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Predicting Spelling Scores from Math Scores in a Population of Elementary School Students with a Learning Disability

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by

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The relationship between mathematics and spelling skills was examined in elementary school children with a reading disability. Measures of working memory as a mediator were included. Results indicate a significant predictive relationship of mathematics on spelling. Moreover, measures of working memory were found to partially mediate this relationship.

INDEX WORDS: Spelling, Mathematics, Reading, Disability

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Predicting Spelling Scores from Math Scores in a Population of Elementary School Students with a Learning Disability

The definition of what constitutes a learning disability (LD), that is whether the disability is comprised of one or many factors, has been a major focus of research since the early 1950s. Some researchers have used reading as the litmus test for LD believing that students diagnosed with LD must show a significant deficit in at least one area of cognitive functioning related to reading performance (Silver, Pennett, Black, Fair, & Balise, 1999). Others have operationalized LD in more general terms viewing it as a disorder in one or more domains including: basic reading skills, listening, speaking, reading comprehension, written language, mathematics calculation, and mathematics reasoning (Lyon, 1994). This more general definition allows LD to encompass additional areas of dysfunction and suggests multi-directional influence among these areas. The purpose of the proposed study is to investigate the degree of influence between two possible sources of dysfunction in students with LD: basic mathematic computation (i.e., addition and subtraction) and spelling.

Development of reading skills

Reading has received most of the attention in the literature on LD and has provided much of the theoretical basis for research on spelling and arithmetic. A discussion of reading development, therefore, is fundamental to our understanding of the development of spelling and arithmetic. Vellutino, Scanlon, and Tanzman (1994) view reading as developing through the interaction between word identification and spoken language comprehension. In the early stages of reading, word identification plays a larger role in reading development and provides a basis for the development of reading comprehension. Word identification, as conceptualized by Vellutino and colleagues, encompasses three distinct strategies. One strategy is to attach meaning to a whole word and to use that meaning to extract the word name from memory. A second strategy is to attach a name to the word and use the name to extract the meaning of the word from memory. The third strategy states that the child uses the word's letters and associated sounds to retrieve both its name and meaning from memory (Vellutino et al., 1994). Building on these conceptualizations, Vellutino et al. studied a sample of good and poor readers from two age ranges: grades 2^{nd} - 3^{rd} and 6^{th} - 7^{th}. Word identification was found to be the central component of reading for both groups, such that poor word identification skills inhibited the development of reading comprehension. Hierarchical regression was used to demonstrate that much of the variance in word identification was explained by a child's facility with letters and sounds, i.e., their phonological awareness. In addition, however, measures of spelling also accounted for a significant portion of the variance. Wagner, Torgeson, Laughon, Simmons and Rashotte (1993), utilizing a sample of both readers and pre-readers, found that phonological processing skills remain relatively stable in much the same way other cognitive skills do. This is in opposition to the idea that phonological processing is a malleable construct influenced by a child's reading experience and instruction. They argued that this stability provides a coherent basis for the development of reading skill. Together these studies suggest that reading, phonological awareness, and spelling are closely related.

Development of spelling

The beginning speller must first learn the names of the letters of the alphabet and their corresponding phonological components. Treiman and Bourassa (2000) view this process in three stages. During the first stage, the beginning speller will tend to represent each syllable in a word as a separate letter (i.e., spelling 'car' as 'k'). As the child's phonological awareness increases, the child is able to analyze a word as a sequence of sounds and begins utilizing simple phoneme-grapheme correspondences (i.e., spelling 'car' as 'kr'). Through a developing phonological awareness and exposure to print, the child enters stage three. In this stage, the child is able to separate each sound of the target word and symbolize it with phonetically, if not orthographically, correct letters. The congruent development of spelling and phonological awareness, according to Treiman and Bourassa, arises from the phonological representations that are common to both skills (Treiman & Bourassa, 2000).

Correct applications of the sound-symbol relationships are integral to spelling in the English language. According to Hanna, Hanna, Hodges, and Rudorf (1966, as cited in Moats, 1994) half of all English words can be spelled correctly using sound-symbol correspondences alone. In addition, 37% of additional words could be spelled with only these correspondences while allowing for one error (e.g., spelling 'pack' as 'pak'). Through time and experience, the novice speller expands on these correspondences and integrates more of the simple, and eventually complex, rules of the language (Treiman & Bourassa, 2000). The over-arching goal of the novice speller is an automated process that allows for both the recognition of familiar words and the construction of new words (Kulak, 1993; Rittle-Johnson & Siegler, 1999).

Development of mathematics

The acquisition of mathematical skills begins with a similar emphasis on the integration of symbol and meaning (Ashcraft & Fierman, 1982). This process starts with simple procedural strategies, such as using the fingers or objects to count and pairing meaning with real world constructs (Nesher, 1986). Counting at this early stage is based on the formal counting words of the child's culture. In addition, Geary postulates a possibly innate understanding of numerical relationships, such as magnitude, that is evident even in infants (Geary, 2000). This early skill is built upon to allow the child to enumerate larger and larger sets of objects. The most difficult aspect of early mathematic skills in English speaking children arises when learning the correspondence between the base-10 Arabic number system and the English number words. For example, though the word 'one' has a direct correspondence with the base-10 system, numbers beyond 10, such as 13, do not.

As children progress in their proficiency and understanding of the basic correspondences, more numerals are added and they begin to learn how to manipulate these symbols in additive and subtractive ways (Geary, 2000). The early arithmetic equations children begin with, such as 2+2=4, rely on the child's understanding of counting and counting procedures. Though various strategies can be, and are, used in conjunction with counting (i.e., the 'min' strategy, or adding up from the larger number in the equation), they are time consuming and encompass several steps at which any confusion could enter and disrupt the process (Geary & Hoard, 2001). Over time, the process of retrieving arithmetic facts becomes automated for quick retrieval and allows for expansion into higher-level mathematical operations (Geary, 1993; Kulak, 1993; Rittle-Johnson & Siegler, 1999).

Disability in reading, spelling and mathematics

As stated earlier, a learning disability can arise from deficits in one of many domains. The predominant theories of children evidencing disorders of reading disabilities (RD) have focused on poor phonological awareness (Wagner et al., 1993). A study by Bruck (1992) compared elementary school students and adults with dyslexia to age-matched participants without disabilities on measures of phonological awareness. The results indicated that individuals with dyslexia did not evidence phonological awareness skills appropriate for their age or reading level. Further, increased reading experience did not lead to an increase in phonological awareness. A separate study by Bruck (1990) examined the same adults with dyslexia on measures of word recognition skills. Adults with dyslexia performed similarly to children with dyslexia on these measures that the author believes tap knowledge of sound-spelling correspondences. Bruck suggests that even when individuals with dyslexia have become familiar with these correspondences, they do not automatically activate them for phonological tasks (Bruck, 1990).

Poor phonological awareness also plays a role in spelling disabilities. The inability to segment sounds can lead to inadequate or inappropriate strategies for pairings between letters and sounds (Lindamood, 1994; Treiman & Bourassa, 2000). Several studies (see Bourassa & Treiman, 2001, for a review) have found that children with spelling disabilities tend to make more non-phonetic than phonetic errors when spelling. A non-phonetic error would include errors where a phoneme is not represented in the spelling (e.g., 'gad' for 'glad'), while phonetic errors include those where the misplaced letter could be replaced by a different letter (or letter grouping) in conventional English (e.g., 'chrain' for 'train'). Beyond correspondences between phonemes and graphemes, disability in spelling can arise due to difficulty with analyzing orthographic and morphological patterns (Bourassa & Treiman, 2001). This pattern of disability arises out of a specific difficulty for appreciating the common structure of English words.

The acquisition of mathematic skill can be interfered with by an even greater variety of areas of disability. Relevant to the proposed study, however, are only those at the basic levels of counting, addition, and subtraction. Geary (1990) characterized disability in early mathematics learning as a multi-component problem. In this study, Geary compared children with learning disabilities to children achieving normally on 29 simple addition problems. The children with learning disabilities performed significantly more poorly on this measure than did children achieving normally. The children with LD, as part of an ongoing remedial instruction program, were further divided into those who improved and those who did not. While children who improved generally came to mirror children achieving normally in terms of strategy choice and information processing speed, children with LD who did not improve evidenced a continuous and componentially diverse pattern of disability. These children exhibited deficits in areas of counting strategy, retrieval, rate of execution, and strategy choice for solving equations (Geary, 1990).

Many studies have noted a high comorbidity between reading and arithmetic/mathematical difficulties (Geary, 1990, 1993; Rourke, 1993; Share, Moffit, & Silva, 1988). Though precise prevalence rates are confounded by differing definitions of mathematical disability (Badian, 1999), it has been estimated that 5 to 15% of school-age children evidence some degree of mathematic difficulty (Kosc, 1974; Share et al., 1988). Of those children, few are characterized by a mathematics disability alone. Most also have deficits in linguistic areas, such as reading and spelling (Kulak, 1993; Rourke, 1993; Share et al., 1988). Evidence for the comorbidity between linguistic and mathematics deficits has been found not only through a focus on scholastic achievement, but also through studies of genetics.

Genetic influences on academic achievement have focused primarily on the domain of reading (DeFries & Alarcon, 1996). Twin studies have revealed that approximately 50% of the participants' reading disabilities were due to genetic factors with only an additional 10% attributed to shared environmental influences (Light & DeFries, 1995). A separate twin study, utilizing twin pairs with at least one twin exhibiting RD, found a correlation of .53 between reading and mathematic skill. This result suggests that a high degree of reading and math deficits are attributable to genetic influences. Of the genetic influence on reading, however, 25% of the variance was found also to influence math scores. Similarly, 20% of the variance in genetic influence on math scores was found also to influence reading ability. These outcomes suggest that the influence of genetics on these two areas could be arising from the same genes (Alarcon, Knopik, & DeFries, 2000).

In addition to genetics, gender differences have been investigated as a possible source of connection between reading and mathematic disabilities. Royer, Tronsky, Chan, Jackson, and Marchant (1999) proposed that men and boys are favored in mathematical abilities due to a sex-related difference in the speed of arithmetical fact retrieval. Badian (1999), conversely, found the rates of comorbidity between reading and mathematical disability to be approximately equal in early grades for boys and girls. Significant differences between the genders were not found until after the fourth grade, at which point boys were twice as likely to exhibit a mathematical disability as girls. Conceptual understanding of numbers across grades 1 thru 8 for both genders, however, showed no significant differences, indicating that the nature of the relationship between mathematic ability and gender is not yet fully understood (Badian, 1999).

Comparisons between other areas of linguistic function, such as spelling, and mathematics, however, have only begun to be focused on by researchers. A study by Lennox and Siegel (1993) examined how the use of spelling-sound correspondences varied across subtypes of LD. Comparing children with reading disability alone (RD), arithmetic disability alone (AD) and children achieving normally (NA), the researchers further separated these subtypes into good and poor spellers. Results indicated that young children with RD exhibited as much difficulty using sound-symbol correspondences as children with AD and poor spelling skills. The performances of children with AD and good spelling skills fell in between children with LD and children achieving normally. Lennox and Siegel concluded that the use of spelling strategies varies across LD subtypes and ages. This suggests that both spelling and math skills, in the early stages of development, may rely heavily on a similar skill underlying sound-spelling correspondences.

Finally, the role of working memory differences in mathematic and reading disabilities has been of great interest (Bull & Johnston, 1997; Bull, Johnston & Roy, 1999). Working memory, however, is not a single entity. According to one model, it is comprised of three domains: the phonological loop, visual-spatial sketchpad, and the central executive (Baddeley, 1986). Though the visual-spatial sketchpad and central executive have been found to play a role in mathematic computation (see Bull & Johnston, 1997, or Rourke, 1993, for a review), their role in linguistic functioning is an ongoing area of research interest. The phonological loop, however, has been found to have a significant impact on reading, spelling and mathematics. This area is used to assemble and associate phonemes and graphemes retrieved from long-term memory storage to create spellings. A study by Dark and Benbow (1991) found increased digit spans for children evidencing advanced skills in math. Similarly, children with precocity for language were able to hold longer strings of letters in working memory. The authors attribute this difference to characteristics of the stimulus or its 'compactness.' They theorize that children gifted on either verbal or arithmetic tasks form more compact and meaningful representations in long-term memory. This type of representation may lend itself to quicker retrieval and ease in manipulation. The phonological loop is the primary area of working memory to which these representations would be retrieved and manipulated in words and equations. Disabilities of spelling have cited poor retrieval, inadequate rehearsal strategies, and poor representations as possible sources of deficit. Geary (1993), in his review of mathematics disabilities, cited all three areas of working memory (i.e., phonological, visual-spatial, and central executive) as possible sources of deficit responsible for the disability. He did suggest, however, that difficulty in representation and retrieval may be a more fundamental problem and may not be ameliorated by cognitive development. In other words, this difficulty may not disappear as the child's experience with mathematics grows. Research, to date, has not specifically examined how deficits in one or more of these domains might affect both spelling and mathematics.

Proposed Study

The goal of this study is to explore the relationship between mathematics and spelling skills within the context of an intervention study focusing on elementary school-age children who have deficits in at least one area of reading. The effect of gender and working memory skill on the mathematics/spelling relationship also will be explored. This proposed relationship will be explored in three main hypotheses.

The first hypothesis is that there will be no significant gender difference on the measures of spelling, mathematics, or phonological working memory. Given the age and level of disability of the participants, it is hypothesized that no difference will be seen on the measures between males and females. This will be assessed using analysis of variance techniques.

The second hypothesis of the proposed study is that measures of arithmetic will account for a significant amount of variance in spelling measures. This hypothesis will be assessed using hierarchical regression techniques. Broadly, after accounting for demographic variables, measures of arithmetic will be regressed on measures of spelling. Mathematics will be measured by the arithmetic subtest of the WRAT (Wilkinson, 1993). Spelling will be measured by the spelling subtest of the PIAT (Markwardt, 1989). It is hypothesized that the skill needed to associate sound and spelling is based on the same skill needed to associate number to meaning in young children. Weakness in mathematics skills, therefore, is expected to significantly predict weakness in spelling skills in this sample of children with learning disabilities.

The final hypothesis of this proposed work is that the relationship between spelling and arithmetic is mediated by phonological working memory skills. As phonological working memory skills have been implicated as significant to both spelling and arithmetic, it is hypothesized that a deficit in this area may account for deficits in the other two skills. In order to examine this hypothesis, tests of phonological working memory will be included in an additional analysis. Both the WRAT-arithmetic and PIAT-spelling subtests will be used in this analysis. In addition, measures of working memory will include the digit span subtest of the Weschler Intelligence Scale for Children-III (WISC-III; Weschler, 1991) and the elision and blending subtests of the Comprehensive Test of Reading Related Phonological Processing (CTRRPP; Torgeson & Wagner, 1996). To explicate this, a second hierarchical regression will be used. It is expected that the partial regression coefficient associated with regressing arithmetic measures on spelling measures will be significantly reduced after regressing the interaction term comprised of working memory and arithmetic measures on spelling measures.

Methods

Participants

Children were selected from public and private second and third grade classes in three large metropolitan cities: Atlanta, Toronto, and Boston. Children were initially recruited on the basis of teacher referral and his/her observation of early reading ability. The included participants were either African-American (or African Heritage) or Caucasian, had hearing and vision within normal limits, and English as their primary language. Children were excluded from the study if they had repeated a grade, had a history of psychological/neurological disorder and/or a K-BIT (Kaufman Brief Intelligence test) composite score below 70 (Kaufman & Kaufman, 1990). Children were not excluded for the presence of disorders commonly associated with reading disability, such as Attention-Deficit Hyperactivity Disorder (ADHD). Children meeting the inclusionary criteria were included in a large, multi-site treatment intervention program focused on the improvement of reading ability.

Disability Defined

A series of intellectual and reading ability assessments were obtained to determine the presence of a reading disability. One of the following three subtests were used to determine the child's overall achievement level: the average of the standard scores of the Woodcock Reading Mastery Test-Revised (WRMT-R) Word Identification, WRMT-R Passage Comprehension, WRMT-R Word Attack (Woodcock, 1987) and the Wide Range Achievement Test (WRAT-3) Reading subtest (Wilkinson, 1993); the standard score from the WRMT-R Total Reading cluster short-form (Word Identification and Passage Comprehension subtests); and/or the standard score of the WRMT-R Basic Skills Cluster (Word Identification and Word Attack; Woodcock, 1987). Participants were selected for the study if they met one of two criteria: Low Achievement (LA) and/or Ability Achievement Regression Corrected Discrepancy (AA-D). Children with a K-BIT composite score above 70 and whose reading skills were equal to or less than a standard score of 85 were identified under the LA criteria. Children whose actual reading performance was at least one standard error of the estimate below their Expected Achievement Standard Score (EASS) were included under the AA-D criteria. EASS was calculated based on an average correlation of .60 between reading ability and intellectual ability.

Intervention

Children meeting the study criteria were enrolled in one combination of five different intervention programs: Phonological Analysis and Blending/Direct Instruction (PHAB/DI); Word Identification Strategy Training (WIST; Lovett, Lacerenza, & Borden, 2000); Retrieval-Rate, Automaticity, Vocabulary Elaboration - Orthography (RAVE-O; Wolf, Miller, & Donnelly, 2000); Classroom Survival Skills (CSS); and Mathematics instruction (MATH). All intervention programs were taught in combination (e.g., PHAB/DI+RAVEO).

Procedure

Masters and doctoral level graduate students and post-doctoral fellows administered measures of reading, spelling and arithmetic ability at the baseline timepoint prior to intervention. Measures were administered to individuals during the course of a normal school day. Though the test battery is very extensive only the following measures were used in this study: the arithmetic subtest of the Wide Range Achievement Test-Third Edition (WRAT-3; Wilkinson, 1993), the spelling subtest of the Peabody Individual Achievement Test-Revised (PIAT-R; Markwardt, 1989), the digit span (forward and backward) subtest of the Weschler Intelligence Scale for Children-Third Edition (WISC-III; Weschler, 1991), Kaufman Brief Intelligence Test (Kaufman & Kaufman, 1990), and the Elision and Blending phonemes-words subtests of the CTRRPP (Torgeson & Wagner, 1996).

Measures

Wide Range Achievement Test-Third Edition (WRAT-3) - The spelling subtest of the WRAT-3 provides information about the child's ability to recognize letters, transcribe words from dictation, and write his/her name. The arithmetic subtest provides information on the child's ability to count multiple objects, solve simple sentence problems, and basic calculation problems. The norms for this test were obtained from 4,433 individuals 5 to 75 years old, stratified based on region, gender, ethnicity, and socioeconomic level (Wilkinson, 1993). Standard scores were used in this analysis.

Peabody Individual Achievement Test-Revised (PIAT-R) **-** The spelling subtest of the PIAT-R provides information about the child's ability to discriminate between symbols and letters, and words. The words are discriminated on the basis of sound and orthography. The PIAT-R was standardized on a sample of 1,563 children between kindergarten and the 12^{th} grade (Markwardt, 1989). Standard scores were used in this analysis.

Weschler Intelligence Scale for Children-Third Edition (WISC-III) – The Digit Span subtest of the WISC-III was used in this analysis (Weschler, 1991). The Digit span subtest consists of two parts, a digit-backward task (7 items) and a digit-forward task (8 items). Both tasks have been shown to reliably measure working memory skills. A standard score comprised of both the forward and backward subtests was used in the analysis.

Kaufman Brief Intelligence Test (K-BIT) - This measure provides an estimate of a child's intelligence quotient. The composite score in this analysis included both the vocabulary and matrices subtests of the K-BIT (Kaufman & Kaufman, 1990). Only standard scores for this measure were used for analysis.

Elision and Blending Phonemes - The Elision subtest measured a student's ability to separate and vocalize phonemes, while the Blending phonemes subtest measured a student's ability to combine phonemes into words. Both are subtests of the *Comprehensive Test of Reading Related Phonological Processes* (CTRRPP) (Torgeson & Wagner, 1996), which was the experimental precursor to the *Comprehensive Test of Phonological Processing* (CTOPP: Wagner, Torgesen & Rashotte, 1999). A standard score for each task was used in the analysis.

Sample Participants

In an effort to examine only those participants with significant difficulties in spelling, only those participants that scored below the 30^{th} percentile on the Peabody Intelligence Achievement Test-Revised (PIAT-R) spelling subtest, were included in the analysis. Two hundred fifty-seven out of an original 305 second and third grade students referred met the study's inclusionary criteria. Sixty-four percent (n = 184) were male. Approximately fifty-one percent (n = 120) were Caucasian. Participants were distributed through the intervention conditions as follows: MATH+CSS, 24% (N=62), PHAB/DI+RAVEO, 25% (n=65), PHAB/DI+WIST, 27% (n=70), and PHAB/DI + CSS, 23% (n=60). Scores at the baseline timepoint only were used in this analysis.

Data Analysis

All participants' scores were converted into standard scores. Pearson R correlations were run between measures of intelligence, spelling, mathematics, and phonological working memory. All measures were expected to be significantly correlated with one another. In order to investigate the contribution of gender to spelling, mathematics, and phonological working memory skills, a 2x3 within-subjects analysis of variance was run. The predictor variable of gender was entered at step 1. In step 2, the scores for the three areas of interest (i.e., spelling, mathematics, and working memory scores) were entered. Finally, the third step consisted of the interaction term between gender and the three areas of interest. No difference between the genders on all three areas of interest was hypothesized.

A second hypothesis was that the factor comprised of mathematics scores would contribute a significant amount of variance to the spelling scores. To investigate this, a hierarchical regression was run. In the first step, demographic variables were regressed on the spelling scores. It was expected that this step would not be significant. In the second step, the scores for mathematics were regressed on the spelling scores. A significant amount of variance attributable to the mathematics scores was expected.

Finally, the third hypothesis stated that the significant relationship between the mathematics and spelling scores was mediated by working memory. To investigate this, a second hierarchical regression was run. The first step consisted of regressing demographic variables on the spelling scores. The second step consisted of regressing the mathematics scores on the spelling scores. In the third step, measures of phonological working memory were regressed on the spelling scores. Their interaction term was entered as the final step. It was expected that the partial regression coefficient associated with the second step would be significantly reduced with the addition of the phonological working memory scores. In addition, it was expected that the measures of phonological working memory would account for a significant amount of variance in the spelling scores.

Results

Descriptive Statistics

The overall sample of 305 was constrained to include only those participants with a PIAT spelling standard score below the 30th percentile. Three additional participants missing one or more of the measures employed in the analysis also were excluded according to listwise deletion. The final sample for the analysis consisted of 254 participants. Means and standard deviations for the measures used are displayed in Table 1. The correlation matrix revealed significant correlations between all the measures (r=.20 - .55; see Table 2.). The highest correlations were found between the measures of phonological working memory (i.e., Elision and Blending).

Table 1. Means (and SD) for measured variables

Measured variable	Mean (SD)	Range
PIAT Standard Score	78.3 (6.95)	60-89
WRAT Arithmetic Standard Score	83.1 (11.86)	53-115
Blending z-score	.589 (1.22)	-1.86-3.00
Elision z-score	-1.82 (.829)	-3.00-2.27
K-BIT Composite Standard Score	89.99 (9.86)	71-122
WISC-Digit Span Total Scale Score	8.55 (2.68)	3-19

Table 2.

Intercorrelations between the standard scores for measures of spelling, mathematics, and phonological working memory

	1.	2.	3.	4.	5.	6.
1. PIAT-Spelling	__					
2. WRAT-Arithmetic	.41**	__				
3. WISC – Digit Span	.11	.20**	__			
3. K-BIT	.27**	.36**	.25**	__		
4. Blending	.27**	.16**	.07	.34**	__	
5. Elision	.37**	.22**	.11	.34**	.53**	__

Note: *p<.05, **p<.01.

Gender

A multivariate analysis of variance was run to test for gender differences between the pertinent areas: PIAT spelling, WRAT arithmetic, WISC-III digit span, K-BIT composite, and Elision and Blending subtest scores. No significant differences between males and females were found on the measures of phonological processing, spelling, or mathematics. A small, but significant, difference was found between the genders on the K-BIT composite score (Female: M= 87.94 (9.35); Male: M=92.25 (10.64). Females evidenced significantly lower scores on the K-BIT ($F = 10.53$, $p < .05$) than males (see Table 3).

Math and spelling

Hierarchical regression analyses were conducted using the standard scores of the spelling subtest of the PIAT as the dependent variable with the standard scores of the arithmetic subtest of the WRAT and K-BIT standardized composite score as predictors.

Table 3.

Multivariate analysis of variance for gender

Source	df	F	η^2	p
PIAT-Spelling	1	2.45	.01	.12
WRAT-Arithmetic	1	0.73	.00	.39
WISC – Digit Span	1	0.04	.00	.85
K-BIT	1	9.72**	.04	.00
Blending	1	0.84	.00	.36
Elision	1	0.33	.00	.57

Note: $^{**}p<.01$

When entered as the first step into the regression equation, the K-BIT composite score, including the vocabulary and matrices subtests, accounted for 4% of the variance in PIAT standard spelling scores ($F = 9.761$, $p<.01$). The second step in this regression analysis added standard scores of the arithmetic subtest of the WRAT, which uniquely accounted for an additional 11% of the variance in spelling scores ($F=20.973$, $p<.01$). Furthermore, the beta weight associated with the K-BIT composite score was not significant ($p >.05$) with the addition of the WRAT scores to the regression equation (see Table 4).

Working memory, mathematics, and spelling scores

The second regression analysis explored the impact of working memory on the relationship between mathematics and spelling scores. Only 230 of the participants that received a PIAT standard spelling score below the 30th percentile also received the digit span subtest of the WISC-III. The K-BIT standardized composite scores were controlled

Table 4.

Summary of hierarchical regression analysis for variables predicting PIAT- Spelling standard scores (N=254)

Variable	B	SE B	β
Step 1			
K-BIT	0.2	0.04	.27**
Step 2			
K-BIT	0.10	0.04	.14*
WRAT - Arithmetic	0.23	0.04	.36**

Note: *p<.05, **p<.01

for in the first step. This step accounted for a significant 8% of the variance in PIAT spelling standard scores (F=20.97, p<.01). The second step consisted of the total scaled scores for both the forward and backward digit span subtests of the WISC-III digit span. This step did not significantly account for any unique variance in PIAT standard spelling scores (F= 3.59, p>.05). Standard scores for the WRAT arithmetic subtest were entered at the third step. This step accounted uniquely for 12% of the variance in PIAT spelling standard scores (F= 33.41, p<.01; see Table 5).

Table 5. Hierarchical regression analysis for variables predicting PIAT – Spelling standard scores (N=230).

Variable	B	SE B	β
Step 1			
K-BIT	0.21	0.05	.29**
Step 2			
K-BIT	0.20	0.05	.28**
WISC – Digit Span	0.11	0.18	.04
Step 3			
K-BIT	0.12	0.05	.17
WISC – Digit Span	-0.02	0.17	-.01
WRAT - Arithmetic	0.23	0.04	.37**

Note: *p<.05, **p<.01

Phonological awareness, mathematics, and spelling

The third regression analyses explored the impact of the Blending and Elision subtests of the CTRRPP, as measures of phonological working memory, on the relationship between spelling and mathematics. This sample again consisted of 254 participants. The K-BIT composite scores were statistically controlled for in the first step. The first step accounted for 8% of the variance (F=20.51, p<.01). The second step was comprised of the standardized scores of the Elision and Blending subtests of the CTRRPP. These phonological working memory measures uniquely accounted for 9% of the variance in spelling scores (F=13.41, p<.001). Finally, the standard scores of the arithmetic subtest of the WRAT were entered at the third step in the regression analysis. This step accounted for an additional unique 10% of the variance in spelling PIAT standard scores (F=13.41, p<.01). The individual beta weight of the Blending subtest was nonsignificant in the final two steps of the regression while the beta weight of the Elision subtest remained significant even after the addition of the WRAT arithmetic subtest. (See Table 6).

Table 6. Hierarchical regression analysis for variables predicting PIAT – Spelling standard scores (N=254)

Variable	B	SE B	β
Step 1			
K-BIT	0.2	0.04	.28**
Step 2			
K-BIT	0.11	0.05	.16*
Blending	0.40	0.43	.07
Elision	2.48	0.61	.28**
Step 3			
K-BIT	0.03	0.05	.05
Blending	0.41	0.40	.07
Elision	2.17	0.58	.25**
WRAT - Arithmetic	0.21	0.04	.34**

Note: *p<.05, **p<.01

Follow-up Analyses

To explore the difference between the two measures of phonological working memory two additional separate regression analyses were conducted. First, the contribution of Blending standard scores to the prediction of PIAT spelling standard scores was investigated. The K-BIT was controlled for in the first step accounting for 8% of the variance ($F=20.51$, $p<.01$). Only the phonological working memory task, Blending, was entered in the second step. This step accounted for a significant 5% of the variance in spelling scores above and beyond the variance accounted for by K-BIT ($F=9.62$, $p<.01$). In the final step of the regression analysis, the standard scores of the WRAT arithmetic subtest were added to the equation. This step uniquely accounted for 11% of the variance in PIAT spelling standard scores ($F=35.26$, $p<.01$; see Table 7).

In the second regression analysis, the contribution of Elision standard scores to the prediction of PIAT spelling standard scores was explored. The first step of this analysis also controlled for K-BIT composite standard scores. This step accounted for 8% of the variance in PIAT standard spelling scores ($F=20.51$, $p<.01$). Only the phonological processing task, Elision, was entered in the second step. Elision standard scores uniquely accounted for 9% of the variance in PIAT standard spelling scores ($F=27.08$, $p<.01$). In the final step of this regression analysis, the standard scores of the arithmetic subtest of the WRAT were added. This step accounted for a unique 10% of the variance in PIAT standard spelling scores (See Table 8). Results indicate the presence of a factor common to both Blending and Elision in the prediction of PIAT spelling standard scores.

Table 7. Hierarchical regression analysis for variables predicting PIAT – Spelling standard scores (N=254).

Variable	B	SE B	β
Step 1			
K-BIT	0.2	0.04	.28**
Step 2			
K-BIT	0.15	0.05	.21**
Blending	1.21	0.39	.20*
Step 3			
K-BIT	0.06	0.05	.09
Blending	1.11	0.36	.18*
WRAT - Arithmetic	0.23	0.04	.36**

Note: *p<.05, **p<.01

Mediational analyses

To explore the extent to which measures of phonological working memory may mediate the relationship between spelling and mathematics, two analyses were performed. In the first, mediation of the mathematics-spelling relationship was explored after first covarying intelligence. These scores were covaried due to their significant and unique prediction of spelling scores. Initial correlations between all variables, however, were not significant. Significant relationships between all variables is required to test for mediation.

In the second analyses, K-BIT intelligence scores were not covaried through each step of the mediational analyses. Despite the significant and unique contribution to the prediction of spelling scores by the K-BIT, it was possible that its inclusion to the equation may be 'washing out' any mediational influences by the measures of phonological working memory. Each measure of phonological working memory was tested separately. The digit-span subtest of the WISC was not significantly related to the PIAT-spelling subtest scores. It was not shown to mediate the mathematics-spelling relationship. The blending subtest of the CTRRPP did evidence significant relationships with both the WRAT-arithmetic subtest and the PIAT-spelling subtest. The blending subtest was found to account for 7% of the mathematics-spelling relationship. Finally, the elision subtest was found to be significantly related to both measures of mathematics and spelling. It was found to account for almost 15% of the mathematics-spelling relationship.

Table 8. Hierarchical regression analysis for variables predicting PIAT – Spelling standard scores (N=254).

Variable	B	SE B	β
Step 1			
K-BIT	0.2	0.04	.28**
Step 2			
K-BIT	0.12	0.04	.17*
Elision	2.75	0.54	.31**
Step 3			
K-BIT	0.04	0.04	.06
Elision	2.43	0.51	.28**
WRAT - Arithmetic	0.21	0.04	.34**

Note: *p<.05, **p<.01

Discussion

The purpose of this research was to investigate the relationship between spelling and mathematics skills in a population of elementary school students with an identified learning disability. Further, this research explored the impact of phonological working memory on the relationship between spelling and mathematics.

As hypothesized, no significant differences were found for gender on measures of spelling, mathematics, or phonological working memory. This finding supports earlier research on the impact of gender on these areas in typically achieving young children and children with learning disabilities (Badian, 1999).

A significant difference was found for gender on the K-BIT. This finding for the K-BIT could be due to the nature of this sample. Girls are traditionally viewed as stronger in linguistic areas at this chronological age. The same is true of this sample as almost twice the number of boys were found to be below the 30^{th} percentile on spelling skill than girls. Therefore, the sampling procedure may have pulled only those girls struggling with spelling. Furthermore, the sample population from which the analyzed sample was drawn was identified using an IQ-discrepancy definition. Share and Silva (2003) are among the many researchers who have recently questioned the usage of this definition in the realm of learning disabilities. In a recent article, these authors found that the IQ-discrepancy definition of learning disabilities frequently over-estimates the number of boys while under-estimating the number of females with a reading disability. As a result, only the most severely affected girls are typically included in studies operating under this definition. By further constricting the sample to only those participants below the 30th percentile on the PIAT, the analyzed sample of females represents the lowest level of available participants in this population sample.

The significance of this finding and any explanation of it, however, must be viewed relative to the other measures in this study. Though the K-BIT was an initial significant predictor of spelling scores, it did not retain a significant impact with the addition of either mathematics or phonological working memory measures. Further, the effect size for this significant finding was less that 4%. Together this suggests a relatively small impact on spelling scores by the K-BIT that becomes even less significant with the addition of other predictors.

The finding that mathematic scores contributed significant variance to spelling scores confirms the main hypothesis of this study. The implication is that at low levels of spelling and arithmetic skill, such as those found in some students with a learning disability, children are accessing a similar ability to complete the tasks. Though reading and spelling are closely related (Moats, 1994; Treiman, Tincoff, Rodriguez, Mouzaki, & Francis, 1998) the finding of a mathematics/spelling relationship lies outside reading skill. Scores used in this study were obtained from children who exhibited a significant reading disability and had not yet received an instructional intervention that targeted this skill. Therefore, even with little or no ability to read, a relationship exists between aspects of spelling and mathematics performance.

The finding that digit span was not a significant predictor of spelling scores was surprising. Earlier work had suggested an important role for working memory, as measured by the digit span, in spelling scores for both typically achieving children and children with a learning disability (Kroese, Hynd, Knight, Hiemenz, & Hall, 2000). Correlational analyses revealed that the digit span was not significantly related to any of the measures of spelling, mathematics or even the other measures of phonological working memory. The lack of relationship between these measures could be a result of the numerical nature of the digit span. Both the spelling and other phonological working measures focus entirely on the manipulation of alphabetic symbols. Further, Torgesen (2000) has suggested that only the backward digit span is representative of working memory while the forward digit span is predictive of short-term memory alone. Given the extremely low range in scores on the digit span subtest in this sample it is possible that there was simply not enough variance to capture the effect of the digit span on the spelling/mathematics relationship.

Another intriguing finding was the significant contribution, both together and separately, of the blending and elision subtests of the CTRRPP to spelling scores. These subtests have been used consistently throughout the literature to provide an index of a participant's phonological awareness (Cormier & Dea, 1997; Kroese et al., 2000; Wagner et al., 1993). While the relationship between phonological awareness and spelling has been established (Treiman et al., 1998), it was the mediating influence of measures of phonological working memory on the mathematics/spelling relationship that was hypothesized in this study. Mediational analyses revealed that elision accounted for 15% of the relationship between mathematics and spelling. Furthermore, blending was found to account for almost 7% of the variance between mathematics and spelling. The digit span task, however, was not found to mediate the relationship between spelling and mathematics. At least some measures of phonological working memory mediated the relationship between mathematics and spelling skills in this sample of children with a learning disability.

One possible explanation for this mediation lies in the similarities between letters and numbers with regard to their symbol to meaning connections. Phonological skill is required to string together the sounds in the word ‘seven’ in same way it is needed to string the letters together to form ‘cat.’ While the two words carry functionally different meanings and contexts, each word requires phonological assembly for recognition and use.

In addition to phonological working memory acting as a mediator of the spelling/mathematics relationship a separate metacognitive skill used to connect symbol relationships (i.e., words and equations) to conceptual meaning also may play a role in the spelling/mathematics relationship. Bull and Johnston (1997) found item identification (i.e., the ability to name presented items) to have a significant impact on speed of processing which in turn carried the largest proportion of variance in mathematical abilities. The central executive in the Baddeley model directs this retrieval of item names. A separate study by Bull and Johnston (1999) found that the central executive plays a larger role in children with a learning disability than either the phonological or visual-spatial slave systems. Further, Wilson and Swanson (2001) found both slave systems to contribute significant variance in mathematics scores but the largest overall impact came from the central executive. They attribute this influence to the central executive’s role in activating the proper concepts in long-term memory and then directing those and other energy related resources to the slave systems to produce the answer. If students with a learning disability are forming few or poor representations for mathematical and spelling related concepts, the central executive could be strained by the search and would have to supply inadequate information to the slave systems for processing. This search involves accessing the long-term memory store for number meanings and word names. Geary (1993), in a review of the literature, hypothesizes that children comorbid for arithmetical and reading disabilities are slower at retrieving numerical information from long term memory. This slow retrieval leads to the poor formation of the conceptual relationships generally represented by arithmetic equations. In this model, the child is accessing faulty representations when attempting to solve an arithmetic problem, leading to an incorrect answer. If both mathematics and spelling are dependent on the central executive’s ability to comb through multiple conceptual relationships, inhibiting the incorrect and activating and integrating the correct relationships, then this could be the location of the common variance shared by the two skills. More direct measurement of the role of the central executive in spelling and in the spelling/mathematics relationship, however, is needed to establish this connection. While this does not prove that the skill needed to solve an equation and the skill needed to encode a word are the same, it does suggest similarities between the component parts of the processes. Future directions for research on this connection should focus on identifying the specific components of working memory held in common between mathematical and spelling processes, such as the role the episodic buffer may play in this relationship. Moreover, the strength of the relationship between these two areas in children with a reading disability suggests a degree of utility for investigating possible interventions designed to stimulate both mathematics and spelling development simultaneously.

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