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Arithmetic Disabilities: Training in Attention and Memory Enhances Arithmetic Ability

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Abstract: The purpose of the present study was first to determine the prevalence of arithmetic disabilities in elementary school and then to compare the efficacy of a combination of content based remediation along with neuropsychological training in enhancing the arithmetic ability of children diagnosed with arithmetic disability. Using a standardized battery of arithmetic tests, 44 children (3.76%) were identified as having arithmetic disorder from among 1171 boys and girls enrolled in grades 2 through 5 at schools. Prevalence rates for boys and girls were similar except among 4th graders where more girls were identified as having arithmetic disabilities. To compare the content based remediation method with a method combining content based remediation and neuropsychological training, the sample was divided into 2 matched groups: Group 1 received a combination of content based remediation along with neuropsychological training and group 2, received content based remediation alone. At the end of the interventional phase, children of both groups were administered a parallel form of the arithmetic battery administered at the beginning of the study. Findings obtained from the study demonstrated that the 2 groups differed significantly, with the children exposed to a combination of content-based remediation and neuropsychological training faring better. However, a comparison of children within grades revealed that the content-based approach failed to be effective in the higher grades. It can be concluded that supplementing content based intervention with training in attention and memory can help improve the mathematical ability of children with arithmetic disabilities.

Key words: Neuropsychological methods, content-based instruction, dyscalculia

INTRODUCTION

Arithmetic involves recognizing numbers and symbols, memorizing facts such as the multiplication table, aligning numbers and understanding abstract concepts like place value and fractions. Any of these may be difficult for children with developmental arithmetic disorders, or dyscalculia as it is sometimes called. Children who present with difficulty in learning arithmetic and who fail to achieve adequate proficiency in this cognitive domain, despite normal intelligence, scholastic opportunity, emotional stability and necessary motivation have developmental dyscalculia. As different terms like mathematics disabilities, developmental arithmetic disorders, developmental dyscalculia or specific arithmetic disorders have been used interchangeably to refer to such children, in the present study, the term specific arithmetic or mathematics disabilities will be used.

Prevalence studies using different definitions of mathematics disabilities have been carried out in various countries. Badian (1983) found a prevalence of 6.4% in an American study, Kosc (1974) found a rate of 6.4% in Bratislava and English studies reported a prevalence rate of 3.6% (Lewis *et al*., 1994). German researchers found prevalence between 4.4% (Klauer, 1992) and 6.6% (Hein, 1999), Israeli researchers reported that 6.5% of children in their country had mathematical disabilities (Gross-Tsur *et al*., 1996), Von Aster *et al*. (1997) found prevalence to be 4.7% in Switzerland and Desoete *et al*. (2004) found a prevalence rate between 3 and 8% in Belgium. It has also been suggested that the prevalence of mathematical disabilities probably depends on the criteria used to define those disabilities (Dowker, 2004; Mazzocco and Myers, 2003). In spite of the lack of definitional consistency, the prevalence of mathematics disabilities across countries is relatively uniform, ranging from 3-8% in the normal population and girls and boys seem to be affected equally by mathematics disabilities (Shalev *et al*., 2000; Hein, 1999; Lewis *et al*., 1994) though some studies have found a slightly higher prevalence in girls (Gross-Tsur *et al*., 1996; Klauer, 1992; von Aster, 2000).

As per the Diagnostic and Statistical Manual-IV (DSM-IV) American Psychiatric Association the child must substantially underachieve on a standardized test of xsarithmetic relative to the level expected given age, education and intelligence and must experience disruption to academic achievement or daily living. The DSM-IV-TR criteria for a mathematical disorder are that failure to achieve is not due to deficits in intelligence, sensory function, educational opportunity or emotional disturbance.

Research on students with mathematics disabilities has identified several reasons why some children struggle with arithmetic. Gross-Tsur *et al*. (1996) found high comorbidity of AD/HD and arithmetic disabilities, which indicates the likelihood that attention-related symptoms are important factors that need to be addressed in children with mathematics disability.

Rourke (1993), Rourke and Fuerst (1995) and Rourke and Del Dotto (1992) discussed nonverbal/ visual-spatial discrepancies among children with arithmetic disability. According to Silver *et al*. (1999), visuo-spatial deficits may be the core deficit for students with isolated mathematics disabilities. In a literature review, Jordan *et al*. (1995) found 3 subtypes of mathematics disabilities, including one identified as having visuo-spatial deficits. Geary (1993) examined visuo-spatial deficits as one of 3 core difficulties (along with semantic memory and procedural deficiencies) experienced by students with calculation difficulties.

Geary *et al*. (1991) found students with mathematics disability rely on counting procedures, a less than optimum strategy when building math fluency. 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. Geary (1993) argued that semantic memory deficits and procedural deficits could be related to an underlying memory deficit. Students with semantic memory continue to mentally calculate the answers rather than obtain them through direct retrieval from long term memory. Students with procedural deficits are more likely to use inappropriate developmental procedures because they appear to struggle with remembering the appropriate ways to complete certain problems.

McLean and Hitch (1999) found that students with arithmetic difficulties were impaired on spatial working memory and executive processing. Keeler *et al*. (2001) investigated the relationship between Working Memory (WM) and math achievement in children with and without math disabilities. Keeler *et al*. (2001) concluded from the results of their study that since one of the main functions of working memory is retrieval of stored long-term knowledge, storage rather than processing efficiency may account for the poor WM performance of children with MD and consequently, one way to improve math achievement is to understand the factors that relate to working memory deficits and to develop methods of improving students' awareness of effective strategies (Keeler *et al*., 2001).

Geary *et al*. (1999) found that children with low arithmetic achievement scores have difficulties retaining information in working memory while engaging in a counting task, but acknowledged that this may be due to a deficit in attentional capacity rather than a working memory deficit.

Von Aster (1997) and Jordan and Montani (1997) demonstrated that students with specific mathematics difficulties in grades 3 through 12 did better on tasks when their retrieval ability was not tested by time. Both studies inferred that short-term memory and semantic memory difficulties may be the reason that timed tests have an effect.

Some research evidence indicates that children with learning disabilities are not necessarily strategy deficient, but that the strategies they use are inefficient or inflexible (Torgesen and Houck, 1980). Bull and Scerif (2001) have proposed that the particular difficulties that children with arithmetic disability encounter are lack of inhibition and poor working memory, which result in problems with switching and evaluation of new strategies for dealing with a particular task. They have found that executive function measures predict mathematics ability. Others have pointed out that students may benefit less from intensive drill and practice more from help searching for, finding and using patterns in learning the basic number combinations and arithmetic strategies (Baroody, 1996).

Significant instructional strategies for children with mathematics learning difficulties have been developed in recent years. These strategies include explicit direct instruction, relevant practice, peer-mediated instruction and alternative algorithms that foster mathematical understanding and evaluative thinking. Constructivist activities that support active student learning around problem-solving situations can be facilitated by the teacher's guidance and questioning. Social settings and classroom communities are now recognized as important factors in helping to develop mathematical cognitions (Rivera, 1998).

Studies regarding the efficacy of remediation methods in arithmetic disability have focused on the Direct Instruction method based on principles suggested by Engelmann and Carnine (1991). In a large follow through study the performance of children in over 20 different instructional models which represented the broad range of current educational practice. The evaluation of Project Follow Through (Watkins, 1988) revealed that the Direct Instruction model was clearly the most effective of all programs on measures of basic skills achievement, cognitive skills and self-concept. Results from other studies have indicated that Direct Instruction students are more likely to receive high school diplomas, less likely to be retained in any grade and less likely to drop out and acquire superior problem solving abilities (Carnine and Gersten, 1982; Gersten, 1985; Gerstenet al., 1987; Gersten and Keating, 1987).

While evidence demonstrates the effectiveness of direct content-based instruction in teaching skills and knowledge, from the literature review of difficulties manifested by children with arithmetic disability, it can be inferred that students with mathematics disability not only need remediation with specific mathematics techniques, but they also need remediation techniques specifically designed to address deficits in, nonverbal/visual skills, working memory and math fluency. Remediation strategies that aim to modify attention and working memory, for example, will improve children's ability to grasp new concepts and reduce errors such as number omission and transfer of wrong numbers. It appears that the strengths of these methods might complement those of direct instruction. To tailor a relevant instructional program, it is necessary to focus on the problems of students with mathematics learning disabilities by addressing the attentional and memory deficits of these children.

One particular area in need of more research is the place of remediating cognitive deficits in math-based learning disabilities. No test is currently available for a combined assessment of the efficacy of content based direct instruction and cognitive remediation. This study was designed to determine the validity and utility of cognitive training. Specifically, the purpose of the study was to determine whether a combined interventional procedure of content-based instruction and training in attention and memory is better than an approach based exclusively on content in improving the performance of children with arithmetic disabilities.

MATERIALS AND METHODS

The aim of the first phase of the study was to determine the prevalence of arithmetic disorders in elementary school children. To this end, a sample of 1171 7-10 year old school children, attending grades 2-5 in elementary schools, was selected using a stratified cluster sampling procedure and the standardized arithmetic test battery was administered. A child was classified as having specific arithmetic difficulties if his or her intelligence quotient was equal to or greater than 90 and when the score achieved on the standardized arithmetic test was equal to or less than 2 standard deviations below the mean score for normal children of the same chronological age. In accordance with these criteria, a total of 46 children who scored below 2 SD were selected and Raven's Progressive Matrices was administered. Two students were excluded from the study on account of having borderline IQ scores. Of the remaining 44 children (28 boys and 16 girls) identified as having specific mathematics learning disabilities were matched on their pretest scores and assigned to experimental or control conditions, with 14 boys and 8 girls in each condition. None of the children had emotional or behavioral difficulties.

The aim of the second phase was to compare the effectiveness of content based remediation plus cognitive training with that of content based remediation alone. Therefore, the sample was divided into 2 groups: Group 1 (that received a combination of content based remediation plus cognitive training) and group 2 (that received only content based remediation). In the initial phase of the study, group 1 received 15 sessions (260 min sessions per week) of individualized practice in neuropsychological tasks. In order to control for possible effects of therapist attention, simultaneously, group 2 received an equal number of individualized sessions of handwriting practice (260 min sessions per week). In the next phase of the study, children of both groups received 15 sessions (260 min sessions per week) of direct content based instruction. Finally, a parallel form of the test used at the start of the study was administered to the whole sample.

Measures

A standardized arithmetic battery: An age-standardized test of arithmetic skills based on the neuro-cognitive model of arithmetic suggested by McCloskey *et al.* (1985) and developed by Shalev *et al.* (1993) was used. This test comprises 3 sections: Section 1 tests number comprehension and consists of 8 subtests of counting, understanding concepts of greater than and less than, matching, number reading, writing numbers in words and digits, comparing numbers, using arithmetic signs and arranging numbers. Section 2 concerns number production and consists of subtests of addition, subtraction, simple one-digit multiplication and division. Section 3 concerns number processing and includes subtests of addition, subtraction, multiplication and division with multiple digits. The test is a reference group test with a total possible score of 100.

On a study sample of 703 children, a reliability coefficient of 0.92 was obtained for the Standardized Arithmetic Test (Shalev *et al.*, 1993). In the present study a Cronbach α of 0.95 was obtained. Two parallel forms of the test were used as pre and post tests in this study.

Neuropsychological methods

Trail making: The Trail Making Test (TMT) is primarily a test of motor speed and visual attention and consists of 2 parts A and B. In the present study, only Part A was used as Part B is a more difficult cognitive task owing to its increased demands in motor speed and visual search. An equivalent of Trail Making Test Part A for native Iranians was used. Part A requires the subject to draw lines connecting consecutively numbered circles on a worksheet. To provide for sufficient practice, Trail Making part A was administered in 3 forms with numbers 1-20, 1-25 and 1-30. The score derived for each trail was the number of seconds required to complete the task. Reliability of scores for each individual trail is reported to be high and the composite score has a reliability coefficient of 0.90 or higher at all ages. In the present study the test was found to be internally consistent, with the value of Cronbach's coefficient (α) being 0.80.

The digit symbol test: The Digit Symbol test has been an integral part of the Wechsler intelligence scales since their inception. Although, a relatively weak predictor of IQ, Digit Symbol has received considerable research attention owing to its remarkable value as a neuropsychological screening test, yet the cognitive operations required for successful performance of the test remain poorly understood. Symbols are matched with numbers or shapes according to a key. The test measures visual-motor speed and short-term visual memory. The reliability of the test is reported to range from 0.73-0.82. In the present study, the internal consistency of the test using Cronbach's alpha was 0.91.

Memory tasks

Visual memory tasks: The visual memory task, constructed by Rosmer (1985), consists of a 3×4 grid with simple geometric shapes (triangle and circle) drawn in different parts of the grid. The difficulty level increases with the addition of the number of shapes to be remembered. The test was administered in 3 levels of difficulty, with the lowest difficulty level having 4 shapes, the next level 5 and the third level 6. The geometric figures are placed in different parts of the grid and the subject is required to recall and reproduce the shape and its location as accurately and as quickly a possible in a blank grid. In several studies the reliability of this task has been reported to be over 0.96 (Siegel and Ryan, 1989). In the present study a Cronbach α of 0.72 was obtained.

Verbal memory task: The verbal memory task was constructed by Hulme and Roodenrys (1995) and includes 5 lists of words (each with 5, 6, 7, 8, or 9 words) to be recalled. Each of the words is read out loud to the subject. Practice begins with the 5 word list and when the subject is able to recall the 5 words correctly and in the right order, the next list is administered. Each new list is administered in a new session in order to prevent interference from the previous list. As the level of difficulty increases, the length of time required to complete each subtest also increases. Most studies have reported reliability coefficients for the verbal memory test to be 0.94 and in the present study the Cronbach α coefficient for this task was found to be of 0.72.

Handwriting practice: As the group of children exposed to the combination of content-based remediation and neuropsychological training would be receiving more therapeutic attention, to control for the effects of therapist attention, the children exposed to content-based remediation alone were given additional compensatory therapist attention through providing sessions in which they engaged in handwriting practice.

Content based remediation: Content-based remediation includes 3 parts: number comprehension, classification, grouping, sequencing and ordering, matching, meaning, concepts of less than, greater than, equal to, number production (counting, simple addition, subtraction, multiplication and division), number processing (vertical calculation by adding and subtracting, multistage processing with multiplication and division). These 3 parts were administered systematically in a hierarchy beginning from elementary levels and proceeding to more advanced levels.

RESULTS

Table 1 shows the mean and standard deviations along with the cut off scores (2SD below the mean) for each of the grades. Findings reveal that the mean scores of children in grades 2-5 on the standardized arithmetic test were 24.56 (S.D. = 8.53), 47.54 (S.D. = 11.97), 60.20 (S.D. = 15.03) and 68.51 (17.65), respectively. Accordingly, the criterion cut off scores to identify children with arithmetic disabilities were 7.5, 23.47, 30.75, 34.68 for grades 2-5, respectively. Using the specific cut off scores for each grade, 8 children from grade 2 (2 girls, 6 boys), 12 children from grade 3 (4 girls, 8 boys), 12 children from grade 4 (2 girls, 10 boys) and 12 children from grade 5 (8 girls, 4 boys) were emerged as low scorers. Taking children's IQ into account, a total of 44 children (16 girls and 28 boys) were identified as children with specific arithmetic disabilities (SAD), indicating an overall prevalence rate of SAD 3.76%. Prevalence rates of SAD for each of the sexes and grades are displayed in Table 2. As can be seen prevalence rates of SAD are 2.77, 4.14, 3.65 and 4.17 in grades 2-5, respectively. Gender differences are noted in the prevalence of SAD, with the rate being higher among boys. Gender differences within each grade were also examined and significant differences were noted only in grade 4 where boys had more arithmetic problems (Table 3 and 4).

Comparison of pre-test arithmetic scores and IQ scores of the experimental and control groups revealed no significant overall or within grade differences (Table 5-8) denoting that the 2 groups were comparable at the start of the experiment.

Table 1: Mean and standard deviations on the standardized arithmetic test

Grades	n	Mean	S.D.	Cut off score
2	289	24.56	8.53	7.5
3	290	47.54	11.97	23.47
4	304	60.20	15.03	30.75
5	288	68.51	17.65	34.68

Table 2: Number of children with specific arithmetic disorder and prevalence

		Grades				
Group		2	3	4	5	Total
Girls	n (%)	8 (5.06)	2 (1.38)	4 (2.55)	2 (1.54)	16 (2.71)
Boys	n (%)	4 (3.08)	10 (6.29)	8 (6.01)	6 (2.01)	28 (4.82)
Total	n (%)	12 (4.17)	12 (3.65)	12 (4.14)	8 (3.77)	44 (3.76)

Table 3: Comparison of prevalence rates of specific arithmetic disorders in boys and girls

	N	No. of SAD	(%)	Z
Girls	590	16	0.027	2.19*
Boys	581	28	0.048	

* denotes significance at 0.05 level

Table 4: Comparison of prevalence rates of specific arithmetic disorders in boys and girls in different grades

Grades	Groups	Girls	(%)	Boys	(%)	z
2	SAD	2	0.01	6	0.03	0.30
	Normal	130		159		
3	SAD	4	0.02	8	0.05	1.43
	Normal	157		133		
4	SAD	2	0.01	10	0.06	2.28*
	Normal	145		159		
5	SAD	8	0.05	4	0.03	-0.85
	Normal	158		130		

* denotes significance at 0.05 level

Table 5: Comparison of pre test scores in the experimental and control groups

Group	N	Mean	S.D.	df	t	p-value
Experimental	16	17.34	7.04	31	-0.25	0.79
Control	17	18.08	9.30			

Table 6: Comparison of pre test scores in the experimental and control groups by grade

Grade	Group	Mean	S.D.	df	t	Sig.
2	Experimental	6.75	0.5	7	-0.19	0.55
	Control	7	2.52			
3	Experimental	19.60	2.88	8	0.11	0.91
	Control	19.40	2.63			
4	Experimental	23.12	4.09	6	-0.69	0.51
	Control	25.25	4.55			
5	Experimental	20	3.90	4	-0.64	0.55
	Control	24	12.34			

A comparison of total pre-and post-test scores of the experimental and control groups revealed that in both groups, the arithmetic scores of subjects had significantly increased. That is, increases in the mean scores of both the groups reveal that both the neuropsychological with content-based and content-based only interventional programs were effective (Table 9 and 10). However, closer examination of pre-and post-test scores of the 2 groups reveals that children of all grades exposed to a combination of neuropsychological and content-based intervention showed significant increases in their arithmetic scores, while among those exposed to a content-based approach alone, only children from grades 2 and 3 showed significant increases in their post-test arithmetic scores (Table 10).

When the mean post-test scores of the 2 groups were compared, a significant difference was obtained, with the arithmetic scores of the experimental group being higher (Table 11), although within grade comparisons indicated a significant difference only between mean scores of the 2 groups in grade 3 (Table 12).

Table 7: Comparison of IQ score in the experimental and control groups

Group	n	Mean	S.D.	df	t	Sig.
Experimental	16	99.18	4.23	31	1.84	0.074
Control	17	96.05	5.39			

Table 8: Comparison of IQ score in the experimental and control groups by grade

Grade	Group	Mean	S.D.	df	t	Sig.
2	Experimental	97.75	0.5	7	0.49	0.63
	Control	96.40	5.4			
3	Experimental	101	3.39	8	1.75	0.11
	Control	94.80	7.12			
4	Experimental	98.50	7.23	6	0.17	0.87
	Control	97.75	4.92			
5	Experimental	99	4.35	4	0.95	0.39
	Control	95.33	5.03			

Table 9: Comparison of pre and post scores of the experimental group by grade

Grade	df	t	p-value
2	3	-20.33	0.000
3	4	-7.11	0.002
4	3	-6.45	0.008
5	2	-7.81	0.016
Total	15	-13.01	0.000

Table 10: Comparison of pre and post scores of the control group by grade

Grade	df	t	p-value
2	4	-6.67	0.003
3	4	-2.91	0.044
4	3	-2.96	0.059
5	2	-2.99	0.096
Total	16	-7.12	0.000

Table 11: Comparison of post test scores of the experimental and control groups

Group	n	Mean	S.D.	df	t	Sig.
Experimental	16	55.25	15.11	31	2.87**	0.007
Control	17	39.70	15.85			

Table 12: Comparison of post test scores in the experimental and control groups by grade

Grade	Group	Mean	S.D.	df	t	Sig.
2	Experimental	37.25	2.50	7	0.75	0.47
	Control	34.20	7.68			
3	Experimental	53.70	9.21	8	3.59	0.007
	Control	32	9.88			
4	Experimental	63.37	13.28	6	1.16	0.28
	Control	49.87	19.02			
5	Experimental	71	10.53	4	1.46	0.21
	Control	48	24.80			

DISCUSSION

The present study was conducted in 2 phases. The purpose of the initial phase was to estimate the prevalence of arithmetic disorders in elementary school children and in the next phase an attempt was to determine whether cognitive tasks could be used in an interventional approach to improve the performance of children with arithmetic difficulties. With this objective, the study assessed the efficacy of a combination of content based direct instruction and cognitive remediation.

Findings from the first phase indicated the overall prevalence rate of arithmetic disorders to be 3.76%. This is congruent with findings from previous studies conducted in England (Lewis *et al*., 1994), Switzerland, (Van Aster *et al*., 1997), Germany (Bzufka *et al*., 2000), Israel (Shalev *et al*., 2000) and Greece (Koumoula *et al*., 2004) where prevalence rates were reported to range between 3 and 6%. Furthermore, while the percentage of children with SAD fluctuated across grades 2-5, the prevalence rate is higher for boys in grades 2-4, while in grade 5 more girls were identified as having arithmetic disorder. Several studies (Lewis *et al*., 1994) have reported no sex difference in the prevalence of arithmetic disabilities, while others have reported that children with arithmetic disabilities are characterized by a slightly higher prevalence of females than males (Shalev *et al*., 2000). It is likely that the sex ratio also depends on the definition of arithmetic disabilities used in the study or probably prevalence rates by gender changes as children get older.

Results from the second phase indicate that although both methods of intervention are effective in improving the arithmetic performance of the children with arithmetic disorders in grades 2 and 3, in the higher grades content-based remediation alone failed to improve the arithmetic ability of the children. The combined content based and cognitive remediation was found to be superior to the direct content based instruction used alone, indicating the beneficial effect of training in attention and memory. This finding underscores the importance of cognitive deficits in the arithmetic disabilities and implies that the positive effects of tasks involving the strengthening of attention and memory may be age dependent. It might also be the case that, at different levels of skill acquisition, strategies to strengthen attention and memory become more or less important. Whether training in attention and memory requires a certain amount of mental maturity and/or whether training in attention and memory should be graded in order of increasing complexity needs to be investigated. Longitudinal studies would allow us to determine whether an early delay in neuropsychological functioning results in a developmental lag in learning skills, such as mathematics. What can be concluded from the obtained findings is that for some children with arithmetic disorders training in improving their attention and memory, which can be provided in sessions outside regular classroom teaching can be expected to enhance their ability to concentrate and recall arithmetic facts and concepts, thereby providing with skills to solve arithmetic problems better.

Previous researchers have concluded that memory, especially working memory, is a deficit area for students with mathematics disabilities (Geary, 1993; Geary *et al*., 1991, 2004; McLean and Hitch, 1999; Swanson, 1993). Other studies have pointed out that Mathematical problem solving involves several cognitive skills (Desoete and Roeyers, 2005) and students with mathematics disabilities are a heterogeneous group of individuals whose difficulties in math may be based on failure in one or more of these cognitive skills.

Combined with findings from the present study it can be hypothesized that graded training to improve attention and memory might be beneficial in remedying arithmetic disorder in a subset of children with mathematics disabilities. It is anticipated that specific remediation techniques that focus on intervention of not only specific mathematical weaknesses, but also on intervention of attention and memory deficits, if geared to the child's age, will maximize the child's ability to acquire, assimilate and utilize age congruent mathematics concepts and skills.

Further research is needed to investigate the saliency of a wider range of cognitive tasks in improving the ability of children with mathematics disabilities. However, given the significant time and related cost advantages provided by utilization of simple attention and memory tasks, it appears they would be of great potential benefit to practitioners and teacher as a supplement to content-based remedial methods.

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