reading skills were equal to, or less than, a standard score of 85 on the Woodcock Reading Mastery Test-R (WRMT-R; Woodcock, 1987) were identified as meeting the LA criteria for RD. Participants whose actual reading performance was at least one standard error of the estimate below their Expected Achievement Standard Score (EASS), calculated based on an average correlation of .60 between measures of reading performance and intellectual ability, were included under the AA-D criteria. Participants' mean age in months was 93.84 (SD = 6.36) and ranged from 81.25 to 108.32 months. Sixty-seven (64%) of the participants were male and fifty-five participants (53%) were of African heritage.

We first evaluated students with a performance below the 25th percentile on a standardized achievement measure of mathematics skill (i.e., the KeyMath-Revised Test; Connolly, 1988) because to the 25th percentile has been cited frequently for determining whether a child was at risk for a disability (Fuchs et al., 2004; Geary, 2004). Based on the 25th percentile cutoff, 60 students (52.6%) evidenced RD only, while 54 children (47.4%) showed concurrent difficulties in both basic reading and math skills. The exact role of IQ in MD is still unknown, and failing to account for IQ may confound results. For analytic purposes, therefore, students in the RD only and RD + MDR groups were matched on IQ scores. IQ matches were made with the constraint that IQ scores did not differ by more than one

standard score. Using this criterion, 68 (59.6%) of the 114 students were matched on IQ. The mean IQ score of the RD only group ($n = 34$) was 87.32 and the mean IQ score of the RD + MDR group ($n = 34$) was 86.97. Demographic information associated with this group of students is seen in Table 1.

In order to contrast the 25th percentile cutoff, a more conservative cutoff point to determine RD + MDR also was used in this study. Using the 15th percentile cutoff (a standard score of 84.5), 75 children (66%) out of the 114 participants evidenced RD only, while 39 children (34%) were identified as a comorbid group which demonstrated difficulties attaining both basic reading and math skills. With this more conservative cutoff point, 60 (52.6%) of the original 114 students were matched on IQ. The mean IQ score of the RD only group ($n = 30$) was 85.07 and the mean IQ score of the RD + MDR ($n = 30$) group was 84.97. See Table 1 for the demographic breakdown of this group of students.

Measures

IQ—The Kaufman Brief Intelligence Test (K-BIT; Kaufman & Kaufman, 1990) is an IQ screening measure of verbal (vocabulary) and nonverbal (matrices) abilities for children and adults aged 4 through 90. The K-BIT manual reports split-half reliability coefficients for the Vocabulary subtest as high, ranging from .89 to .98 (mean = .92), demonstrating high reliability for children and adolescents ages four through 19 (mean = .91). Matrices split-half coefficients ranged from .74 to .95. Lower reliability coefficients occurred for the youngest children in the sample, ages 4 to 6 years (mean = .78). For the age group of 5 through 12, test-retest reliability coefficients for Vocabulary was .86, for Matrices .83, and for the K-BIT Composite .92.

Phonological Awareness—This measure included the Elision and Blending Words subtests of the Comprehensive Test of Reading Related Phonological Processing (CTRRPP; Torgesen & Wagner, 1996). The CTRRPP is the experimental predecessor of the Comprehensive Test of Phonological Processing (CTOPP; Torgesen & Wagner, 1999). Internal consistency reliability among items within a subtest reached coefficients of .89 for Elision and .84 for Blending Words. The test-retest reliability was constant over time for early grade children (Elision = .88; Blending Words = .78).

Rapid Naming Speed—The materials comprised the Letters, Numbers, and Objects subtests of the Rapid Automatized Naming tasks (RAN; Denckla & Rudel, 1976; Wolf, Bally, & Morris, 1986), and Rapid Alternating Stimulus (RAS—a mixture of letters and numbers; Wolf, 1986) that measured retrieval speed with set switching between numbers and letters.

Reading Performance—Reading measures were composed of the Word Identification, Word Attack, and Passage Comprehension subtests of the Woodcock Reading Mastery Test-Revised (WRMT-R; Woodcock, 1987). Internal consistency reliability was excellent across these subtests for grades 1 through 3, with reliability ranging from .94 to .99. When compared with independent criterion reading measures, the WRMT-R evidenced strong validity, with coefficients ranging .43 to .86.

Mathematics Performance—In order to measure different components of math skills, basic mathematics attributes were assessed using the KeyMath-Revised Test (Connolly, 1988), and included Numeration, Geometry, Addition, Subtraction, Measurement, and Time/Money subtests. The KeyMath Test comprised basic concepts (numeration and geometry), operations (addition and subtraction), and application (measurement and time/money). Numeration measured quantity, order, and place value, while Geometry evaluated spatial and attribute relations, two-dimensional shapes and their relations, coordinate and transformational geometry, and three-dimensional shapes and their relations.

Addition focused on basic facts and models, algorithms to add whole numbers, and adding rational numbers, while Subtraction paralleled the coverage in the Addition. Measurement covered comparisons using non-standard units and standard units (e.g., length, area, weight, capacity), whereas Time and Money included identification of passage of time, use of clocks and clock units, and understanding of monetary amounts from one dollar to one hundred dollars and business transactions. Alternate-form reliability for each subtest of the KeyMath test ranged from .63 to .75, while split-half reliability for grade 1 through 3 ranged from .52 to .89.

Procedure

Students identified by their teachers as evidencing difficulty with learning to read were referred to the project. These students were given a recruitment packet containing a description of the study and a consent form to take home to their parents. Those students who returned a signed consent form were screened for entry into the study. After initial screening for a reading disability, doctoral-level graduate students and psychologists administered all measures in a one-on-one setting within the child's typical school day.

All graduate students received several hours of training in test administration and were monitored by experienced psychologists before data collection was carried out independently. All reported assessments were conducted at the beginning of the school year before students were exposed to any reading intervention efforts designed by the larger, original study.

Results

Multivariate Analysis of Variance

Multivariate Analysis of Variance (MANOVA) techniques were used to test for differences between groups on the subtests assessing PA skills, RAN skills, reading achievement, and math achievement. When a cutoff level of the 25th percentile was used, analyses indicated that the RD + MDR group evidenced significantly lower scores than the RD only group on the Elision subtest assessing PA skills, and all subtests of reading and mathematics achievement (see Table 2). The two groups did not evidence significantly different scores on any of the subtests assessing RAN skills. When a 15th percentile cutoff level was employed, the RD + MDR group evidenced significantly lower scores than the RD only group on the Elision subtest and on all subtests of math achievement (see Table 3). In contrast, there was

no significant difference between the two groups on any of the subtests representing reading achievement or RAN skills.

Hierarchical Regression Analyses

In order to evaluate how PA and RAN skills predicted reading achievement and to compare the results with mathematics outcomes, a set of hierarchical regression analyses was performed. As a way of checking assumptions for the regression model, correlation coefficients, multicollinearity diagnostics, and standardized residuals scatterplots were examined. In order to reduce redundancy in the analyses and to address the issue of multicollinearity among predictor variables, a composite score of PA skills (Blending Words and Elision) and RAN skills (Letter Naming, Number Naming, and Alternating Naming) were created. The Object Naming subtest was not included in the composite score of RAN skills because of its failure to evidence a significant relationship with reading or mathematics achievement subtests.

Analyses conducted with the combined group—Two sets of hierarchical regression analyses were conducted. In the first set of analyses, real word reading, nonword reading, and passage comprehension skills were utilized as dependent variables. For each dependent variable, the composite score of PA was entered in the first step and the RAN composite score was entered in the second step (see Table 4). Analyses indicated that for each dependent variable, PA skills accounted for a significant amount of unique variance. In addition, RAN performance accounted for a significant amount of unique variance after PA skills had been controlled for.

Included in this initial set of hierarchical regression analyses, the order of the predictors was reversed such that the RAN composite score was entered in the first step and the PA composite score was entered in the second step (see Table 4). RAN skills accounted for a significant amount of unique variance in each dependent variable. PA skills, however, accounted for a significant amount of unique variance only when word identification skills were utilized as a dependent variable.

In the second set of hierarchical regression analyses, the subtests of mathematics achievement were used as dependent variables (i.e., Addition, Geometry, Measurement, Numeration, Subtraction, and Time/Money; see Table 5). For these analyses, PA scores accounted for a significant amount of unique variance for each dependent variable of math achievement. RAN skills accounted for an additional significant amount of unique variance for all math domains except for Geometry. When the order of predictor entry was reversed, RAN skills accounted for a significant amount of unique variance for each dependent variable except Geometry. When PA skills were entered in the second step, a significant amount of unique variance was accounted for in all math domains.

Hierarchical regression analyses conducted with RD only and RD +MDR groups created with the 25th percentile cutoff criterion—In order to further explicate the relationships between PA and RAN skills and reading and math achievement, the same hierarchical regression analyses were conducted when the sample was categorized into RD only and RD + MDR groups based on a 25th percentile cutoff criterion. For the RD

group, analyses indicated that RAN skills accounted for a significant amount of unique variance after controlling for PA skills for the word identification, word attack, and passage comprehension subtests (see Table 6). In the RD + MDR group, a similar pattern of results was seen with the exception that the amount of unique variance accounted for on the Word Attack subtest by RAN skills after controlling for PA skills did not reach conventional levels of statistical significance ($p = .07$). PA skills, however, did not account for a significant amount of unique variance in any of the subtests assessing reading achievement once RAN skills had been entered into the regression equation. This pattern of results was seen in both the RD only and RD + MDR groups.

When the composite score of PA was entered into the regression equation followed by the composite score of RAN for the RD only group, neither predictor accounted for a significant amount of unique variance in any of the subtests representing mathematics achievement (see Table 7). Similarly, when the order of entry of predictors was reversed, neither PA nor RAN composite scores accounted for a significant amount of unique variance in any of the mathematics achievement subtests.

Analyses utilizing math achievement scores as dependent variables conducted with the RD + MDR group indicated that for the numeration subtest, PA skills accounted for a significant amount of unique variance after controlling for RAN skills (see Table 8). No other significant effects were detected.

Hierarchical regression analyses conducted with RD only and RD +MDR groups created with the 15th percentile cutoff—For the reading achievement subtests, analyses conducted with the RD only group indicated that RAN skills accounted for a significant amount of unique variance across all subtests of reading achievement once PA skills were accounted for (see Table 9). In contrast, analyses conducted with the RD + MDR group indicated that RAN skills did not account for a significant amount of unique variance ($p < .05$) after controlling for PA skills. For both the RD only and RD + MDR groups, PA skills did not account for a significant amount of unique variance once RAN skills had been controlled for.

Utilizing mathematics achievement as a dependent variable, analyses conducted with the RD only group revealed that RAN skills accounted for a significant amount of unique variance in the Measurement subtest after controlling for PA skills (see Table 10). No other significant results were found.

With the RD + MDR group, PA skills accounted for a significant amount of unique variance in Addition and Numeration subtests after controlling for RAN skills (see Table 11). No other significant effects were found.

Discussion

Recent research on children with RD only and children with RD + MD has indicated that differences between these two groups may be in degree and not in nature (Fletcher, 2005). The first objective of this study, therefore, was to investigate the role of PA and RAN in reading and mathematics achievement in early elementary school age students with RD only

and RD + MDR. Because various strategies are used to classify children with MD (Fuchs et al., 2004), it was also of interest to examine the consequences of employing different cutoff levels to classify children as at-risk for mathematics difficulties.

The results of this study have two primary implications. First, this study did not find support for previous research that has suggested children with RD only differ from children with RD + MD only in severity and not in their performance profile (e.g., Fletcher, 2005). In support of this, when analyzed as a combined sample, results indicated that RAN skills were the best predictor of reading achievement, while PA skills were the best predictor of math achievement. With respect to reading achievement, this pattern of results was replicated in both RD only and RD + MDR groups when children in the sample were classified as RD + MDR using the 25th percentile as a cutoff level. When the 15th percentile was used, however, this pattern of results was constrained to the group of children classified as RD only. In the RD + MDR group classified with a 15th percentile cutoff level, neither PA nor RAN skills were found to account for a significant amount of unique variance in any domain of reading achievement that was assessed. This difference in results appears to be a result of group dynamics defined by mathematics classification criteria rather than a loss in statistical power due to a reduction in sample size. This fact is evidenced by a considerable drop in r^2 (range .10–.14) among significant findings evidenced with the MDR group classified with the 25th percentile cutoff to the nonsignificant findings with the MDR group classified with the 15th percentile cutoff.

With respect to mathematics achievement, using a 25th percentile cutoff, neither PA nor RAN was found to significantly predict mathematics achievement with the RD only group. In contrast, with the RD + MDR group, PA was found to account for a significant amount of unique variance in the Numeration subtest. When a 15th percentile cutoff level was implemented, RAN accounted for a significant amount of unique variance in the Measurement subtest by the RD only group. With the RD + MDR group, PA was found to account for significant amounts of unique variance in the Addition and Numeration subtests.

All of these results taken together indicated that children with RD only and children with RD + MDR evidenced different patterns of results concerning the relationships between PA and RAN skills and reading and math achievement. These differences in patterns of results were seen whether a RD + MDR classification was made using the 25th or the 15th percentile cutoff. Thus, because many children with RD also have concomitant math difficulties, RD researchers should be aware of the possibility the existence of an RD + MD subtype that is conceptually and functionally different from children with RD only.

A second implication of this study is that children demonstrating more severe math difficulties evidenced different patterns of skill relations than children who exhibited less severe math difficulties. Using a more stringent classification criterion, differential relations were found between PA and RAN skills and math and reading achievement domains in the hierarchical regression analyses. For example, when a 25th percentile cutoff point was implemented, analyses conducted with the RD + MDR group indicated that RAN skills accounted for a significant amount of unique variance in word identification, nonword identification, and passage comprehension performances. Utilizing a 15th percentile cutoff

level, however, RAN skills did not account for a significant amount of unique variance in any measure of reading performance.

Results concerning math performance indicated that when using a 25th percentile cutoff level, PA was found to account for a significant amount of unique variance in the Numeration subtest. In contrast to these findings, when the 15th percentile cutoff level was utilized, PA skills accounted for a significant amount of unique variance in the Addition and Numeration subtests.

In addition to these results, a differential pattern of significant effects also was evidenced in the MANOVA analyses. Using the 25th percentile cutoff criterion, the students in the RD + MDR group demonstrated significantly lower reading achievement than students in the RD only group. When the 15th percentile cutoff criterion was implemented, no significant differences in reading achievement were found between the two groups. Researchers interested in the mechanisms underlying deficits associated with RD and MD, therefore, should remain cognizant of the classification issues.

Limitations and Future Directions

It should be noted that classifying a student with math difficulties based on a single measurement in time can be problematic because children's performance on mathematics achievement tests can be variable over time (Geary, 2004). Thus, it has been argued that only those children who consistently score low on mathematics achievement tests deserve a classification of MD. Conclusions regarding the findings of this study, therefore, should be made with caution as some of the students examined may not be representative of children who evidence consistent math difficulties over time.

A second difficulty associated with this study that could influence interpretations was the lack of inclusion of an MD only group for comparison. It would be of interest for future research to examine whether the use of different criteria to classify children with MD only would result in differential findings as was seen in this study examining children with RD +MDR. Because previous research has indicated that children with MD only evidence different mathematics difficulties than children with RD + MD (Fuchs et al., 2004; Hanich, Jordan, Kaplan, & Dick, 2001; Jordan, et al., 2003; Rourke & Finlayson, 1978), classification differences obtained in this study may not be seen in children with MD only.

Conclusions

Overall, the current study indicates that children with RD only and children with RD + MDR differ in levels of PA and RAN in addition to the ways in which these two skills relate to reading and mathematics achievement. Further, results from this study provide evidence that using different classification cutoff levels to classify students as at-risk for mathematics difficulties results in groups that show different patterns with respect to the relationships between PA and RAN skills and reading and mathematics achievement. In light of these findings, research conducted with children with RD should control for mathematics performance as combining samples of children with RD only and children with RD + MD may be unwarranted and may lead to misleading interpretations of the underlying

mechanisms operating in these two groups of students. Further, careful attention should be directed to the cutoff level used to classify children with difficulties in mathematics. Children falling under more stringent criteria may be a conceptually different group than those who meet less stringent criteria.

Additionally, these findings have educational implications and suggest that teachers and those providing educational support for children with RD and children with RD + MD should remain aware of these differences. Instructional strategies may need to be structured differently for these two groups of children. For example, results from this study suggest that for those students meeting RD + MDR criteria at the 15th percentile cutoff level may need instructional strategies outside of those focused on fostering PA and RAN skills, as these skills did not relate significantly to reading achievement in this group of students.

Further, those individuals within the school setting that are responsible for assessment and educational placement need to account for potential group classification differences and issues related to the stringency of the criteria used for placement. Results of this study suggest that those students meeting less stringent criteria may not fit into an educational setting designated for children who meet more stringent criteria. These students may only need additional instructional assistance rather than services in a remedial classroom.

Acknowledgments

Support for this research was provided by the National Institute of Child Health and Human Development Grant HD30970 to Georgia State University, Tufts University, and the Hospital for Sick Children/University of Toronto, and by the Research Program Enhancement Fund of Georgia State University. We thank the participants and their families for their cooperation and support. Correspondence concerning this article should be addressed to Robin Morris, Department of Psychology, P. O. Box 5010, Georgia State University, Atlanta, GA, 30302; email: psyrdm@langate.gsu.edu.

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Table 1Demographic Breakdown of 25th and 15th Percentile IQ Matched Groups

Demographic Variables		IQ Match 25 th Percentile (n = 68)	IQ Match 15 th Percentile (n = 60)
Ethnicity	African Heritage	35	32
	Caucasian	33	28
Gender	Female	28	23
	Male	40	37

Table 2
Descriptive Statistics of PA, RAN, Reading and Math Performance by Group (25th Percentile)

	RD Only			RD + MD		
	Mean	SD	Range	F	η^2	Mean SD Range
PA^a						
Blending Words	103.70	13.89	72–125	2.45	.04	97.77 16.50 72–138
Elision	104.01	16.16	76–142	4.04*	.06	96.64 13.99 67–129
RAN^b						
Letters	70.48	23.15	25–109	1.83	.03	62.41 25.60 25–105
Numbers	69.39	20.82	25–104	0.36	.01	66.29 21.36 25–104
Objects	75.45	19.34	25–110	0.02	.00	76.06 20.03 28–108
Alternating	70.99	24.37	25–108	0.78	.01	65.76 24.01 25–103
WRMT^b						
Word Identification	77.68	7.82	54–90	5.19*	.07	72.82 9.64 54–91
Word Attack	73.15	7.80	59–87	4.41*	.06	68.71 9.55 41–88
Passage Comp	76.56	8.70	46–93	8.06**	.11	68.32 14.50 33–87
KeyMath^c						
Addition	9.40	3.48	4–18	34.00***	.34	5.62 1.58 1–10
Geometry	8.97	2.49	1–13	32.52***	.33	5.54 1.89 1–11
Measurement	9.79	2.28	6–14	56.13***	.46	5.49 1.83 3–11
Numeration	8.49	2.74	4–19	26.30***	.29	5.23 1.51 3–8
Subtraction	7.92	2.76	3–14	23.49***	.26	5.05 1.90 2–10
Time/Money	8.09	2.27	4–14	37.79***	.36	5.13 2.00 2–9

^aTransformed scores with a mean 100 and standard deviation of 15;

^bstandard scores;

^cscale scores

* p < .05;

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d < .01;
p < .001

Note: RAN = Rapid Automatized Naming (Wolf, Bally, & Morris, 1986)
WRMT = Woodcock Reading Mastery Test-R (Woodcock, 1987)
KeyMath = KeyMath-R: A Diagnostic Inventory of Essential Mathematics (Connolly, 1988)

Table 3
Descriptive Statistics of PA, RAN, Reading and Math Performance by Group (15th Percentile)

	RD Only				RD + MD			
	Mean	SD	Range	F	η^2	Mean	SD	Range
PA^a								
Blending Words	102.25	13.34	79–125	1.91	.03	96.75	17.24	72–138
Elision	101.03	14.87	76–137	4.61 [*]	.07	93.26	13.08	67–129
RAN^b								
Letters	70.59	27.61	25–108	1.17	.02	63.00	26.20	25–105
Numbers	65.21	25.72	25–105	0.01	.00	64.50	22.63	25–104
Objects	71.79	24.69	25–110	0.71	.01	76.77	20.67	26–108
Alternating	70.24	28.88	25–109	0.29	.01	66.40	26.03	25–103
WRMT^b								
Word Identification	76.20	9.97	54–88	1.65	.03	73.03	9.12	54–88
Word Attack	70.60	10.82	41–88	0.04	.00	70.13	7.76	54–88
Passage Comp	71.70	14.19	33–93	0.32	.01	69.83	11.16	43–85
KeyMath^c								
Addition	8.57	2.93	4–15	22.89 ^{***}	.28	5.60	1.71	1–9
Geometry	8.53	1.80	5–12	42.99 ^{***}	.43	5.40	1.90	1–10
Measurement	9.60	1.79	6–14	82.27 ^{***}	.59	5.47	1.74	1–9
Numeration	7.87	2.13	4–13	32.18 ^{***}	.36	5.20	1.45	1–8
Subtraction	7.73	2.45	3–13	19.34 ^{***}	.25	5.20	1.99	1–10
Time/Money	7.60	2.25	4–14	25.93 ^{***}	.31	4.87	1.89	2–9

^aTransformed scores with a mean 100 and standard deviation of 15;

^bstandard scores;

^cscale scores

^{*}p < .05;

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100

p < .001

Note: RAN = Rapid Automatized Naming (Wolf, Bally, & Morris, 1986)

WRMT = Woodcock Reading Mastery Test-R (Woodcock, 1987)

KeyMath = KeyMath-R: A Diagnostic Inventory of Essential Mathematics (Connolly, 1988)

Table 4

Hierarchical Regression Analyses for Reading Achievement (n=114)

RD Only					
Dependent Variable	Predictor	R ²	ΔR ²	F _{change}	p value
Word Identification	1. PA	.10		12.27	.001
	2. RAN	.33	.23	37.39	.001
	1. RAN	.28		42.29	.001
	2. PA	.33	.05	8.53	.004
Word Attack	1. PA	.03		3.55	.06
	2. RAN	.11	.08	9.18	.003
	1. RAN	.09		10.95	.001
	2. PA	.11	.02	1.96	.165
Passage Comprehension	1. PA	.05		5.53	.02
	2. RAN	.24	.19	28.05	.001
	1. RAN	.22		31.64	.001
	2. PA	.24	.02	2.78	.098

Note: PA = Phonological Awareness, RAN = Rapid Automatized Naming

Table 5

Hierarchical Regression Modeling for Math Achievement (n=114)

Dependent Variable	Predictor	R ²	ΔR^2	F _{change}	p value
Addition	1. PA	.09		11.17	.001
	2. RAN	.14	.05	5.98	.02
	1. RAN	.07		8.42	.004
	2. PA	.14	.07	8.65	.004
Geometry	1. PA	.09		10.54	.002
	2. RAN	.09	.00	0.00	.99
	1. RAN	.00		0.28	.60
	2. PA	.09	.09	10.13	.002
Measurement	1. PA	.13		16.31	.001
	2. RAN	.17	.04	5.21	.02
	1. RAN	.07		7.88	.006
	2. PA	.17	.10	13.34	.001
Numeration	1. PA	.15		19.60	.001
	2. RAN	.20	.05	6.58	.01
	1. RAN	.08		9.64	.002
	2. PA	.20	.12	16.20	.001
Subtraction	1. PA	.09		10.87	.001
	2. RAN	.12	.03	4.19	.04
	1. RAN	.05		6.30	.01
	2. PA	.12	.07	8.64	.004
Time/Money	1. PA	.06		6.94	.01
	2. RAN	.10	.04	5.35	.02
	1. RAN	.06		7.26	.008
	2. PA	.10	.04	5.03	.03

Note: PA = Phonological Awareness, RAN = Rapid Automatized Naming

Table 6

Hierarchical Regression Analyses for Reading Achievement in the RD Only and RD + MDR Groups (25th Percentile)

RD Only					
Dependent Variable	Predictor	R ²	ΔR^2	F _{change}	p value
Word Identification	1. PA	.12		4.40	.04
	2. RAN	.27	.15	5.82	.02
	1. RAN	.22		8.65	.006
	2. PA	.27	.05	2.00	.17
Word Attack	1. PA	.08		2.56	.12
	2. RAN	.20	.12	4.41	.04
	1. RAN	.17		6.35	.02
	2. PA	.20	.03	0.93	.34
Passage Comprehension	1. PA	.05		1.60	.22
	2. RAN	.34	.29	12.97	.001
	1. RAN	.33		15.54	<.001
	2. PA	.34	.01	0.10	.75

RD +MDR					
Dependent Variable	Predictor	R ²	ΔR^2	F _{change}	p value
Word Identification	1. PA	.06		2.05	.16
	2. RAN	.27	.21	8.79	.006
	1. RAN	.24		10.25	.003
	2. PA	.27	.03	1.07	.31
Word Attack	1. PA	.05		1.82	.19
	2. RAN	.15	.10	3.60	.07
	1. RAN	.12		4.48	.04
	2. PA	.15	.03	1.07	.31
Passage Comprehension	1. PA	.02		0.76	.40
	2. RAN	.24	.22	8.75	.006
	1. RAN	.23		9.77	.004
	2. PA	.24	.01	0.18	.68

Note: PA = Phonological Awareness, RAN = Rapid Automatized Naming

Table 7
Hierarchical Regression Analyses for Math Achievement in the RD Only Group (25th Percentile)

Dependent Variable	Predictor	R ²	ΔR^2	F _{change}	p value
Addition	1. PA	.06		2.01	.17
	2. RAN	.06	.00	0.03	.87
	1. RAN	.01		0.33	.57
	2. PA	.06	.05	1.63	.21
Geometry	1. PA	.01		0.31	.58
	2. RAN	.01	.00	0.00	.75
	1. RAN	.00		0.02	.89
	2. PA	.01	.01	0.39	.54
Measurement	1. PA	.01		0.27	.61
	2. RAN	.04	.03	0.90	.35
	1. RAN	.04		1.16	.29
	2. PA	.04	.00	0.04	.84
Numeration	1. PA	.02		0.71	.41
	2. RAN	.03	.01	0.13	.72
	1. RAN	.01		0.37	.55
	2. PA	.03	.02	0.47	.50
Subtraction	1. PA	.03		0.79	.38
	2. RAN	.04	.01	0.61	.44
	1. RAN	.01		0.22	.64
	2. PA	.04	.03	1.17	.29
Time/Money	1. PA	.00		0.12	.73
	2. RAN	.01	.01	0.13	.72
	1. RAN	.00		0.06	.81
	2. PA	.01	.01	.019	.67

Note: PA = Phonological Awareness, RAN = Rapid Automated Naming

Table 8
Hierarchical Regression Analyses for Math Achievement in the RD + MDR Group (25th Percentile)

Dependent Variable	Predictor	R ²	ΔR^2	F _{change}	p value
Addition	1. PA	.03		0.95	.34
	2. RAN	.03	.00	.01	.92
	1. RAN	.00		0.01	.95
	2. PA	.03	.00	0.93	.34
Geometry	1. PA	.01		0.19	.66
	2. RAN	.09	.08	2.80	.11
	1. RAN	.07		2.48	.13
	2. PA	.09	.02	0.56	.46
Measurement	1. PA	.00		0.12	.73
	2. RAN	.02	.02	0.51	.48
	1. RAN	.01		0.42	.52
	2. PA	.02	.01	0.22	.65
Numeration	1. PA	.15		5.82	.02
	2. RAN	.16	.01	0.15	.71
	1. RAN	.00		0.00	.96
	2. PA	.16	.16	5.80	.02
Subtraction	1. PA	.02		0.58	.45
	2. RAN	.06	.04	1.21	.28
	1. RAN	.03		0.89	.35
	2. PA	.06	.03	0.91	.35
Time/Money	1. PA	.04		1.25	.27
	2. RAN	.04	.00	0.12	.73
	1. RAN	.01		0.29	.60
	2. PA	.04	.03	1.04	.32

Note: PA = Phonological Awareness, RAN = Rapid Automated Naming

Table 9

Hierarchical Regression Analyses for Reading Achievement in the RD Only and RD + MDR Groups (15th Percentile)

RD Only					
Dependent Variable	Predictor	R ²	ΔR^2	F _{change}	p value
Word Identification	1. PA	.14		4.30	.05
	2. RAN	.42	.28	12.31	.002
	1. RAN	.39		17.12	<.001
	2. PA	.42	.03	1.19	.29
Word Attack	1. PA	.15		4.68	.04
	2. RAN	.32	.17	6.46	.02
	1. RAN	.27		10.02	.004
	2. PA	.32	.05	1.78	.19
Passage Comprehension	1. PA	.10		3.14	.09
	2. RAN	.39	.29	12.28	.002
	1. RAN	.38		16.43	<.001
	2. PA	.39	.01	0.57	.50

RD +MDR					
Dependent Variable	Predictor	R ²	ΔR^2	F _{change}	p value
Word Identification	1. PA	.10		3.27	.08
	2. RAN	.18	.08	2.57	.12
	1. RAN	.14		4.40	.05
	2. PA	.18	.04	1.53	.23
Word Attack	1. PA	.06		1.87	.18
	2. RAN	.06	.00	0.08	.78
	1. RAN	.02		0.50	.49
	2. PA	.07	.05	1.39	.25
Passage Comprehension	1. PA	.04		1.14	.30
	2. RAN	.12	.08	2.36	.14
	1. RAN	.11		3.35	.08
	2. PA	.12	.01	0.29	.60

Note: Phonological Awareness = PA, RAN = Rapid Automatized Naming

Table 10
 Hierarchical Regression Analyses for Math Achievement in the RD Only Group (15th Percentile)

Dependent Variable	Predictor	R ²	ΔR^2	F _{change}	p value
Addition	1. PA	.04		1.14	.30
	2. RAN	.11	.07	2.05	.16
	1. RAN	.10		3.04	.09
	2. PA	.11	.01	0.30	.61
Geometry	1. PA	.05		1.29	.27
	2. RAN	.10	.05	1.64	.21
	1. RAN	.02		0.61	.44
	2. PA	.10	.08	2.32	.14
Measurement	1. PA	.01		0.02	.90
	2. RAN	.16	.16	4.84	.04
	1. RAN	.13		4.08	.05
	2. PA	.16	.03	0.82	.38
Numeration	1. PA	.04		1.17	.29
	2. RAN	.10	.06	1.82	.19
	1. RAN	.09		2.79	.11
	2. PA	.10	.01	0.31	.58
Subtraction	1. PA	.07		2.07	.16
	2. RAN	.00	.00	0.09	.76
	1. RAN	.00		0.04	.84
	2. PA	.07	.07	2.05	.17
Time/Money	1. PA	.03		0.74	.40
	2. RAN	.08	.05	1.36	.25
	1. RAN	.02		0.61	.44
	2. PA	.08	.06	1.49	.23

Note: PA = Phonological Awareness, RAN = Rapid Automated Naming

Table 11
Hierarchical Regression Analyses for Math Achievement in the RD + MDR Group (15th Percentile)

Dependent Variable	Predictor	R ²	ΔR^2	F _{change}	p value
Addition	1. PA	.13		4.28	.05
	2. RAN	.16	.03	0.76	.39
	1. RAN	.00		0.22	.88
	2. PA	.16	.16	4.99	.03
Geometry	1. PA	.01		0.16	.70
	2. RAN	.01	.00	0.23	.63
	1. RAN	.00		0.11	.74
	2. PA	.01	.01	0.28	.60
Measurement	1. PA	.04		1.18	.29
	2. RAN	.07	.03	0.74	.40
	1. RAN	.01		0.21	.65
	2. PA	.07	.06	1.69	.20
Numeration	1. PA	.17		5.89	.02
	2. RAN	.17	.00	0.2	.90
	1. RAN	.03		0.79	.41
	2. PA	.17	.14	4.90	.04
Subtraction	1. PA	.01		0.16	.69
	2. RAN	.05	.04	1.12	.30
	1. RAN	.03		0.77	.39
	2. PA	.05	.02	.52	.48
Time/Money	1. PA	.05		1.54	.22
	2. RAN	.06	.01	0.27	.61
	1. RAN	.03		0.79	.38
	2. PA	.06	.03	0.98	.33

Note: PA = Phonological Awareness, RAN = Rapid Automatized Naming