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Effects of Fact Retrieval Tutoring on Third-Grade Students with Math Difficulties with and without Reading Difficulties

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Abstract

The purpose of this study was to assess the efficacy of fact retrieval tutoring as a function of math difficulty (MD) subtype, that is, whether students have MD alone (MD-only) or have concurrent difficulty with math and reading (MDRD). Third graders (n = 139) at two sites were randomly assigned, blocking by site and MD subtype, to four tutoring conditions: fact retrieval practice, conceptual fact retrieval instruction with practice, procedural computation/estimation instruction, and control (no tutoring). Tutoring occurred for 45 sessions over 15weeks for 15–25 minutes per session. Results provided evidence of an interaction between tutoring condition and MD subtype status for assessment of fact retrieval. For MD-only students, students in both fact retrieval conditions achieved comparably and outperformed MD-only students in the control group as well as those in the procedural computation/estimation instruction group. By contrast, for MDRD students, there were no significant differences among intervention conditions.

INTRODUCTION

Students with math difficulties (MD) demonstrate varying levels of reading performance: Some students perform adequately in reading, whereas others demonstrate concurrent reading difficulties (Gross-Tsur, Manor, & Shalev, 1996). As proposed by Geary (1993), this dichotomy may represent a productive scheme for subtyping MD (Geary, 1995; Rourke &Finlayson, 1978; Robinson, Menchetti, & Torgesen, 2002). The hypothesis suggests that students who struggle with math and reading difficulties (i.e., MDRD) do so because of weak phonological processing skills (Hecht, Torgesen, Wagner, & Rashotte, 2001; Robinson et al., 2002). Deficits in phonological processing hinder acquisition of vocabulary and math facts, therefore leading to MDRD. On the other hand, students with MD alone (i.e., MD-only) have weak number sense, which leads to poor recall of math facts (Robinson et al., 2002). These students do not have phonologically based deficits.

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Prior work examining fact retrieval differences as a function of MD subtype relies on a causal-comparative research paradigm whereby researchers use broad achievement measures to identify two groups of students: those with MD who experience concurrent reading difficulties (MDRD) and those who suffer MD alone (MD-only; e.g., Andersson & Lyxell, 2007; Cirino, Fletcher, Ewing-Cobbs, Barnes, & Fuchs, 2007; Swanson & Jerman, 2006). Then the researchers examine patterns of performance on various mathematical skills to gain insight into the mathematical cognition associated with the two subtypes. In the present study, we took a different experimental, methodological approach to extend understanding about whether fact retrieval differences represent an important aspect of mathematical cognition distinguishing MD-only from MDRD students. That is, after identifying MD-only versus MDRD students, we randomly assigned them to intensive tutoring conditions, some of which were designed to enhance fact retrieval performance and others of which were not. We examined responsiveness to fact retrieval intervention as a function of MD subtype. This design offers an important advantage over the more typical causal-comparative study by eliminating poor instruction as a possible explanation for performance deficits. This is especially important in mathematics, where the quality of classroom instruction is uneven (Nye, Hodges, & Konstantopoulos, 2000). In this introduction, we synthesize prior fact retrieval intervention work and summarize prior work examining differences in the mathematical cognition of MD-only and MDRD students, including differences in fact retrieval performance. Finally, we provide an overview of the present study.

Fact Retrieval Intervention

Number combinations and subsequent fact retrieval are important components of every elementary mathematics curriculum. Conventionally, number combinations are incorporated into the curriculum at kindergarten, first grade, and second grade. Typically developing students are on their way toward automatic retrieval of number combinations by the beginning of third grade (Hudson & Miller, 2006). Therefore, when students still manifest large deficits with fact retrieval at the beginning of third grade, a pressing need exists for remediation.

One method for remediating fact retrieval deficits relies on computer-assisted instruction. Hasselbring, Goin, and Bransford (1988) divided students with learning disabilities ages 7 through 14 (n = 160) into experimental and control groups. The experimental group received 49 sessions, 10 minutes each session, of a computer-assisted instruction program called *Fast Facts*. The *Fast Facts* program introduced new number combinations to students and reviewed already practiced facts simultaneously. On average, experimental students increased the number of facts recalled from memory from pre- to posttest by 73 percent, whereas control students did not demonstrate pre- to posttest improvement. Experimental students demonstrated maintenance of fact retrieval skill after 4 months with very little decline in the number of facts recalled correctly. From the report, it was not possible to determine whether random assignment to conditions was employed.

Christensen and Gerber (1990) and Okolo (1992) extended this line of work, both contrasting computer-assisted instruction on fact retrieval in a game-like format to computer-assisted instruction in an unadorned drill format. Neither study, however, was a randomized control trial, and neither utilized a no-treatment control group for comparison. Christensen and Gerber found that students with learning disabilities (n = 30) in grades three through six were disadvantaged by a game-like format, perhaps due to the distracting nature of the presentation. Also, working with fourth-through sixth-grade students with learning disabilities (n = 41), Okolo found no significant differences between game-like and unadorned drill groups. Both groups demonstrated significant improvement on fact retrieval.

More recently, Fuchs et al. (2006) investigated the efficacy of computer-assisted instruction with first-grade students. Thirty-three students at risk for math and reading difficulties were randomly assigned to math (n = 16) or spelling (n = 17) computer-assisted instruction. Students participated in 50 sessions, three times a week, 10 minutes a session. The math computer-assisted instruction program briefly presented basic math facts to the student (without representational pictures), and the student entered, from memory, the entire math fact. The computer program presented facts to students in a specific order: Only addition facts were practiced for the first 6–12 sessions and then fact families (e.g., 1 + 2, 2 + 1, 3 − 1, 3 − 2) were practiced, one family at a time. Spelling computer-assisted instruction students served as the control condition. Students in the math computer-assisted instruction condition significantly outperformed the spelling students on addition, but not subtraction, computation growth. The differential effect for addition over subtraction reflected the fact that the computer-assisted program presented more addition than subtraction facts over the course of the study.

Moving up to third grade and working with a larger number of students, Fuchs et al. (2008) used computer-assisted instruction as part of a tutoring program to teach math facts and procedural computation and estimation. Utilizing random assignment, 64 MD-only and 63 MDRD students were assigned to one of four tutoring conditions: math fact, procedural/estimation, math fact plus procedural/estimation, or spelling. Students in the math fact tutoring received computer-assisted instruction on basic math facts as well as flash card practice and a paper-and-pencil review. The procedural/estimation tutoring used computer-assisted instruction to walk students step by step through understanding, solving, and estimating answers to double-digit addition and subtraction problems. Students also participated in a flash card activity and a paper-and-pencil review. Spelling computer-assisted instruction students served as a control. All students participated in 45 sessions, three times a week, 15–25 minutes a session. At posttest, students in the math fact tutoring outperformed students in the other three groups in terms of basic fact retrieval. Students in the two groups that received procedural/estimation tutoring outperformed math fact and control students on estimation problems, but not on double-digit procedural computation. Overall, the tutoring programs with computer-assisted instruction benefited MD-only and MDRD students comparably in terms of development of math facts and estimation skills.

Beyond computer-assisted instruction, Tournaki (2003) questioned the value of paper-and-pencil fact retrieval drill and practice by contrasting this approach with instruction designed to teach students to count answers to arithmetic problems in a strategic fashion. With 8- to 10-year-old students with learning disabilities (n = 42), results revealed an advantage for strategic counting over rote practice. This result was not surprising, however, because the format for practice in the two conditions differed. The rote practice condition failed to incorporate well-established instructional design features for promoting learning, instead providing feedback on a delayed schedule, without deliberately mixing known with unknown combinations and without systematic review of mastered combinations. By contrast, the strategy instruction incorporated immediate corrective feedback and reteaching whenever an error occurred. Thus, the comparison of the paper-and-pencil drill versus strategy instruction was confounded by these differences.

Fact retrieval intervention research therefore suggests that students in the elementary grades with MD may benefit from computer-assisted instruction (Christensen & Gerber, 1990; Fuchs et al., 2006; Hasselbring et al., 1988; Okolo, 1992) or strategy instruction focused on fact retrieval (Tournaki, 2003). These studies, however, suffer some important limitations. In some studies, no control group was employed (Christensen & Gerber, 1990; Okolo, 1992); or it was not clear whether random assignment was employed (Hasselbring et al., 1988); or the intervention effects pertained only to addition, with participants limited to first graders at risk for MDRD (Fuchs et al., 2006). In addition, only one of these studies examined intervention efficacy or responsiveness to intervention as a function of MD subtype (Fuchs et al., 2008). Because the absence of treatment by MD subtype interaction only represents "proof of the null hypotheses," additional studies of this type are warranted before rejecting the notion that MD subtype does not moderate fact retrieval skill.

Mathematical Cognition as a Function of MD Subtype: Causal-Comparative Studies

Prior research suggests distinctive mathematical deficits between MD-only and MDRD students, supporting the need for intervention studies that compare the response of these subtypes to math intervention. Geary, Hoard, and Hamson (1999) assessed 15 MD-only and 25 MDRD students in the fall and spring of first grade on a global mathematics test, assessing performance across many dimensions of mathematical cognition. MD-only students scored below the 20th percentile in math, but had reading scores in the average range. By contrast, MDRD students scored below the 20th percentile in math and reading. Geary et al. (1999) determined how the two groups performed on various aspects of mathematical cognition. In terms of number comprehension, MDRD students performed significantly below MD-only students and average-performing peers. Many MDRD students were unfamiliar with proper representations of number. In terms of counting, MD-only students performed better than MDRD students on counting items out of order, but then scored worse than MDRD students on tasks where items were counted twice. In terms of arithmetic, both groups demonstrated deficient addition skills; however, compared to MD-only students, MDRD students made many more procedural and retrieval errors and less frequently used the more sophisticated min strategy (starting with the bigger number and counting up; see Groen & Parkman, 1972).

Building on that study, Geary, Hamson, and Hoard (2000) tested 12 MD-only and 16 MDRD students in the fall and spring of first and second grade, again on a global test of mathematics. MD-only students scored below the 20th percentile in math but above the 35th percentile in reading, whereas MDRD students scored below the 20th percentile on math and reading. Similar to the Geary et al. study (1999), MDRD students had difficulty determining values of adjacent numbers on number comprehension tasks. By contrast, MD-only students did not demonstrate number comprehension difficulties, performing similarly to students without MD. MDRD and MD-only students both demonstrated understanding of basic counting principles, but both groups made assumptions that counting must be carried out in a sequential manner. Again, on arithmetic problems, MD-only students used more efficient counting procedures. As MD-only students entered second grade, they used the min procedure more frequently and actually caught up to average-performing peers. No MDRD students used the min procedure in first grade, and this group of students did not catch up to peers during second grade.

To examine mathematics competence at second grade, Jordan and Hanich (2000) assessed students on a global test of mathematics. MD-only students (n= 10) scored below the 30th percentile in math but above the 40th percentile in reading. MDRD students (n = 10) scored below the 30th percentile in math and reading. Four mathematics tasks were administered: number facts, story problems, place value, and written calculations. MDRD students performed significantly worse than control students on all four tasks, whereas MD-only students only performed significantly below control students on the story problems task. An assessment of student strategies revealed that MD-only students used counting strategies more successfully than MDRD students.

A related literature focuses specifically on fact retrieval deficits associated with these MD subtypes. Hanich, Jordan, Kaplan, and Dick (2001) administered tests of arithmetic calculation to MD-only (n = 53) and MDRD (n = 52) second graders. MD-only students performed below the 35th percentile in math but above the 40th percentile in reading. MDRD students performed below the 35th percentile in math and reading. On untimed arithmetic calculations, MDRD students performed significantly worse than MD-only students, but MD-only students performed worse than control students. On timed retrieval of number facts, MDRD and MD-only students performed comparably, yet significantly below control students.

At third grade, Jordan and Montani (1997) analyzed differences between MD-only (n = 12) and MDRD (n = 12) students on simple (6 + 2 = ?) and complex (2 + ? = 6) calculations in timed and untimed conditions. MD-only students scored below the 30th percentile in math and above the 30th percentile in reading. MDRD students scored below the 30th percentile in math and reading. Under timed conditions, students were given 3 seconds to provide an answer for a calculation. MD-only students performed significantly better than MDRD students under timed conditions across simple and complex calculations, but MD-only students performed worse than control students. Under untimed conditions, MD-only students performed similarly to control students on both simple and complex calculations and significantly better than MDRD students.

Outside of the United States, Andersson and Lyxell (2007) studied second, third, and fourth graders in Sweden on timed and untimed arithmetic tasks. Students were classified into MD subtypes by performance on math and reading tests, although the authors did not report percentile cutoffs. On arithmetic, MD-only students answered as many number combinations correctly as average-performing peers, but only when given more than 3 seconds to respond. MDRD students did not solve as many problems correctly regardless of the time provided.

In Norway, Reikeras (2006) administered addition and subtraction basic facts to 8-year-old students in an untimed format. On a standardized test, MD-only students (n = 25) scored below the 15th percentile in math and above the 20th percentile in reading. MDRD (n = 36) students scored below the 15th percentile in math and reading. MD-only and MDRD students performed significantly below students above the 20th percentile in math and reading. Contrary to Andersson and Lyxell (2007), Hanich et al. (2001), and Jordan and Montani (1997), there were no differences between MD subtypes on the untimed task.

In Australia, Micallef and Prior (2004) also did not detect MD subtype differences on basic facts. MD-only students (n = 15) scored below the 25th percentile in math and above the 25th percentile in reading. MDRD students (n = 24) scored below the 25th percentile in math and reading. Students were 7–14 years old. MD-only and MDRD students performed significantly worse and took longer to solve problems than chronological age controls. Both MD-only and MDRD students used a greater variety of strategies to solve the facts, but the strategies were less reliable than those utilized by control students.

To summarize, research suggests that MDRD and MD-only students perform similarly on simple counting tasks (Geary et al., 1999, 2000). Yet, MD-only students use more efficient counting procedures on arithmetic problems than MDRD students (Geary et al., 2000; Jordan & Hanich, 2000). Moreover, MD-only students perform better on untimed fact retrieval tasks than MDRD students (Andersson & Lyxell, 2007; Hanich et al., 2001; Jordan & Montani, 1997), but both groups of students perform similarly on timed fact retrieval tasks. By contrast, some research conducted outside the United States finds MD-only and MDRD students perform comparably on fact retrieval tasks, even when time is not constrained (Micallef & Prior, 2004; Reikeras, 2006).

Overview of Present Study

As shown, although inconsistent in findings, causal-comparative studies suggest the possibility that math fact retrieval skill may differ as a function of MD subtype. Yet, only a few studies have analyzed whether fact retrieval interventions are efficacious for students with or at risk for learning disabilities (Christensen & Gerber, 1990; Fuchs et al., 2006; Hasselbring et al., 1988; Okolo, 1992; Tournaki, 2003), and only one prior study has assessed responsiveness to fact retrieval intervention as a function of MD subtype, with no significant interactions found. Assessing responsiveness to fact retrieval intervention is important to pursue further because efficacy studies eliminate poor instruction as a possible explanation for deficient performance.

Given that different MD subtypes may vary in their initial fact retrieval skill, and/or have difficulty with fact retrieval for different underlying reasons, it may also follow that they respond differentially to intervention.

Consequently, a well-designed, randomized control study is needed to test the efficacy and transportability of interventions for enhancing automatic fact retrieval and to examine responsiveness to this fact retrieval intervention as a function of MD subtype. In addition, we assessed the differential efficacy of two approaches to fact retrieval tutoring, one targeted solely on practice (as is commonly the case within special education) and the other additionally focused on conceptual understanding and practice. We also included a treatment condition that focused on procedural computation/estimation but did not explicitly target fact retrieval. This group was incorporated into the study to control for instructional time and to determine if, when trying to improve fact retrieval, students need explicit and direct instruction on math facts or if fact retrieval improves when students work on other math computation skills. Finally, we incorporated a control (i.e., no tutoring) group.

METHOD

Participants

Across 17 schools, in 43 third-grade classrooms in Nashville and 32 third-grade classrooms in Houston, we administered the Wide Range Achievement Test 3 (WRAT) Arithmetic (Wilkinson, 1993) in large-group format to all students for whom we had obtained parental consent (n = 1,141). Three hundred thirty-three (29 percent) met the WRAT Arithmetic criterion of scoring at or below the 25th percentile. Of these 333 students, 129 were randomly selected not to be screened further to distribute resources across schools and classrooms. This random selection occurred at the classroom level using a random numbers table so that no more than 4 students from any classroom continued with the screening process. The remaining 204 students were assessed individually on WRAT Reading and on the 2-subtest version of the Wechsler Abbreviated Scale of Intelligence WASI; (Psychological Corporation, 1999). Students scoring between the 26th and 39th percentiles on WRAT Reading (n = 24) or earning a T-score below 30 on both WASI subtests (vocabulary and matrix reasoning; n = 5) were excluded. We identified students as MD-only (WRAT Arithmetic <26th percentile but WRAT Reading>39th percentile, n = 86) or MDRD (WRAT Arithmetic <26th percentile and WRAT Reading <25th percentile, n = 89).

Random assignment of these 175 students to the four study conditions occurred by blocking on site (Nashville vs. Houston) and on MD subtype (MD-only vs. MDRD). The four study conditions were fact retrieval practice (FR-P), conceptual instruction with fact retrieval practice (FR-C/P), procedural computation/estimation instruction (PROC/E), and control (no tutoring). Of these, 16 were unavailable by the time pretesting began (3 controls and 13 in the three tutoring conditions). Nine students in the three tutoring conditions became unavailable by the time intervention tutoring began, and a further five received some intervention but did not remain for the duration of the intervention; six controls became unavailable in between pretest and posttest. Thus, by the end of the intervention, 139 participants remained. Two of these students were mistakenly assigned to conditions other than that to which they were randomly assigned. Results were the same whether these students were excluded or analyzed within an intent-to-treat framework; therefore, results reflect the treatment conditions students actually received.

The number of students in the tutoring groups did not differ in or across site and/or MD subtype, supporting the randomization procedure. Tutoring groups also did not differ in their proportions of several demographic indices (English as second language [ESL] status, subsidized lunch status, special education status, ethnicity, sex, years retained). Also, tutoring groups did not

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differ on these demographic indices within site or within MD subtype. Site was considered as an additional factor, but doing so did not alter the results, and therefore is not included in the tables or the analyses reported below.

Difficulty groups differed on two demographic indices, special education status, $\chi^2(1, n = 139)$, 15.65, $p < .0001$, and whether a student was retained, $\chi^2(1, n = 127)$, 12.05, $p < 0005$. These differences are expected given the greater level of severity associated with the MDRD subtype. Including special education status or retention status in models did not alter the overall pattern of results. Age was weakly and typically not significantly related to performance on outcome measures at pre- and posttest and, therefore, was not included in analyses. Table 1 presents demographic and screening data, arranged by study condition and MD subtype. (We note that we conducted supplementary analyses to determine whether adding ESL, IQ, or WRAT Arithmetic altered the nature of the findings. Because none did, we did not include these variables as covariates in the analyses described below.)

Measures

Academic and IQ measures were used for screening students as MD-only and MDRD. At pre- and posttreatment, automatic fact retrieval measures were used for evaluating the effect of different treatments.

Screening—With WRAT Arithmetic (Wilkinson, 1993), students have 10 minutes to complete calculation problems of increasing difficulty. If students do not meet a basal of five calculation problems answered correctly, students read numerals aloud. Median reliability is .94 for ages 5–12 years. With WRAT Reading (Wilkinson, 1993), students read words aloud until a ceiling is reached. If students do not meet a basal of five words read correctly, students read letters aloud. Reliability is .94.

General cognitive functioning was measured by two subtests on the WASI (Psychological Corporation, 1999). The *vocabulary* subtest assesses expressive vocabulary, verbal knowledge, memory, and learning ability, as well as crystallized and general intelligence with 4 pictures and 37 words. Students name pictures and define words. The *matrix reasoning* subtest measures nonverbal fluid reasoning and general intelligence with 35 items. Students select an option (out of five choices) that best completes a visual pattern. Subtest scores are combined to yield an Estimated Full Scale IQ score. The standardization sample is 1,100 children (between the ages of 6 and 16). Reliability exceeds .92.

Automatic Fact Retrieval—The third-grade math battery (Fuchs, Hamlett, & Powell, 2003) incorporates four fact retrieval subtests. *Addition Fact Retrieval 0–12* comprises 25 addition fact problems with sums from 0 to 12, presented vertically on one page. Students have 1 minute to write answers. The score is the number of correct answers. Coefficient alpha on a similar sample (Fuchs et al., 2008) was .89. *Subtraction Fact Retrieval 0– 12* comprises 25 subtraction fact problems with minuends from 0 to 12, presented vertically on one page. Students have 1 minute to write answers. The score is the number of correct answers. Coefficient alpha was .92. *Addition Fact Retrieval 0–18* comprises 25 addition fact problems with sums from 0 to 18, presented vertically on one page. Students have 1 minute to write answers. The score is the number of correct answers. Coefficient alpha was .88. *Subtraction Fact Retrieval 0–18* comprises 25 subtraction fact problems with minuends from 0 to 18, presented vertically on one page. Students have 1 minute to write answers. The score is the number of correct answers. Coefficient alpha was .89.

Tutoring

Students in the three tutoring conditions (FR-P, FR-C/P, and PROC/E) received 37–45 (*M* = 41.48, *SD* = 1.97) one-on-one tutoring sessions: three sessions per week over 15 weeks. Tutoring sessions lasted 15–25 minutes. Tutors were 19 part-time research assistants and 3 project coordinators (1 full-time in Nashville and 2 full-time in Houston). In Nashville, the nine research assistants were working on master's degrees in elementary education, secondary education, school counseling, leadership, or special education. The Nashville project coordinator had a master's degree in secondary education and high school teaching experience. In Houston, one research assistant had a master's degree in reading as well as teaching experience, seven research assistants had a bachelor's degree in a variety of fields ranging from science to business to technology, and two research assistants had associate's degrees. Of the two project coordinators in Houston, one had a master's degree and a teaching license; the other had a bachelor's degree in chemistry.

Each tutor was assigned a caseload that involved tutored students in each of the three tutoring conditions. Tutors were trained over two full-day sessions. During the week preceding tutoring, tutors studied scripts and practiced tutoring alone and with other tutors. The scripts provided tutors with the important concepts and vocabulary they needed to use during each lesson. Tutors were required to study and follow each script, but they did not read scripts verbatim. Tutors also conducted a tutoring session in each condition with a project coordinator. The project coordinator provided corrective feedback for each tutor. Every 2–3 weeks, all research assistants met with project coordinators in Nashville or Houston to address problems or concerns and to review tutoring practices.

FR-P comprised three activities: computer-assisted instruction (7.5 minutes), math fact flash card practice (4 minutes with corrective feedback), and math fact review (4 minutes with corrective feedback). Each session ran 15–18 minutes with time for transitions between each activity.

The first activity of each session, computer-assisted instruction, was conducted using *Math Flash* (Fuchs, Hamlett, & Powell, 2004a) while the tutor supervised and answered questions. In *Math Flash*, the student was presented with an addition or subtraction math fact with the answer; the math fact flashed on the screen for a second or two. When the math fact disappeared from the screen, the student used the computer keyboard to type the math fact. As the student typed the math fact, a number line illustrated the math fact at the top of the screen. This number line included 20 uncolored boxes, with a red line marking the perimeter of the first 10 boxes. As the student typed the first addend of an addition fact, boxes on the number line automatically turned blue to represent the quantity of the first addend; as the student typed the second addend, boxes on the number line automatically shaded yellow to signify the quantity of the second addend. For subtraction problems, boxes on the number line automatically shaded yellow to represent the minuend. As the student typed the subtrahend, black X's were drawn through the yellow boxes. After typing the math fact, the student pressed the return key to determine whether the math fact had been typed correctly. If correct, a number from 1 to 5 sparkled, and the student heard applause. If incorrect, the math fact reappeared on the screen and remained on the screen until the student typed the math fact correctly (no numbers sparkled and no applause was heard). The student pressed the space bar to continue to the next math fact. As students answered more facts correctly, each math fact flashed on the screen more quickly. If students answered math facts incorrectly, math facts flashed on the screen less quickly. Each time the student typed five math facts correctly, a picture of a "treasure," such as an ice cream cone or sun, dropped into the student's "treasure box." The student tried to earn as many treasures as possible during the session. After 7.5 minutes, the program ended. Applause sounded while the student's score (math facts answered correctly) was displayed.

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The second activity in every fact retrieval tutoring session was math fact flash card practice. Math fact flash cards showed math facts without answers. The student responded by saying the answers. The student had 2 minutes to respond to as many cards as possible, and the number correct was graphed each session. Up to five incorrect responses were corrected by the tutor using scripted remediation.

The final activity in each session was a paper-and-pencil math fact review. The student had 2 minutes to complete 15 math facts. The tutor corrected math facts out loud as the student observed. At the end of each session, the tutor gave the student the math fact review to take home.

FR-C/P comprised five activities: math fact flash card practice (4 minutes with corrective feedback), computer-assisted instruction (7.5 minutes), number line flash card practice (4 minutes with corrective feedback),math fact family review(2 minutes with corrective feedback), and math fact review (4 minutes with corrective feedback). Each tutoring session lasted approximately 22–25 minutes with time for transitions between activities.

The first two activities of each session were conducted in the same manner as in fact retrieval tutoring. The first activity was math fact flash card practice for 2 minutes with corrective feedback. The second activity was *Math Flash* computer-assisted instruction for 7.5minutes. Next, the student worked on number line flash cards for 2 minutes. With number line flash cards, the student was presented with a number line illustrating a math fact problem (as represented on *Math Flash*). The student stated the math fact represented by the number line. The student had 2 minutes to respond to as many number line flash cards as possible. The number of flash cards answered correctly was graphed each session, and the tutor corrected up to five incorrect responses with scripted remediation.

The fourth activity during each session was a math fact family paper-and-pencil activity. The student was presented with a number at the top of the paper (e.g., 12). Then the student wrote as many math facts as possible where the number at the top was either the sum or the minuend (e.g., $7 + 5 = 12$ or $12 - 3 = 9$). The student wrote math facts for 1 minute, and at the end of 1 minute, the tutor counted the number of facts written correctly.

Finally, each fact retrieval–revised tutoring session included a math fact paper-and-pencil review. This review was the same review students completed in the fact retrieval tutoring condition. The student had 2 minutes to answer 15 math facts. The tutor corrected math facts aloud as the student observed. At the end of each session, the tutor gave the student the math fact review to take home.

The difference between the two fact retrieval interventions was that FR-C provided explicit instruction on fact families and how facts relate to one another whereas FR-P merely provided practice on learning math facts. FR-C was conceptual because students worked with manipulatives to represent addition and subtraction facts. That is, students used blue and yellow blocks to represent addition and subtraction problems on a number line mat with a red box indicating a group of 10. The computer practice used a similar number line that filled in as students typed a fact with blue and/or yellow to represent addition or subtraction.

PROC/E comprised three activities: computer-assisted instruction (5–10 minutes), double-digit flash card practice (4 minutes with corrective feedback), and computation review (4 minutes with corrective feedback). Each session lasted 15–18 minutes per session with time for transitions between activities. Intervention targeted algorithmic procedures and estimation of addition and subtraction of two-digit numbers with and without regrouping.

The first activity of each session was conducted using a computer-assisted instruction program named *Magic Math* (Fuchs, Hamlett, & Powell, 2004b). *Magic Math* comprised three segments, with one computer screen dedicated to each segment. *Magic Math*'s first segment addressed conceptual understanding of double-digit addition or subtraction, using pictorial representations of ones and tens. The student was presented with an addition or subtraction problem and used an external computer mouse to represent the ones and tens of each number in the problem with pictures of units and rods. Two characters, the “Addition Magician” and “Subtraction Sorceress,” provided positive and corrective video feedback for addition and subtraction problems, respectively. *Magic Math*'s second segment taught procedural steps of two-digit addition and subtraction, relying on the same addition or subtraction problem worked in the first segment. The student was presented with nine questions or directives about the problem, and worked through the nine steps with corrective video feedback from the Addition Magician or Subtraction Sorceress. *Magic Math's* final segment focused on estimation. The student estimated the answer (to the nearest ten) of a double-digit addition problem. Corrective feedback via video was provided by the Addition Magician.

The second activity was double-digit flash card practice with a set of addition and subtraction double-digit math problems. For 2 minutes, the student responded as to whether the problem was addition or subtraction and whether regrouping was involved. The number correct was graphed each session. After mastery was established by answering 35 or more flash cards correctly during three consecutive sessions or 25 or more over six consecutive sessions, the student then responded for 2 minutes to a set of addition double-digit flash cards as to whether the ones column would be rounded to 0, 10, or 20. Again, the number correct was graphed each session, and the same mastery criteria were used to determine whether a student would move on to a new response format on the double-digit addition flash card set where the student would estimate the answer to the nearest 10.

The final activity of each session was a computation and place value review. The student had 3 minutes to answer three double-digit addition or subtraction problems, to estimate three double-digit addition problems, and to write two double-digit numbers represented by pictures of rods and units. The tutor corrected the student's work, talking through the procedure for each problem, while the student observed.

Tutoring Fidelity

Every tutoring session was audiotaped. Four project coordinators listened to tapes while completing a checklist to identify the percentage of essential points in each lesson. In Nashville, 11.27 percent and, in Houston, 14.90 percent of tapes were sampled such that tutoring conditions, research assistants, and lesson types were sampled comparably. In Nashville, the mean percentage of points addressed was 99.85 (*SD* = 0.64) for FR-P tutoring, 99.77 (*SD* = 0.95) for FR-P/C tutoring, and 99.70 (*SD* = 1.20) for PROC/E tutoring. In Houston, the mean percentage of points addressed was 98.66 (*SD* = 0.87) for FR-P tutoring, 98.57 (*SD* = 0.77) for FR-P/C tutoring, and 99.01 (*SD* = 0.60) for PROC/E tutoring. The length of each tutoring session was recorded by tutors in Nashville and Houston. The average total amount of intervention time in Nashville was 581.7 minutes (*SD* = 84.0) for FR-P tutoring, 786.8 (*SD* = 79.1) for FR-P/C tutoring, and 733.8 (*SD* = 92.3) for PROC/E tutoring. In Houston, the average total amount of intervention time was 716.7 minutes (*SD* = 70.6) for FR-P tutoring, 1009.2 (*SD* = 92.7) for FR-P/C tutoring, and 775.6 (*SD* = 124.9) for PROC/E tutoring.

Analyses

Preliminary analyses of the 139 students included distributional exploration of relevant variables via statistical (e.g., skewness and kurtosis) and graphical (e.g., box plots, stem, and leaf plots) means. Two MDRD students (one each from fact retrieval tutoring and procedural computation and estimation tutoring) were low outliers on multiple measures at pre- and posttest; results were the same with or without these individuals, and therefore these students were retained in the analyses. The fact retrieval measures were grouped together into a fact retrieval skill factor with a mean of 0 and *SD* of 1. Primary analyses utilized a two-way analysis of covariance, with the four tutoring levels and two MD subtype levels comprising the factors; pretest performance was used as the covariate. Follow-up comparisons were conducted on the adjusted posttest means using a Tukey correction for multiple comparisons. Effect sizes were also computed for comparisons of interest. The most basic formula for effect size of differences between groups is given by Cohen's d = (Mean 1 − Mean 2)/*SD*. Our calculation of effect size opted for unadjusted group means in the numerator and the pooled *SD* across the groups being compared in the denominator to correct for sample overestimation bias (Hedges & Olkin, 1985), which was generally small. Effect sizes were similar when adjusted least-squares means were used in place of the unadjusted factor score means.

RESULTS

Fact Retrieval Skill

Table 2 displays pre- and posttest fact retrieval data, arranged by tutoring group and MD subtype. [1] Table 3 displays effect sizes for comparisons among tutoring groups (MD subtypes combined and separated) and MD subtypes. At pretest for fact retrieval skill, there was no interaction of tutoring group and MD subtype, nor were there main effects for tutoring group or MD subtype at pretest. This was expected given the randomized design. At posttest for fact retrieval skill, there were no interactions of pretest with tutoring condition or MD subtype, and these were trimmed from the model. There were significant main effects for the pretest covariate, $F(1,127) = 129.59$, $p < .0001$; for MD subtype, $F(1,127) = 14.95$, $p < .0002$; and for tutoring condition, $F(3,127) = 7.13$, $p <$ 0002.

Follow-up tests indicated that MD-only students outperformed MDRD students ($p < .0002$), and the two fact retrieval tutoring groups outperformed the comparison students ($p < .0047$ and < .0008 for FR-P and FR-C/P, respectively); in addition, the FR-C/P group outperformed the PROC/E group ($p < .0202$). These effects, however, were subsumed by the interaction of tutoring condition with MD subtype, which was also significant, $F(3,127) = 2.90$, $p < .0375$.

Examination of adjusted means and follow-up analyses with Tukey correction for multiple comparisons revealed that, for MD-only students, the two fact retrieval tutoring groups did not differ from one another, but each outperformed the PROC/E group ($p < .0159$ and $p < .0051$, respectively) as well as the control group ($p < .0089$ and $p < .0028$); the latter two groups also did not differ from one another. In contrast, for MDRD students, there were no differences among tutoring conditions.

DISCUSSION

The primary purpose of this study was to assess whether MD-only and MDRD students respond differentially to two fact retrieval tutoring conditions. Toward that end, we randomly assigned students, while stratifying on MD subtype, to four conditions: FR-P, FR-C/P, PROC/E, and control (no tutoring). We found that MD-only students in the two fact retrieval tutoring conditions significantly outperformed MD-only students in the two contrast groups that did not receive fact retrieval tutoring (i.e., procedural computations/estimation instruction and control). For MD-only students, effect sizes comparing FR-P or FR-C/P against PROC/E tutoring (which controlled for instructional time) were 1.11 and 0.96, respectively. When

[1] Analyses examining differences on double-digit addition and subtraction PROC/E indicated no differences between treatment groups or MD subtype. Therefore, these analyses are excluded and fact retrieval skill remains the sole focus of this study.

compared to the control group, effect sizes for the two fact retrieval tutoring conditions were 1.50 and 1.19, respectively. By contrast, MDRD students who received either version of fact retrieval tutoring did not improve significantly better than MDRD students in either of the contrast conditions. These findings echo previous work (Andersson & Lyxell, 2007; Hanich et al., 2001; Jordan & Montani, 1997), where MD-only students outperformed MDRD students on fact retrieval tasks.

This finding, indicating that MD-only students respond to fact retrieval tutoring (with practice or conceptual instruction plus practice) differentially better than MDRD students, adds to prior research in a number of ways. First, prior work examining fact retrieval differences as a function of MD subtype has relied almost entirely on a causal-comparative research paradigm. By contrast, in the present study, we took an experimental approach, examining responsiveness to fact retrieval intervention as a function of MD subtype. This design offers an important advantage over the causal-comparative study by eliminating poor instruction as a possible explanation for performance deficits. Using this experimental paradigm, we showed differential responsiveness to fact retrieval tutoring and, in this way, lend support to Geary's (1993) hypothesis that MD-only versus MDRD students experience differential difficulty with automatic retrieval of math facts and that MD-only versus MDRD may represent a viable scheme for subtyping mathematics disability. This scheme suggests mathematical performance differences between MD-only and MDRD students based on the specific disabilities of the student. MDRD students may struggle with math and reading because of weak phonological processing skills (Hecht et al., 2001), whereas MD-only students may struggle with math because of weak number sense (Robinson et al., 2002). However, the present study was not designed to determine whether MD-only and MDRD differences in intervention response are in fact due to phonological processing or number sense skills. Future work should address this possibility.

We note that the present study contradicts the findings of Fuchs et al. (2008), where the interaction between treatment and MD subtype on fact retrieval skills was not significant. In Fuchs et al. (2008), the set of fact families addressed during computer practice was identical to the fact families addressed in the present study. The order of the fact families was, however, different in the two programs. For example, the first fact family practiced in Fuchs et al. (2008) was 0 + 1, 1 + 0, 1 − 0, and 1 − 1. The first fact family in the current study was 2 + 3, 3 + 2, 5 − 3, and 5 − 2. Although this small difference may be responsible for the inconsistent findings between studies, additional work is warranted to explore the instructional variables that produce varying response as a function of MD subtype.

Second, our findings corroborate the potential for computer-assisted instruction for MD students, as shown by Christensen and Gerber (1990), Hasselbring et al. (1988), and Okolo (1992). In our study, however, only MD-only students demonstrated fact retrieval improvement via computer-assisted instruction. Those earlier intervention studies did not explore MD subtype as a moderating variable, and it is possible that effects in those investigations were dominated by the subset of MD students who were relatively strong in reading. Additional work to corroborate the present set of findings is warranted.

Third, in terms of how to design fact retrieval tutoring, both conditions provided immediate and corrective feedback via computer or tutor immediately following errors in fact retrieval. Our study thereby echoes Tournaki's (2003) investigation where students with math difficulties benefited from fact retrieval strategy instruction with feedback over paper-and-pencil drill without feedback. Yet, based on the present study, we have no way of discerning which components of the tutoring protocol were essential. Future controlled studies should investigate the effect of computer-assisted instruction with and without immediate corrective feedback, with and without flash cards, and with and without paper-and-pencil review to determine the active ingredients of our fact retrieval tutoring for MD-only students.

Fourth, we offer a few comments about the PROC/E tutoring. We found no evidence that this condition, which served to control for tutoring time, promoted the development of automatic fact retrieval among MD-only or MDRD students. This is interesting because, within PROC/E tutoring, students combined single-digit operands, as in fact retrieval, for every problem used for instruction. Within these activities, however, students worked these facts without time constraints, within the context of two-digit procedural calculation problems with and without regrouping. Although the instructional focus was on place value concepts and algorithms, tutors did correct fact retrieval errors; however, they did not provide timed practice on fact retrieval or explicitly teach strategies for deriving solutions. Our findings, in which PROC/E tutoring failed to effect improvements in automatic fact retrieval, suggest that promoting such outcomes in MD-only or MDRD students requires direct work on fact retrieval, with carefully designed timed practice activities that include corrective feedback with strategic counting (such as the min strategy), as in Tournaki (2003).

This brings us to consider the efficacy of the two fact retrieval tutoring protocols we tested. Overall, across MD-only and MDRD students, no significant differences between fact retrieval practice, with or without conceptual instruction, emerged (*ES* = 0.08). Students in fact retrieval practice tutoring received practice via computer-assisted instruction, flash cards, and a paper-and-pencil review. Students in conceptual instruction with FR-P tutoring participated in the same three activities but also received conceptual instruction that focused on the number line and fact families, requiring conceptual instruction with FR-P tutoring to run for more minutes per session. Even so, FR-P tutoring produced comparable outcomes. This is surprising, not only given more instructional time for the conceptual condition but also in light of theoretical arguments in the literature that conceptual instruction should enhance automatic retrieval of math facts (e.g., Baroody, 2006; Baroody, Feil, & Johnson, 2007; Ginsburg, 1997). Baroody (2006) argued that fact retrieval fluency develops when students have conceptual understanding of numbers and the connections and interactions between numbers; Baroody et al. (2007) suggested that fact retrieval is more efficient when students have conceptual understanding connecting sets of facts rather than memorizing facts in isolation. Ginsburg (1997) bolstered these arguments by emphasizing that, although rote knowledge is important, it does not allow students to theorize or develop a deeper understanding of math or mathematics principles. Of course, it is possible that the conceptual component of our fact retrieval tutoring failed to tap the key conceptual underpinnings students need to develop the kind of understandings Baroody and Ginsburg describe. Future studies should isolate conceptual instructional techniques such as teaching fact retrieval through number lines, fact families, pictorial representations, manipulatives, or self-exploration to see which, if any, benefit MD-only and/or MDRD students.

The final purpose of the present study concerned the transferability of the tutoring protocols. That is, we assessed whether tutoring efficacy interacted with site (i.e., whether intervention occurred at a site local to the intervention developers as opposed to a distal site). Analyses revealed no significant interactions involving site that affected the interpretation of results. This leads us to conclude that the tutoring protocols were transportable and suggests the potential for scaling up these tutoring protocols, given the proviso that tutors are trained as done in the present study. That is, tutors (1) receive a full day of training, (2) practice implementing the procedures alone and with each other during the subsequent week, (3) conduct a session with a supervisor who provides corrective feedback, (4) study (not read) the tutoring scripts as they implement tutoring, and (5) meet with fellow tutors and the supervisor every 2–3 weeks to address problems or questions as they arise.

Before closing, we note that our study has shortcomings. We did not examine the strategies students used to retrieve answers on pre- or posttests. MD-only students may have realized their differential math fact learning by memorizing facts or by utilizing a counting or other strategy to find the answer. In a related way, there could have been MD sub-type differences in terms of strategy type and efficiency of the strategy as reported by Geary et al. (1999) and Geary et al. (2000). Future studies should examine strategies within the context of a randomized control trial focused on fact retrieval. In addition, based on our study, we cannot account for the lack of significant differences between fact retrieval practice and conceptual instruction with fact retrieval practice conditions. Our initial hypothesis that the conceptual instruction would promote stronger fact retrieval was rejected. This null effect needs to be explored in future studies. Finally, we cannot explain why MDRD students did not profit from either fact retrieval intervention. Perhaps MDRD students, with their more pervasive language and working memory deficits compared to MD-only students (Andersson & Lyxell, 2007; Geary, 1993; Geary et al. 2000; Hanich et al., 2001; Jordan & Hanich, 2000; Jordan & Montani, 1997), may require longer or more thorough interventions than those we incorporated in the present study. To better understand how fact retrieval in MDRD students may be enhanced, different or more intensive fact retrieval interventions should be designed and tested via randomized control trials. Also, research should investigate whether fact retrieval work needs to occur earlier, in first or second grade, to enhance fact retrieval skills for the population of students with MD and MDRD.

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TABLE 1

Demographic and Screening Data by Tutoring Condition and MD Subtype

	Tutoring Condition				MD Subtype	
Variable	**FR-P (n = 33)**	**FR-C/P (n = 37)**	**PROC/E (n = 36)**	**No Treatment Control (n = 33)**	**MD-Only (n = 70)**	**MDRD (n = 69)**
Age in years	9.11 (0.5)	9.15 (0.5)	8.99 (0.5)	9.06 (0.4)	8.84 (0.3)[a]	9.31 (0.5)[b]
Female	39%	41%	39%	55%	47%	39%
Subsidized lunch*	72%	78%	67%	73%	69%	77%
Special education	24%	19%	11%	21%	6%[a]	32%[b]
Retained*	15%	19%	22%	24%	9%[a]	32%[b]
English second language	12%	5%	8%	12%	6%	13%
Ethnicity: African American	45%	59%	47%	55%	49%	55%
Caucasian	33%	14%	28%	21%	27%	20%
Hispanic	21%	27%	25%	24%	24%	25%
Other	0%	0%	0%	0%	0%	0%
WASI FSIQ	89.70 (11.2)	89.97 (13.9)	92.42 (12.7)	89.45 (12.3)	96.74 (11.6)[a]	83.99 (9.8)[b]
WRAT Arithmetic	82.11 (8.1)	81.21 (7.8)	82.89 (6.9)	82.64 (7.0)	85.56 (4.6)[a]	78.84 (8.2)[b]
WRAT Reading	92.51 (15.0)	93.48 (18.3)	96.89 (16.6)	94.39 (13.8)	107.79 (8.4)[a]	80.48 (7.4)[a]

Note Percentages are computed relative to the number of individuals in that group (e.g., 39% of the 33 students in FR-P tutoring were female). Percentages for ethnicity within a column total of 100 percent. WASI = Wechsler Abbreviated Scales of Intelligence; WRAT = Wide Range Achievement Test–Third Ed. Numbers in parentheses are standard deviations. For MD subtype mean scores, values in a given row with different superscripts are significantly different from one another. There were no significant differences among tutoring groups on any variable in Table 1.

* Subsidized lunch and retention data were unavailable for 12 students in one school.

TABLE 2

Pre- and Posttest Performance by Tutoring Condition and MD Subtype

	Tutoring Condition					MD Subtype		
Variable	**F**	**FR-P (n = 33)**	**FR-C/P (n = 35)**	**PROC/E (n = 35)**	**No Treatment Control (n = 33)**	**F**	**MD-Only (n = 69)**	**MDRD (n = 67)**
Fact retrieval pretest	<1	−0.06	−0.04	0.03	0.07	<1	0.03	−0.03
		(1.09)	(1.00)	(0.94)	(1.00)		(0.88)	(1.12)
Fact retrieval posttest	7.13*	0.17	0.26	−0.14	−0.28	14.95*	0.23	−0.23
		(0.98)	(1.16)	(0.98)	(0.79)		(1.02)	(0.94)

Note Scores are unadjusted factor scores derived from a combination of four similar measures. See text for explanation.

* $p<.001$; other *F* values not significant. The significantmain effects at posttest are superseded by a significant interaction of tutoring condition andMDsubtype.

TABLE 3

Effect Sizes by Tutoring Condition and MD Subtype

	Contrast Tutoring Condition						MD Subtype
	FR-P vs.			FR-C/P vs.		PROC/E vs.	MD-Only vs.
Variable	FR-C/	PROC/E	No Treatment Control	PROC/E	No Treatment Control	No Treatment Control	MDRD
Fact retrieval	−0.08	0.31	0.50	0.37	0.53	0.15	0.47
(MD subtypes combined)	(−0.56 to 0.39)	(−0.17 to 0.79)	(0.01 to 0.99)	(−0.10 to 0.84)	(0.05 to 1.02)	(−0.32 to 0.63)	(0.13 to 0.81)
Fact retrieval	−0.03	1.11	1.50	0.96	1.19	0.13	
(MD−only)	(−0.72 to 0.65)	(0.40 to 1.83)	(0.73 to 2.27)	(0.27 to 1.65)	(0.46 to 1.91)	(−0.53 to 0.78)	
Fact retrieval	−0.15	−0.34	−0.19	−0.18	−0.03	0.17	
(MDRD)	(−0.81 to 0.52)	(−1.03 to 0.35)	(−0.87 to 0.49)	(−0.86 to 0.49)	(−0.70 to 0.65)	(−0.53 to 0.86)	

Note ;Effect sizes based on unadjusted means at posttest and pooled standard deviation of both groups being compared. Positive effect sizes indicate higher means for the first group named in the comparison. Values in parentheses are confidence intervals for the effect sizes.