The mathematics skills of children with reading difficulties

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A B S T R A C T

Although many children with reading difficulty (RD) are reported to struggle with mathematics, little research has empirically investigated whether this is the case for different types of RD. This study examined the mathematics skills of third graders with one of two types of RD: dyslexia (n = 18) or specific reading comprehension difficulty (n = 22), as contrasted to a comparison group (n = 247). Children’s performance on arithmetic fact fluency, operations, and applied problems was assessed using standardized measures. The results indicated that children with dyslexia experienced particular difficulty with arithmetic fact fluency and operations: they were 5.60 times and 8.54 times more likely than other children to experience deficits in fact fluency and operations, respectively. Our findings related to arithmetic fact fluency were more consistent with domain-general explanations of the co-morbidity between RD and mathematics difficulty, whereas our findings related to operations were more consistent with domain-specific accounts.

1. Introduction

Research on learning disabilities (LD) has largely focused on reading difficulty (RD) despite documentation that RD is more likely to co-occur with mathematics difficulty (MD) than without (Dirks, Sper, van Lieshout, & de Sonneville, 2008; Rubinstei n, 2009). For example, Badian (1983) found that 56% of students with RD had poor mathematics achievement; other research has found that, as a group, children with RD had lower mathematics achievement than typical achievers (Fuchs, Fuchs, & Prentice, 2004; Miles, Haslam, & Wheeler, 2001). Yet there is a dearth of research that has systematically investigated mathematics ability as it relates to RD. Responding to calls for such research (Gelman & Butterworth, 2005; Rubinstein, 2009; Simmons & Singleton, 2008), the present study examined the performance on arithmetic fact fluency, operations, and problem solving for two types of RD: dyslexia and specific reading comprehension difficulty.

1.1. Types of reading difficulty

Research that has suggested a relationship between RD and MD has focused primarily on dyslexia, which refers to slow, laborious decoding due to underlying deficits in phonological processes (e.g., Swanson & Siegel, 2001; Torgesen, 2000). Phonological processing has also been shown to influence mathematics performance, particularly arithmetic fact fluency (see Simmons & Singleton, 2008). In contrast, those with specific reading comprehension difficulty have intact word reading ability (e.g., Cain & Oakhill, 1999; Cain, Oakhill, & Bryant, 2000) and thus phonological processing is not implicated. This reader’s difficulties reflect deficits in higher-order cognitive processes, such as integrating information in text, making inferences, and using metacognitive strategies (Cain & Oakhill, 1999; Cain et al., 2000; Oakhill, 1993). Such skills may also influence mathematics achievement, particularly in word problem solving. Preliminary evidence suggests that children with RD broadly construed may not show uniformly weak achievement across different mathematics domains (e.g., Geary, Hamson, & Hoard, 2000; Hanich, Jordan, Kaplan, & Dick, 2001; Jordan, Hanich, & Kaplan, 2003; Miles et al., 2001; Simmons & Singleton, 2009). Thus, a next step is to examine achievement across different mathematics domains using samples that differentiate dyslexia from specific reading comprehension difficulty.

1.2. The multi-faceted nature of mathematics ability

Like the construct of reading, mathematics is multi-faceted in nature. In elementary school, the target areas for mathematics instruction are arithmetic fact fluency, operations, and word problem solving (e.g., Fuchs et al., 2006; Gersten et al., 2009). Arithmetic fact fluency refers to the automatic retrieval of simple single-digit addition and subtraction facts and in later elementary years, multiplication facts. There is evidence that children with dyslexia experience difficulty in this area (see Simmons & Singleton, 2008, 2009). Domain-general explanations posit that deficient phonological processing accounts for this relationship (e.g., Simmons & Singleton, 2008, 2009). In contrast, the domain-specific account...
posits that numerical processing underlies the mathematics deficits children with dyslexia experience (Gelman & Butterworth, 2005; Landerl, Bevan, & Butterworth, 2004; Landerl, Fussenegger, Moll, & Willburger, 2009). Little is known about the arithmetic fact fluency skills of children with specific reading comprehension difficulty. Given that these readers do not have phonological processing deficits, in this study, we expected arithmetic fact fluency to be related only to dyslexia.

Operations refers primarily to the ability to perform calculations using algorithms and arithmetic. Some research shows that children with RD perform operations more poorly than typically achieving children (e.g., Jordan et al., 2003) while other research has not found differences between children with RD and typically achieving children (Hanich et al., 2001; Jordan & Hanich, 2000). These studies did not, however, differentiate dyslexia from specific reading comprehension difficulty, making it difficult to discern how children with specific types of RD perform on operations. Neuropsychological evidence suggests that operations and arithmetic fact fluency are processed in different brain regions and that unlike arithmetic fact fluency, operations do not make heavy demands on the language system (e.g., Dehaene, Piazza, Pinel, & Cohen, 2003). Given the primarily language-based nature of both dyslexia and specific reading comprehension difficulty, we expected minimal impairment on operations. However, because arithmetic fact fluency is foundational for operations (e.g., Fuchs et al., 2006), we expected the dyslexia group would show some impairment on operations.

Word problem solving refers to linguistically presented problems involving mathematical relations and properties. Evidence suggests that children with RD perform similarly to typical achievers on word problems (e.g., Hanich et al., 2001; Jordan et al., 2003). These results are somewhat surprising given the language-based nature of RD. To account for these findings, researchers have speculated that children with RD use their relative strengths in mathematics to compensate for their low reading abilities. However, the children with RD in these studies were selected to demonstrate at least average mathematical ability. More research is needed with RD samples that are not selected on the basis of their mathematics ability. Given that arithmetic fact fluency is foundational for word problems (e.g., Fuchs et al., 2006), we expected that children with dyslexia would perform lower than children with specific reading comprehension difficulty and that both groups would perform lower than a comparison group.

1.3. Present study

Previous research has not systematically investigated the mathematics profiles of children with different types of RD. This lack of knowledge limits a comprehensive understanding of the etiology and typology of dyslexia and specific reading comprehension difficulty, which has implications for both research and practice. We sought to advance the research base by examining the mathematics skills of third graders with dyslexia or specific reading comprehension difficulty, contrasted to a comparison sample. We chose third grade to ensure variation in reading and mathematics achievement (Fuchs et al., 2006). This study was guided by a single research question: What are the differences among third graders with dyslexia, specific reading comprehension difficulty, and comparison children on measures of operations, arithmetic fact fluency, and word problem solving?

2. Method

2.1. Participants

The participants were 287 third graders (mean age = 8.60 years, sd = .31, range = 8.00- to 9.75-years) attending five elementary schools in western Canada. The schools were located primarily in working class neighbourhoods characterized by high mobility rates (43%-67%). Demographic characteristics of the sample are presented in Table 1; there were no differences by demographic group on the study measures.

2.1.1. Classification scheme

Children were classified into one of three groups: dyslexia, specific reading comprehension difficulty, or comparison. Consistent with the RD literature, dyslexia was defined as performance below the 15th percentile on the Woodcock Johnson-III (WJ-III) Letter-Word Identification (LWID) test; and specific reading comprehension difficulty was defined as performance below the 15th percentile on the Stanford Diagnostic Reading Test (SDRT) Reading Comprehension subtest and performance above the 50th percentile on LWID. The dyslexia group included 18 children (6.3%), 22 children (7.7%) were classified with specific reading comprehension difficulty, and the remaining 247 children (86.1%) were placed into the comparison group.

One-way analyses of variance (ANOVA) confirmed three distinct reader groups: word reading, F(2, 284) = 59.13, p < .001; and reading comprehension, F(2, 284) = 56.14, p < .001. The comparison and the specific comprehension difficulty group had significantly higher word reading scores than the dyslexia group; both RD groups had significantly lower reading comprehension scores than comparison children.

2.2. Materials

Raw scores for tests were converted to standard scores based on normative data. Standard scores were utilised in the tables and analyses.¹

2.2.1. Word reading

The LWID test of the WJ-III: Research Edition (Woodcock, McGrew, & Mather, 1999) was used; in this task children identify and pronounce isolated letters and words of increasing difficulty (e.g., cat, palm). The publisher reports reliability between .96 and .97.

2.2.2. Reading comprehension

The Reading Comprehension test of the SDRT (Karlsen & Gardner, 1994) was used; children have 45 min to read short passages and provide responses to multiple-choice questions. The publisher reports .91 reliability for third graders.

¹ Standard scores for reading comprehension represent approximately equal-interval units that are particularly suitable for analyses (Karlsen & Gardner, 1994); however, these scores are not norm-referenced, which makes interpretation difficult. For ease of interpretation, we provide the percentile conversion of these scores where appropriate.
2.2.3. Arithmetic fact fluency

The WJ-III Math Fluency test (Woodcock, McGrew, & Mather, 2001) was used; children are instructed to complete as many simple single-digit addition, subtraction, and multiplication facts within 3 min, skipping those they do not know. The publisher reports reliability between .90 and .93.

2.2.4. Operations

The Calculation test of the WJ-III: Research Edition (Woodcock et al., 1999) was used; children read and complete a series of written calculation problems of increasing difficulty, presented in horizontal or vertical format. The publisher reports reliability between .80 and .87.

2.2.5. Applied problem solving

The Applied Problems test of the WJ-III: Research Edition (Woodcock et al., 1999) was used; children solve practical problems in mathematics read aloud by the experimenter. Because many of these questions require solving applied problems (e.g., telling time or temperature, counting money) instead of word problems, this test is better conceived as a measure of applied problem solving. The publisher reports reliability between .91 and .93.

2.3. Procedure

The assessments occurred between January and March. Children were individually assessed (15 min per child) on word reading and applied problems; arithmetic fact fluency, operations, and reading comprehension were group administered in classrooms (60 min). Table 2 displays the sample characteristics and the correlations among the variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>M (SD)</th>
<th>Correlations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Word reading</td>
<td>105.21 (12.64)</td>
<td>–</td>
</tr>
<tr>
<td>2. Reading comprehensiona</td>
<td>620.53 (47.25)</td>
<td>.65 –</td>
</tr>
<tr>
<td>3. Arithmetic fact fluency</td>
<td>97.41 (16.19)</td>
<td>.41 .32 –</td>
</tr>
<tr>
<td>4. Operations</td>
<td>100.01 (12.13)</td>
<td>.49 .44 .57 –</td>
</tr>
<tr>
<td>5. Applied problems</td>
<td>107.59 (17.11)</td>
<td>.55 .52 .59 .51 –</td>
</tr>
</tbody>
</table>

Note. Means are presented in standard scores. Correlation coefficients are significant at p < .001.

a Percentile score = 38.35 (25.85).

3. Results

To address the research question, a series of one-way ANOVAs were conducted; significant differences were followed-up with Scheffé post-hoc tests. To interpret the magnitude of the group differences, we used Cohen’s d (Cohen, 1988). Given that fact fluency has been found as a determinant of operations and word problems (e.g., Fuchs et al., 2006), we included it as a covariate in one set of models with operations and applied problems as dependent variables. Table 3 summarizes the results.

The groups differed significantly on arithmetic fact fluency, F(2, 284) = 17.19, p < .001, operations, F(2, 284) = 23.80, p < .001, and applied problems, F(2, 284) = 17.56, p < .001. The comparison and specific reading comprehension difficulty groups did not differ significantly on arithmetic fact fluency or operations, and both groups performed significantly higher than the dyslexia group. On applied problems, the RD groups performed lower than comparison children. When fact fluency was included as a covariate, the pattern did not change on either operations, F(2, 283) = 9.66, p < .001, or applied problems, F(2, 283) = 6.53, p = .002, although the performance of the dyslexia group approached the average range.

To further investigate the relationship between RD and mathematics, we conducted chi-square analyses to examine the extent to which RD corresponded with deficits in fact fluency, operations, and applied problems. Children’s performance was categorized into deficit (i.e., ≤15th percentile) or no-deficit (i.e., ≥16th percentile) in each mathematics domain; this cut-score scheme is consistent with how deficits are defined in recent MD research (e.g., Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Murphy, Mazzocco, Hanich, & Early, 2007).

The chi-square analyses were significant for all mathematics measures: arithmetic fact fluency, X² (2, N = 287) = 51.22, p < .001, operations, X² (2, N = 287) = 36.72, p < .001; and applied problems, X² (2, N = 287) = 21.44, p < .001. Table 4 displays the relative risk ratios and Table 5 presents descriptive data on the mathematics deficits of the 18 children with dyslexia.

4. Discussion

Little research has examined how children with different types of RD perform on mathematics skills. The purpose of this study was thus to explore the arithmetic fact fluency, operations, and applied problems skills of children with two different types of RD: children with dyslexia and children with specific reading comprehension difficulty. Our findings indicated that mathematics achievement was differentially associated with type of RD. Specifically, children with dyslexia demonstrated weaker mathematics performance and they...
were also more likely to have mathematics deficits: compared to other reader groups, children with dyslexia were 5.60 times, 8.54 times, and 4.98 times more likely to show deficits in fact fluency, operations, and applied problems, respectively. These findings clarify and extend previous research to show that it is children with dyslexia in particular, not children with reading difficulties broadly construed, who have associated mathematics deficits, especially in arithmetic fact fluency.

4.1. Arithmetic fact fluency

The finding that children with dyslexia, not specific reading comprehension difficulty, showed fact fluency deficits provides indirect support for domain-general accounts, which posit that phonological processing underlies the development of arithmetic fact fluency in children with dyslexia (e.g., Simmons & Singleton, 2008, 2009). Indeed, Landerl et al. (2004) suggested that underlying verbal or phonological deficits might affect performance on mathematics tasks that place demands on such systems; arithmetic fact fluency is one such mathematics task (see Dehaene et al., 2003). Of the 18 children with dyslexia in the present study, only three did not have deficits in arithmetic fact fluency. Thus, dyslexia and deficits in arithmetic fact fluency appear to share a common etiology. Phonological deficits might constitute the common underlying etiology, given that phonological deficits are involved in dyslexia and not in specific reading comprehension difficulty.

However, it is important to note that in our overall sample, mathematics deficits were more likely to occur without corresponding reading difficulties, suggesting that domain-specific processes also contribute to arithmetic fact fluency deficits (Gelman & Butterworth, 2005). Landerl et al. (2004, 2009) found preliminary evidence that dyslexia and MD stemmed from dissociable underlying deficits, namely, phonological processing in dyslexia and numerical processing in MD. More research using direct measures of phonological and numerical processing is needed to understand whether failure to automatize number facts reflects an impaired phonological system, deficits in mathematical understanding, or both. In addition, more research is needed to understand whether the arithmetic fact fluency deficits experienced by children with dyslexia differ from the arithmetic fact fluency deficits experienced by children without word reading deficits. Such research is critical to inform targeted instruction and intervention.

4.2. Operations

We found that children with dyslexia performed significantly lower on operations than other children, even when controlling for arithmetic fact fluency; this suggests that operations is influenced by more than fact fluency – and phonological processes implicitly – which is consistent with domain-specific accounts (e.g., Landerl et al., 2004, 2009). These findings indicate that in the case of dyslexia, operations deficits might reflect mathematical problems that are independent of reading-related processes. Geary (1993) suggested that deficits in operations reflect developmental delays in mathematical understanding and thus these deficits may be more amenable to intervention than are arithmetic fact fluency deficits. More research is necessary to examine the sources of operations deficits in children with dyslexia.

That operations deficits might reflect domain-specific processes also has implications for MD identification, given the inconsistencies in how “mathematics deficit” is defined in MD research. Specifically, we have yet to determine whether children with MD have primary difficulties in arithmetic fact fluency, operations, word problems, or other areas such as measurement, geometry or algebra. One of the most consistent findings in MD research is that these children tend to be characterized by deficits in arithmetic fact fluency (Geary, 1993; Vukovic & Siegel, 2010). However, the current results suggest that it is not clear whether arithmetic fact fluency deficits are underpinned by domain-general or domain-specific processes. In contrast, performance on operations appeared less contingent upon domain-general processes. Together, these results suggest that operations may represent a more suitable construct to identify MD than arithmetic fact fluency.

In this study, children with specific reading comprehension difficulty did not experience operations deficits. Yet these children are thought to have deficits in higher-order cognitive processes, such as inference making and using metacognitive strategies (e.g., Cain & Oakhill, 1999; Cain et al., 2000). This may indicate that general reasoning and metacognitive skills do not underlie operations, supporting a domain-specific account of operations; however, without direct measures of general or number-specific reasoning skills our conjecture is speculative and should be tested. More research is needed to examine the cognitive abilities of children with RD and how different cognitive processes impact mathematics achievement.

4.3. Applied problems

Consistent with our prediction, we found that both RD groups performed lower than comparison children on applied problems, although we did not find a difference in performance between the RD groups. Interestingly, once fact fluency was controlled, children with dyslexia performed in the average range on applied problems. This is consistent with previous research that children with RD do not

Table 4
Chi-square and relative risk analyses of likelihood of mathematics deficits by reader group.

<table>
<thead>
<tr>
<th>Type of mathematics deficit</th>
<th>Comparison (1)</th>
<th>Specific reading comprehension difficulty (2)</th>
<th>Dyslexia</th>
<th>Relative risk dyslexia vs 1+2</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arithmetic fact fluency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No-deficit</td>
<td>211 (85.4%)</td>
<td>18 (81.8%)</td>
<td>3 (16.7%)</td>
<td>5.60 (3.94–7.97)</td>
<td>4.58 (1.84–11.39)</td>
<td>5.72 (3.97–8.24)</td>
</tr>
<tr>
<td>Deficit</td>
<td>36 (14.6%)</td>
<td>4 (18.2%)</td>
<td>15 (83.3%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No-deficit</td>
<td>234 (94.7%)</td>
<td>21 (95.5%)</td>
<td>10 (55.6%)</td>
<td>8.54 (4.13–17.65)</td>
<td>8.44 (4.03–17.69)</td>
<td>9.78 (1.35–71.06)</td>
</tr>
<tr>
<td>Deficit</td>
<td>13 (5.3%)</td>
<td>1 (4.5%)</td>
<td>8 (44.4%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Applied problems</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No-deficit</td>
<td>230 (93.1%)</td>
<td>18 (81.8%)</td>
<td>11 (61.1%)</td>
<td>4.98 (2.45–10.13)</td>
<td>5.65 (2.70–11.83)</td>
<td>2.14 (0.74–6.17)</td>
</tr>
<tr>
<td>Deficit</td>
<td>17 (6.9%)</td>
<td>4 (18.2%)</td>
<td>7 (38.9%)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. Analyses based on n = 247 in the comparison group, n = 22 in the specific reading comprehension difficulty group, and n = 18 in the dyslexia group.

Table 5
Type of mathematics deficit in the 18 children with dyslexia.

<table>
<thead>
<tr>
<th>Type of mathematics deficit</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arithmetic fact fluency</td>
<td>15</td>
</tr>
<tr>
<td>Fact fluency only</td>
<td>6</td>
</tr>
<tr>
<td>Fact fluency and operations</td>
<td>2</td>
</tr>
<tr>
<td>Fact fluency and applied problems</td>
<td>2</td>
</tr>
<tr>
<td>Fact fluency, operations, applied problems</td>
<td>5</td>
</tr>
<tr>
<td>Operations-only deficits</td>
<td>1</td>
</tr>
<tr>
<td>No mathematics deficits</td>
<td>2</td>
</tr>
</tbody>
</table>
struggle with word problems (e.g., Hanich et al., 2001; Jordan et al., 2003). However, the language demands inherent in word problems and the language-based nature of both dyslexia and specific reading comprehension difficulty begs further investigation of this finding.

These results suggest that context – in the form of stories and practical scenarios – assists in the completion of mathematics problems, which has implications for how to teach mathematics to children with RD, particularly dyslexia. That said, we remind the reader that in the current study, as well as in previous studies (Hanich et al., 2001; Jordan et al., 2003), the problems were read to the children, effectively eliminating the reading demands of the task. However, both RD groups performed lower than typical achievers, suggesting that their performance was at least somewhat impaired, presumably due to reading or language-related processes. Examining the performance of children with RD on word problems when the problems are read aloud vs when the children have to read the problems on their own is a necessary next step. Additionally, cognitive clinical interviews, which provide richer insights into children’s mathematical thinking than traditional standardized achievement tests (Ginsburg, 1997), would enrich the evidence base.

4.4. Summary

The body of research focused on the relationship between RD and mathematics remains very small, and there exists very little specific information about the nature of the mathematics deficits of children with different types of RD. Although it is the case that all children’s mathematics needs are consistently overlooked in favour of literacy skills and support, we know this is especially the case for children with mathematics needs are consistently overlooked in favour of literacy with different types of RD. Although it is the case that all children’s mathematics remains very small, and there exists very little speci fi

References


