DIFFERENTIATING STUDENTS WITH MATHEMATICS DIFFICULTY IN COLLEGE: MATHEMATICS DISABILITIES VS. NO DIAGNOSIS

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Abstract. **Difficulties with college algebra can be the gatekeeper for earning a degree. Students struggle with algebra for many reasons. The focus of study was to examine students struggling with entry-level algebra courses and differentiate between those who were identified as having a mathematics disability and those who were not. Variables related to working memory, math fluency, nonverbal/visual reasoning, attention, and reading were analyzed using a MANOVA and separate ANOVAs. Significant differences were found on all but attention, supporting the findings of research on students in elementary and secondary education. Implications include a focus on techniques that help to remediate these specific deficits.**

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By understanding students struggling with mathematics at the postsecondary level, professionals can offer better assistance both during and before college and can help identify appropriate remediation techniques. Approximately 5-6% of students have significant difficulty in mathematics (Fleischner & Manheimer, 1997), and many struggling students are not identified as requiring special services for math during secondary school. It is becoming increasingly evident that students need help understanding mathematics, especially with the world rapidly evolving scientifically and mathematically. Many college students encounter mathematics difficulties, which can eventually act as a gatekeeper to earning a college degree.

Little research has been published on college students experiencing mathematics difficulties compared to elementary and secondary students having difficulties with mathematics (Strawser & Miller, 2001; Zawaisa & Gerber, 1993). This is especially the case for instructional or remediation interventions. Consequently, researchers often present results involving elementary and secondary students as part of their literature reviews, generalizing this information to students at the college level. Because enrollment in postsecondary settings by students with documented learning difficulties is increasing, researchers must begin to focus on the needs of this population of students (Mercer, 1997).

STUDENTS WITH MATHEMATICS DISABILITY

Research on students with mathematics disabilities often consists of comparisons with other disabilities. That is, students with reading disabilities (RD), disorders of written expression (WD), and mathematics disabilities (MD) and combined reading/mathematics disorders (RD/MD) are compared and contrasted between and among disability groups to establish shared and disparate attributes (Benton, 2001; Greene, 2001; Rourke, 1993; Shafrir & Siegel, 1994). Commonly, these studies focus on elementary and secondary students, highlighting the need for research at the postsecondary level.

Normally achieving (NA) students often make up a fourth group in such comparisons. From the comparisons made, several sources of individual differences can be extracted, including deficiencies in (a) reading ability, (b) nonverbal/visual skills, (c) working memory, (d) poor math fluency, and (e) attention and/or hyperactivity.

Reading Comprehension and MD

Fleischner and Manheimer (1997) identified two primary reasons why students struggle with mathematics. First, some students exhibit difficulty in reading comprehension. Comprehension difficulties seem to exacerbate difficulties in mathematics, especially for solving word or story problems. Examining NA students and students with MD, RD, and MD/RD, Jordan and Hanich (2000) demonstrated that when asked to solve four types of problems (number facts, story problems, place value, and written calculation), the students with MD/RD performed significantly lower than NA students. Further, the students with MD only performed lower on complex story problems compared to the NA students. Students with RD performed similarly to the NA students. Overall, students with MD/RD and MD significantly underperformed the students with RD and NA students on mathematics-related tasks.

Nonverbal Reasoning and MD

Fleischner and Manheimer (1997) also asserted that some students exhibit difficulties in nonverbal reasoning and/or primary mathematics knowledge. Rourke and his colleagues (Rourke, 1993; Rourke & Del Dotto, 1994; Rourke & Fuerst, 1996) have made significant contributions to the field of learning disabilities by studying nonverbal learning disability and its relationship to reading and mathematics disorders from a neurological perspective.

Rourke (1993) summarized several of these studies conducted with children with learning disabilities (LD) using a variety of assessment measures, including the Wechsler Intelligence Scale for Children (WISC) and Woodcock-Johnson Tests of Achievement (WJ). Among the three main clinical groups, Rourke and his colleagues identified differences between students with RD and MD, noting that students with RD typically have verbal deficits whereas students with MD typically have nonverbal deficits, as measured by the discrepancy between VIQ and PIQ measures on the WISC. "Older group [RD] children exhibit normal levels of performance on visual-spatial-organizational, psychomotor, and tactile-perceptual tasks; group [MD] children have outstanding difficulties on such tasks" (p. 220).

Additional findings were presented by Rourke and Fuerst (1996) and Rourke and Del Dotto (1994). For specifics on the range of studies that make up the preceding three studies, the interested reader is referred to Rourke and colleagues' publications on students with RD and MD. Rourke originally referred to MD as MD, but later changed to NLD (nonverbal learning disabilities). For the purposes of this article, Rourke's NLD group is referred to by his initial identification of MD.

According to Silver, Pennett, Black, Fair, and Balise (1999), visuo-spatial deficits may be the core deficit for students with isolated mathematics disorders, yet subtype stability is poorer for the arithmetic-only group. In a literature review, Jordan (1995) found three subtypes of mathematics disabilities, including one identified as having visuo-spatial deficits, similar to the nonverbal deficit discussed by Rourke.

Geary (1993) examined visuo-spatial deficits as one of three core difficulties (along with semantic memory and procedural deficiencies) experienced by students with calculation difficulties. Cirino, Morris, and Morris (2002) further explored Geary's theory on a sample of college students using a comprehensive battery of assessment instruments, Wechsler Adult Intelligence Scale-Revised and Woodcock-Johnson Tests of Achievement-Revised, along with a variety of other neuropsychological instruments. They determined that visuo-spatial deficits did not contribute to the calculation difficulties experienced by this sample. However, they did find evidence that Geary's other two categories of deficiency – semantic memory deficits and procedural deficits – contributed to the calculation difficulties of college students.

Working Memory, Math Fluency, and MD

Geary (1993) described semantic memory deficits and procedural deficits, arguing that they could be related to an underlying memory deficit. *Semantic memory deficits* include difficulties in fact retrieval and in learning mathematic facts to the point that they become automatic or retrieved directly from long-term memory. Students with this deficit continue to mentally calculate the answers rather than obtain them through direct retrieval. *Procedural deficits* are considered more problematic and pervasive, causing faulty procedures that are learned with errors. Students with this deficit are more likely to use inappropriate developmental procedures because they appear to struggle with remembering the appropriate ways to complete certain problems. An oversimplified example of a faulty procedure might be to learn that a plus sign means subtracting instead of adding.

Swanson (1993, 1994) investigated working memory in children with and without LD. He defined working memory as "the system of limited capacity for the temporary maintenance and manipulation of information" (Swanson, 1994, p. 190). Students were operationally defined as having an LD if they had scores that were one half standard deviation below the mean or having scores on the Wide Range Achievement Test-Revised (WRAT-R) that were below the 25th percentile for their age. Normally achieving students were identified as those having scores equal to or above the 50th percentile for their age. Students were excluded in both cases if their scores were deemed due to "retardation, poor teaching, or cultural deprivation" (Swanson, 1994, p. 192). Using a variety of memory measures, Swanson found that students with LD had particular difficulties in several areas of working memory compared to NA students. Further, he (1994) demonstrated that differences in verbal working memory were not as discrepant from NA students as were students considered to be slow learners, but were discrepant nonetheless. McLean and Hitch (1999) found that students with arithmetic difficulties were impaired on spatial working memory and executive processing.

Geary, Hoard, and Hamson (1999) investigated the digit-span scores of first graders and found that "average IQ children with low arithmetic achievement scores have difficulties retaining information in working memory while engaging in a counting task" (p. 235). Further, they demonstrated that students with MD/RD and students with RD committed higher numbers of retrieval errors than the students with RD alone. However, the authors acknowledged that this may not necessarily be due to a working memory deficit, but a deficit in attentional capacity.

Retrieval and reaction time can be linked to working memory as well. For example, Hayes, Hynd, and Wisenbaker (1986) found that students with LD had difficulty building facts into math fluency. Thus, compared to normally achieving peers, groups of students with LD had more difficulty in recalling basic facts and thus made more errors. In addition, these students were more variable when making those errors.

Geary, Brown, and Samaranayake (1991) found similar results in groups of first and second graders. When comparing NA students and students with MD, the NA students were not as likely to rely on counting procedures, a less than optimum strategy when building math fluency, and were more likely to rely on memory for recalling basic facts. Students with MD still relied on the counting procedures and not on memory. According to Geary et al. (1991), this poor working memory not only affects retrieval, it can lead to errors in procedure such as counting errors, which can lead to memorization of wrong facts (e.g., 7 + 6 = 12). All of these compounded can cause further difficulty for students struggling with math.

In studies designed to look at the effects of time on students with and without MD, Alster (1997) and Jordan and Mantani (1997) demonstrated that students with MD in grades 3 through 12 did better on tasks when their retrieval ability was not tested by time. Thus, both studies demonstrated that when doing algebraic and word problems, students with MD performed poorer than students without MD when time was involved, but were similar to students without MD when there was no time limit. Both studies inferred that short-term memory and semantic memory difficulties may be the reason that timed tests have an effect. Jordan and Mantani (1997) found that this is especially true for people with specific mathematics difficulties rather than general academic difficulties.

AD/HD and MD

When examining LD subtypes, some researchers include students with attention-deficit disorders in their analyses and discussion (Hurley, 1996; Marshall, Schafer, O'Donnell, Elliott, & Handwerk, 1999; Rourke, 1993). While 3% of children in the United States have LD, approximately 35% of children with AD/HD have learning difficulties (Woodrich, 2000). Mayes, Calhoun, and Crowell (2000) studied a sample of 8- to 16-year-olds with and without AD/HD. The group was set up to be as similar as possible to those referred to clinical settings. These researchers found that the proportion of LD among AD/HD students was significantly higher than for the sample of students without AD/HD. Mathematics had the second highest comorbidity, with approximately 33% of the students with AD/HD also having MD diagnoses.

Research is sometimes conducted with students with AD/HD to compare their profiles to those of students with LD; at other times, studies address the comorbidity of these two disorders. Riccio, Gonzalez, and Hynd (1994) suggested that the comorbidity of AD/HD and LD is so high that the two may be indistinguishable. Attention-related concerns affect achievement and must be explored when analyzing students struggling in math.

Postsecondary Intervention

Thus far, this literature review has focused on common difficulties among students with MD in order to aid practitioners in identifying students with MD as well as begin to focus on remediation. Again, empirical evidence for effective interventions for postsecondary students struggling with mathematics is, at best, scarce, with much of the intervention literature focusing on elementary and secondary education. Thus, Strawser and Miller (2001) noted that "the literature is silent" on the utility of generalizing to other populations those intervention techniques that have been empirically demonstrated to be successful with elementary and secondary students.

Current Study

The following analysis explored the characteristics of college students with mathematics difficulties who were subsequently identified as having mathematics disabilities. Because lower-than-average abilities on measures of mathematics achievement were expected among this population, mathematics achievement scores were not explored in depth.

The importance of this study lies in its ability to add supporting or refuting evidence of the presence of previously identified sources of individual differences in students with MD by analyzing similar assessment measures and examining the results to determine if the difficulties that exist in younger populations also exist at the postsecondary level. A preliminary discussion on remediation techniques based upon the results is also included.

METHOD

Participants

Participants consisted of undergraduate students attending a public research university in the midwest with a student body representative of the general midwestern population. All participants reported experiencing significant difficulties when attempting to complete the mathematics course requirements for their degree. Participants were full-time students who, at the time of the evaluation, needed to earn course credit in at least one college-level mathematics course to fulfill their degree requirements.

Potential participants were referred by their academic advisors or instructors, or were self-referred through "word of mouth." To qualify as a research participant, each student underwent and passed an initial screening interview conducted by the researchers to document (a) the student's need for additional course credit in a college-level mathematics course, and (b) significant evidence of current and previous mathematics difficulty, such as low grades in high school mathematics courses, low ACT mathematics scores, and/or significant self-reported difficulties in understanding mathematics-related concepts compared to concepts in other subject areas. Students who successfully completed the screening process were asked to volunteer as participants; those who agreed were administered the psychoeducational assessment battery.

In all, 205 students completed at least some of the psychoeducational battery. A total of 129 participants were removed because their diagnostic categories did not match the identified groups used in this study – MD and no diagnosis (ND) – or because they did not complete significant portions of the evaluation. This left 76 participants for the analysis.

Overall, 34 participants were identified as MD and 42 as ND. The database included MD participants ranging from 18 to 23 years of age, with a mean age of 20.6 years, and ND participants ranging from 18 to 43 years of age, with a mean age of 22.9 years. The mean attained ACT composite score for MD was 21.6 and 21.7 for ND, with ranges of 14 (scores from 15 to 29) and 12 (scores from 16 to 28), respectively. The database consisted of 53 females (27 ND; 26 MD) and 23 males (15 ND; 8 MD), who identified themselves as Caucasian, 68 (36 ND; 32 MD), African-American, 7 (5 ND; 2 MD), and Hispanic, 1 (1 ND; 0 MD). Table 1 shows participant characteristics.

Instrumentation

To investigate and describe the characteristics of college students with math difficulties, the researchers administered a complete psychoeducational evaluation battery to each of the participants: structured interview, the Wechsler Adult Intelligence Scale-Third Edition (WAIS-III) (Wechsler, 1997a), the Wechsler Memory Scale-Third Edition (WMS-III) (Wechsler, 1997b), the Woodcock-Johnson-III Tests of Achievement (WJ-III) (Woodcock, McGrew & Mather, 2001), and the Conners Adult ADHD Rating Scale (CAARS) (Conners, Erhardt, & Sparrow, 1998).

WAIS-III. The WAIS-III is an appropriate tool for measuring general levels of cognitive functioning for individuals aged 16 to 89. A complete administration of the WAIS-III yields three composite IQ scores (Full Scale, Verbal, and Performance) and four index scores (Verbal Comprehension, Perceptual Organization, Working Memory, and Processing Speed). The WAIS-III consists of 14 subtests, 7 each in the Verbal and Performance scales (Wechsler, 1997a).

WMS III. The WMS-III is an individually administered test of verbal and nonverbal memory for adolescents and adults aged 16 to 89. It is useful in educational settings to (a) assess the degree to which an individual's memory functioning impacts academic performance, (b) assist in developing individualized education programs, or (c) recommend external strategies or memory training to assist those with learning disorders. The test consists of 11 subtests, 6 primary subtests, and 5 optional subtests (Wechsler, 1997b).

WJ-III. The WJ-III is an individually administered, norm-referenced test of academic achievement that can be administered to individuals from age 2 to over 90. When combined with other pertinent information, the

Table 1
Sample Characteristics—Mathematics Disabilities (MD) vs. No Diagnosis (ND)

	Mathematics Disability	No Diagnosis
Numbers:		
Male	8	15
Female	26	27
Total	34	42
Age:		
Mean	20.6	22.9
Range	18-23	18-43
Race/Ethnicity:		
Caucasian	32	36
African-American	2	5
Hispanic	0	1
Total	34	42
Overall Academic Achievement[a]:		
Mean	21.6	21.7
SD	3.3	3.1
Range	15-29	16-28

[a]ACT scores.

results of the WJ-III aid in developing educational programming and appropriate services for reading, writing, oral language, or math skills. The test consists of 12 subtests within the Standard Battery, yielding composite standard scores in Broad Reading, Broad Mathematics, Broad Written Language, and Oral Language Cluster (Mather & Woodcock, 2001).

CAARS. The CAARS is a self-report rating scale that provides a quantitative measure of ADHD symptoms for adults over the age of 18. The CAARS consists of 66 items presented in a 4-point Likert-style format that contribute to nine empirically derived scales. The CAARS includes four factor-derived subscales: Inattention/ Memory Problems, Hyperactivity/Restlessness, Impulsivity/Emotional Lability, and Problems with Self-Concept. Additionally, three ADHD symptom subscales are generated, including Inattentive Symptoms, Total ADHD Symptoms, and Hyperactive-Impulsive Symptoms. The CAARS may be utilized to help identify, assess, and treat adults with ADHD-related symptoms and behaviors (Conners et al., 1998).

From this battery of tests, six individual variables were selected to analyze differences between students with MD and ND. These variables, representing the sources of individual differences identified by previous research, were as follows: (a) the WMS-III Working Memory Index score (WM), (b) the WJ-III Math Fluency (MF) subtest score, (c) the WJ-III Passage Comprehension (PC) subtest score, (d) the WAIS-III Performance Intelligence Quotient (PIQ), (e) the WAIS-III Verbal Intelligence score (VIQ) minus the PIQ score, and (f) the CAARS DSM-IV Total Symptoms Index score (DSM-IV TSI).

Procedure

To test the significance of observed differences in the mean scores of the two groups on each of the six variables that represent sources of individual differences, a multiple analysis of variance (MANOVA) was used. MANOVA is an extension of the ANOVA method to cover cases where there is more than one dependent variable.

Conducting the MANOVA reduced the chances of a Type I statistical error. Assumptions of MANOVA must be met before analysis was completed; namely (a) independence of observations, (b) multivariate normality, and (c) a check of covariance among the variables. First, independence of observations was assumed for the data. Due to the difficulty of checking for multivariate normality in SPSS (Stevens, 1999), the variables were tested for univariate normality. The assumption of univariate normality was met for each of the variables; thus, the second assumption was met. Because Box's test is affected by non-normality, it can be a good indicator of violations of multivariate data. Also, it helps to determine any covariance among the three variables, and is the third assumption of MANOVA. Box's test determined covariance among the variables and was not significant. Thus, the third assumption was also met (Stevens, 1999).

With Type I statistical error ruled out, a one-way analysis of variance (ANOVA) was used to test the significance of observed differences in the mean scores between the two groups on each of the six variables that represent sources of individual differences. ANOVA is a statistical analysis that utilizes one categorical independent variable (diagnostic group) and one continuous variable (source of individual difference).

RESULTS

The results of the MANOVA indicated significant differences among the variables. Thus, all four of the statistics produced by SPSS were significant. The Pillai's Trace, Wilk's Lambda, Hotelling's Trace, and Roy's Largest Roots all had the same statistical value, significance level, p value, effect size, and power. The statistic was $F(6, 69) = 8.499$, $p < .000$, with an effect size of .425, indicated by a partial eta squared and a power of 1.000.

Separate ANOVAs were run to determine which of the variables were significantly different between the two groups. Results showed that the PIQ, WM, MF, and PC were all significantly different when comparing students with MD and ND. Results of the ANOVA for PIQ indicated an $F(1, 74) = 6.960$, $p < .01$, with an effect size, indicated by a partial eta squared, of .086 and a power indicated at .740. Results of the ANOVA for WM indicated an $F(1, 74) = 16.050$, $p < .000$, with an effect size, indicated by a partial eta squared, of .178 and a power of .977. Results of the ANOVA for PC indicated an $F(1, 74) = 3.991$, $p < .049$, with an effect size, indicated by a partial eta squared, of .051 and a power of .505. Results of the ANOVA for MF indicated an $F(1, 74) = 33.939$, $p < .000$, with an effect size, indicated by a partial eta squared, of .314 and a power of 1.000. The

Table 2
Descriptive Statistics—Mathematics Disabilities (MD) vs. No Diagnosis (ND)

	Mathematics Disability[a]		No Diagnosis[b]	
Instrument	**Mean**	***SD***	**Mean**	***SD***
PIQ[c]**	98.59	12.82	106.02	11.71
VIQPIQDF	9.59	12.52	4.17	11.70
WJPASCOM[c]*	101.29	11.77	106.14	9.40
WJMTHFLU[c]***	82.94	8.41	97.10	11.97
WMSWM[c]***	92.65	11.75	101.74	7.97
DSMIVADHD[d]	50.97	15.88	50.45	8.88

[a] n=42.
[b] n=34.
[c] Normative sample mean = 100; SD = 15.
[d] Normative sample mean = 50; SD = 10.
*p <.05. **p < .01. ***p < .000.

results for the other two variables (VIQ/PIQ difference and ADHD Total Symptoms) were not significant. Table 2 shows the mean and standard deviations for students with MD and ND on each of the variables analyzed.

DISCUSSION

The results of this study suggest that students with mathematics disabilities at the college level tend to mirror research findings for students identified with mathematics disabilities at the elementary and secondary levels.

Among the similarities, college students identified with mathematics disabilities demonstrate significant weaknesses in reading comprehension, nonverbal reasoning, working memory, and math fluency. Interestingly, attention difficulties, which have been identified as a source of individual differences in elementary and secondary students, were found not to be a significant distinguishing factor between students with MD and ND in this study.

Reading Comprehension

The results support previous findings that students with MD have difficulty with reading comprehension (Fleischner & Manheimer, 1997; Jordan & Hanich, 2000). For example, on the WJ-III Passage Comprehension score, students with MD scored lower than students with ND, indicating that they had more difficulty understanding contextual clues relating to reading comprehension.

Nonverbal Reasoning

Rourke (1993), Rourke and Fuerst (1996), and Rourke and Del Dotto (1994) discussed nonverbal/visual-spatial discrepancies among students with MD. Our results indicate that when compared to students with ND, the students with MD had significantly lower WAIS-III PIQ subtest scores; however, the VIQPIQDF scores were not significantly different. This provides some supporting evidence to findings of visual-spatial deficits and nonverbal difficulties for students with MD at the college level.

Working Memory and Math Fluency

Previous researchers have concluded that memory, especially working memory, is a deficit area for students with MD (Geary, 1993; Geary et al., 1991; McLean & Hitch, 1999; Swanson, 1993, 1994). In the current study the WMS-III measure demonstrated that college students diagnosed with mathematics disorders had difficulty with working memory above and beyond that of students who struggle with mathematics who are not diagnosed.

Math fluency scores based upon the WJ-III Math Fluency subtest score were, on average, one standard deviation lower for students with MD than for students with ND. In fact, on average, their score nearly fell in the low instead of low-average range. This is consistent with past findings showing math fluency to be problematic (Geary 1993; Geary et al., 1991; Hayes et al., 1986; Jordan & Mantani, 1997).

While math fluency may be closely related to working memory capacity, it may also be affected by other variables. Students with higher levels of math fluency (or automaticity with math facts) are more likely to utilize their finite working memory capacity for other calculation processes, or "chunking" more relevant content at one time. However, the level of math fluency can also be negatively impacted by inattention, depression, and high or low degrees of anxiety, as well as other factors that are not directly related to working memory.

AD/HD

The results of the AD/HD measure did not distinguish the two groups. Thus, our results with a college student population do not support Riccio and colleagues' (1994) assertion that the comorbidity of AD/HD and LD is so high that the two may be indistinguishable. However, this does not preclude the likelihood that attention-related symptoms are important factors that need to be addressed. We strongly advocate that further research be conducted to examine the effect of AD/HD symptoms on students with mathematics disabilities and students in general at the college level.

Intervention

We now turn to remediation and/or accommodation. While not meant to be comprehensive, this discussion is intended to spark further research into effective remediation and intervention strategies suitable for college students with mathematics difficulties.

Based upon our results, it appears there are factors other than IQ-achievement discrepancies that affect classroom performance. When faced with trying to meet the needs of students with LD in mathematics, universities have traditionally emphasized academic supports, such as classroom accommodations (e.g., extended time to complete examinations) and increased access to tutoring and individualized assistance. While these supports are aimed at increasing the performance of students with documented disabilities, they do little to address the wider variety of differing abilities of students who do not have documented disabilities but experience significant difficulty when performing math tasks.

One emerging trend in providing support for all learners, regardless of disability status, is to implement classroom presentation methods that engender concepts aligned with the universal design for learning (UDL), as advocated by Rose, Meyer, Strangman, and Rappolt (2002). The three principles of the UDL framework promote classroom instruction that provides for (a) multiple, flexible methods of content presentation; (b) multiple, flexible methods of content expression; and (c) multiple, flexible options for individual engagement in the material being presented. Within the UDL perspective, existing curriculum materials can be presented with the necessary flexibility to support the diverse learning needs of a variety of students. UDL instructional concepts intentionally provide multimodal learning support for all students in a classroom, allowing each student to assimilate new content in ways that are most efficacious for the individual learner, as opposed to a traditional, single instructional method.

Students with MD not only need remediation with specific mathematics techniques, they also need remediation techniques specifically designed to address deficits in reading comprehension, nonverbal/visual skills, working memory, and math fluency. Levine (1999) identified academic strategies that can be used to provide learning support for these deficits. With regard to math fluency deficits, Levine suggested that students utilize flashcards to develop automaticity for basic arithmetic and more advanced algebraic concepts, calculations, and manipulations. Mathematics-related computer software will help hold a student's attention while rehearsing common calculations. Finally, students may choose to rehearse, or automatize, common calculation methods and multiple-step processes within an overall solution.

For working memory deficits, Levine (1999) advocated that students concentrate on performing one task or subtask at a time, develop definite and consistent stepwise approaches to problem solving as opposed to tackling the entire problem at once, use self-monitoring techniques (talking their way through a problem) to aid in problem solution, and practice extended arithmetic problems in their head (such as 23 x 22, or 4 x 7 x 3) to develop working memory capacity. Students may also find it beneficial to summarize complex instructions or solution processes before attempting the solution.

For nonverbal reasoning deficits, Levine (1999) recommended the use of graph paper to aid in the spatial placement of numbers and as well as the use of manipulatives or concrete applications of the math concept as an example of the problem to be solved. Instructional techniques should incorporate a highly verbal approach of explaining mathematical or geometric concepts rather than relying solely on algebraic notations and graphical plots.

Finally, for reading comprehension deficits, Levine (1999) suggested that students incorporate visual models to accompany written explanations. Students should also develop an individualized mathematics glossary of terms and concepts used in class so they can be reminded of these definitions as they complete homework assignments. Math-related computer software can increase mathematical conceptual understanding, and the development of good estimating skills can serve as a self-check mechanism. Further, Levine suggested that instruction, including ways to translate specific words into numerical symbols or processes, would support a student's mastery of word problems.

Implications for Practice

For practitioners working with students with MD, two important pieces of information are gained from this research. First, once students have been identified as having MD, it is important to focus on each individual to determine his or her specific strengths and weaknesses. Although we present common characteristics for the sake of simplicity, it is important to recognize that students with MD are a heterogeneous group of individuals with different weaknesses that contribute to their difficulties in math (Fleischner & Manheimer, 1997; Parmar & Cawley, 1997; Strawser & Miller, 2001). Information gained from this study can aid in creating initial hypotheses to gain insight into the strengths and weaknesses of individual students. Specific remediation techniques must subsequently be explored.

Second, it is important to recognize the need for techniques that not only focus on intervention of specific mathematics weaknesses, but also on intervention in areas where students have other identified weaknesses. For example, students struggling with mathematics who are identified as having working memory deficits should receive instruction in mathematics geared toward the difficulty in math together with the working memory deficit to attempt to maximize their ability to gain information. Such interventions must be studied and examined empirically to identify their utility. Further research needs to address the effects of specific strategies and techniques already identified as useful interventions at elementary and secondary levels to determine their usefulness at the postsecondary level.

Limitations

It is important to note that the students who made up the two groups in this study all presented with mathematics difficulties. Thus, a major limitation in understanding students with MD is that there is no purely random comparison group, and the design is not truly experimental. Future research is needed to compare these findings with a normative group, which would allow for the data to be treated as a true experimental design.

Another limitation is the presence of comorbidity in the sample. For the purposes of this study, students with mathematics difficulty were included and the difference between the diagnoses of MD and ND was the focus.

However, in 14 cases comorbidity was an issue. Future research is needed to focus on students with MD alone compared with students with MD and other disorders.

CONCLUSIONS

With the growing demand for mathematics competency, it is becoming increasingly important to understand what differentiates postsecondary students with mathematics disorders/difficulties from their peers. Past researchers have focused on identification and remediation of students with MD in elementary and secondary grades. This article examined information from these studies to determine if the same weaknesses exist in a sample of college students identified as MD. This article is the beginning of what we hope will become an extensive body of research on individuals with LD in mathematics at the college level. Future research must not only focus on what weaknesses these students have, but also on determining which remediation techniques are useful.

Overall, these analyses demonstrated that working memory, math fluency, reading comprehension, and visual/spatial/nonverbal ability weaknesses are significant contributors to difficulties for college students with mathematics disabilities compared to students who are struggling in math but are not diagnosed. Academic supports for these deficits must not only address specific mathematics difficulty areas but also the individual underlying difficulties that exacerbate poor math performance. For example, if a student has a relative and/or normative weakness in working memory and is struggling with mathematics, it is not enough to focus on helping the student learn the importance of a certain mathematical skill or concept. Instructors must also support the working memory deficit that is a contributing factor to the mathematics difficulty. By supporting both the math difficulty and the underlying processing deficits that exacerbate poor math performance, instructors and tutors will significantly increase students' ability to assimilate and utilize the mathematics concepts and skills needed to meet college-level mathematics requirements.

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