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The relationship of spelling recognition, RAN, and phonological awareness to reading skills in older poor readers and younger reading-matched controls

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Abstract. The role of spelling recognition was examined in word reading skills and reading comprehension for dyslexic and nondyslexic children. Dyslexic and nondyslexic children were matched on their raw word reading proficiency. Relationships between spelling recognition and the following were examined for both groups of children: verbal ability, working memory, phonological measures, rapid naming, word reading, and reading comprehension. Children's performance in spelling recognition was significantly associated with their skills in word reading and reading comprehension regardless of their reading disability status. Furthermore, spelling recognition contributed significant variance to reading comprehension for both dyslexic and nondyslexic children after the effects of phonological awareness, rapid naming, and word reading proficiency had been accounted for. The results support the role of spelling recognition in reading development for both groups of children and they are discussed using a componential reading fluency framework.

Key words: Spelling recognition, Reading comprehension, Dyslexia, RAN, Word reading, Fluency

Introduction

Lyon, Shaywitz, and Shaywitz (2003) recently characterized developmental dyslexia as a difficulty in learning to *read* and *spell* words with accuracy and fluency. The inclusion of spelling and fluency in their definition reflects the abundance of findings suggesting that although systematic research on the role of phonological processes in reading failure and intervention has explained reading variance to a large extent, it has been insufficient to account for the difficulties of *all* children with reading disabilities (for a recent review see Meyer & Felton, 1999; see also Breznitz & Share 1992; Wolf & Katzir-Cohen, 2001).

Many studies in the past three decades have shown that many dyslexics have phonological processing deficits (Rack, Snowling, & Olson, 1992;

Snowling, 1995, 1998; Swan & Goswami, 1997a, b). In other words, many dyslexic children have difficulties with specifying and retrieving phonological representations. Specifically, these children are typically characterized as having persistent difficulties with reading nonwords compared to sight words and with phonological processing tasks such as rhyme and nonword repetition (Rack et al., 1992).

More recently, it has been demonstrated that orthographic as well as phonological processes support the growth of word recognition (Badian, 2005). Mehta, Foorman, Branum-Martin, and Taylor (2005) found a very strong relationship between *expressive* spelling and reading comprehension in a large unselected sample of children in grades 1–4. However, the relationship among receptive spelling recognition and various component skills such as phonological awareness (PA) and rapid naming and the degree to which they contribute independently to reading comprehension in children with and without reading difficulties merits additional exploration. Thus, despite current inclusion of spelling problems in the definitions of dyslexia, much less is known about dyslexics' expressive and receptive spelling skills than is known about their phonological processing skills in relation to reading development. This study was designed to investigate the relationship of spelling recognition (i.e., the ability to recognize and retrieve word patterns) to reading comprehension in children with and without dyslexia.

Defining orthographic processing

Despite continuous interest in the role of orthographic processing in literacy development, there is no consensus on the definition of orthographic processing (Wagner & Barker, 1994). Orthographic processing involves abstraction of orthographic regularity and permissible sequences, and mapping of orthographic information to corresponding phonological information (Berninger & Abbott, 1994). Berninger (1994) included connections between linguistic and symbolic coding in addition to visual-spatial coding in orthographic knowledge (e.g., whole written words map onto whole spoken words, letter clusters onto syllables, rimes, or phonemes).

The receptive aspects of orthographic processing have been referred to as "memory for specific visual/spelling patterns" (Barker, Torgesen, & Wagner, 1992, p. 335), or the visually mediated and/or controlled aspect of reading (Vellutino, 2003). In the present study we conceptualize orthographic processing as a visually mediated ability to analyze and recognize letter and letter strings. Thus, in addition to the mastery of matching sounds to graphemes, orthographic awareness requires the knowledge of word structures, i.e., the morphological rules, of language as well as letter distribution (possible and impossible letter strings). This knowledge is built on the integration of phonological, morphological, and visual processes (Berninger & Abbott, 1994). As such it requires many of the same higher order demands that word reading demands. Thus, automatic recognition of orthographic patterns in multi-letter units (e.g. syllables and morphemes) leads to fluent, effortless, and holistic recognition of words (Wolf & Katzir-Cohen, 2001). Although expressive spelling skills and spelling recognition are significantly correlated (Cunningham & Stanovich, 1991), receptive and expressive orthographic knowledge might facilitate different aspects of reading development at different phases. Expressive spelling skills, which largely depend on the knowledge of phoneme to grapheme conversion skills in addition to orthographic knowledge, may not adequately distinguish individuals' phonological processing from orthographic processing compared to receptive spelling recognition tasks. In fact, it was shown that expressive spelling skills had higher loadings on the phonological factors than on the orthographic factors (Stanovich & West, 1989).

While orthographic processing as we define it is a wide umbrella term (Berninger & Abbott, 1994), spelling recognition in this paper is more narrowly defined as one's receptive skills in identifying correct orthographic representations out of several minimally different alternatives (e.g., *cow*, *cou*, *cau*, *caw*). This skill still required integration, yet relies less on grapheme to phoneme conversion skills as some of the foils actually map in their sound to the real target word. The visual representation stored in memory in connection with the morphological and orthographical knowledge will aid the reader to successfully choose the correct auditorally presented word.

Development of orthographic processing

Knowledge of letter sequence seems to develop gradually in a systematic fashion (Adams, 1990; Ehri, 1998; Perfetti, 1992). For instance, kindergartners and first graders have been found to treat and process words and nonwords in a similar way, letter by letter. However, by the end of the first grade, average-achieving readers tend to develop orthographic knowledge of chunks; by third grade, children use spelling patterns in word recognition (Santa, 1976–1977). However, more recently Cassar and Treiman (1997) showed that children develop orthographic knowledge earlier. Children by the end of kindergarten have learned some orthographic patterns so that they preferred final doublets to initial doublets (e.g., *baff* vs. *bbaf*). Treiman (1993) also found that first graders tend to produce and select spelling sequences that are consistent with English spelling conventions. In her study 50% of kindergarteners, 56% of first graders, and 62% of second graders chose nonwords that follow English writing system over those that did not (e.g., *nuck* vs. *ckun*).

The relationship of phonological and orthographic processes to word and connected text reading

Recent research suggests that reading fluency and comprehension deficits, grounded in more fundamental word recognition problems, characterize most children with reading difficulties (Lyon & Moats, 1997). While most of the research on fluency has centered on word reading accuracy, researchers who have examined the nature of fluency report that fluency is a multi-component, developmental process (Wolf & Katzir-Cohen, 2001). Many factors such as WRE, PA, and rapid naming speed predict reading fluency (Katzir et al., in press). In addition, findings from a recent study indicate that spelling recognition contributed a large percent of the variance explained in reading fluency (Katzir, Breznitz, Shaul, & Wolf, 2004). This finding is consistent with other results suggesting that orthographic knowledge has a positive as well as a predictive relationship with reading development (Badian, 2001; Vellutino, 2003). For fluent automatic word reading, children need to develop orthographic representations in their memory for direct access of written words. Continued repetitions of visual-phonological connections allow for the pronunciations of written words to be stored as orthographic images or word specific representations (Ehri, 1987, 1992). Perfetti (1992) similarly argued that autonomy follows from the acquisition of such fully specified and redundant lexical representations.

Many previous studies have consistently shown that there is a moderate to high correlation between spelling skills, phonological skills, and reading skills (Ehri, 1997; Morris & Perney, 1984; Robinson, 1990). In the initial phases of literacy development, PA seems to be associated with spelling development rather than reading development (Ellis, 1997; Torneous, 1984; Wimmer, Landerl, Linortner, & Hummer, 1991). Training studies have indicated that in fact spelling, not reading, might be first influenced by PA development (Ellis, 1997; Lie, 1991; Lundberg, Frost, & Peterson, 1988; Torneous, 1984). It is speculated that the heightened awareness drawn on in manipulating sounds also allows beginning readers to consolidate the letter-sound phonetic relationships in spelling.

The relationship between spelling development and reading comprehension has likewise been shown to exist in individuals, beginning at a young age and through adulthood (Fairbanks & Hobbs, 1982; Morris & Perney, 1984; Robinson, 1990). In Robinson's (1990) study, kindergartners' spelling performance in the fall and the spring provided a moderate, significant prediction for their reading comprehension skills in the second grade. The significant relationship between spelling and reading comprehension has also been observed in Dutch children in a longitudinal study (Mommers & Borland, 1987). Findings demonstrated that spelling and reading comprehension skills from grade one to grade six were highly correlated and that the relationship became stronger as the age of the children increased. These correlations between spelling and reading comprehension were higher than the correlations between decoding speed and reading comprehension.

Expressive vs. receptive spelling

Despite these previous findings and the noted significant relationship between spelling skills and reading skills, the aforementioned studies are limited in that they only use measures of expressive spelling skills (e.g., dictated spelling words) in order to assess orthographic knowledge. Therefore the significant role of receptive orthographic processing in reading development may have been confounded in the majority of extant research. However, the findings from a few recent studies have demonstrated a positive relationship between *receptive* spelling (e.g., spelling recognition) and reading skills (Cunningham & Stanovich, 1991; Cunningham, Perry, & Stanovich, 2001; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997). For instance, in a study with third graders, an orthographic choice task (e.g., one whereby children choose between two homophones) made a significant independent contribution in explaining variance in oral reading rate and silent reading rate after controlling for age, IQ, print exposure, and phonological skill (Barker et al., 1992). Furthermore, students' ability to select the correct standard spelling in an orthographic choice task was positively correlated with word analysis and word identification (Cunningham & Stanovich, 1991). Finally, in a study with fourth and fifth graders, Torgesen et al. (1997) demonstrated that orthographic accuracy (a composite of orthographic choice accuracy and lexical verification accuracy) explained a significant portion of variance in word reading and passage comprehension even after vocabulary and PA were controlled for.

The critical question for research on spelling recognition as framed by Cunningham et al. (2001) is whether it is entirely parasitic on the operation of phonological processes. In other words, is PA both necessary and sufficient for spelling recognition, or is spelling recognition independent of PA? Cunningham et al. (2001) demonstrated that even after the variance associated with phonological processing has been partialed out, receptive orthographic processing skills explain significant additional variance in reading and spelling ability, suggesting that orthographic processing, at least in part, is independent of phonological processing. Similarly, Badian (2001) found that orthographic identification contributed significant variance to reading comprehension in grade three. She suggested that in some children, late reading deficits may be due to poor orthographic skills.

In summary, while many of the existing studies have documented the highly significant relationship of expressive spelling skills, i.e., dictation tasks, to word reading and reading comprehension, the relationship of receptive spelling, or spelling recognition, to reading fluency and comprehension has lacked sufficient investigation (Bourassa & Treiman, 2003; Bruck, 1988). In particular, the role of receptive spelling knowledge has been understudied in the dyslexic population and in reading comprehension. In the present study, we attempt to build on the previous studies and expand our understanding of the relationship between orthographic knowledge, particularly spelling recognition, and reading skills in dyslexic readers and younger children.

Using a reading-level-match design (Backman, Mamen, & Ferguson, 1984), participants in the present study were matched on word reading proficiency (accuracy, not fluency) in order to investigate whether dyslexic readers display different or similar patterns of performance compared to typically developing readers. Although this method is not without potential problems (see Bryant & Goswami, 1986 for a discussion), it is appropriate for assessing whether the performance of dyslexic readers follows an idiosyncratic pattern (Bruck, 1988) and appears to have more benefits for this type of study than does the chronological age match method (see Bourassa & Treiman, 2001, for a review).

The study was guided by the following research questions:

1. When children are matched on word reading accuracy, how do average readers and dyslexic readers differ in their performance in spelling recognition and reading related skills such as word and nonword reading skills in both accuracy and fluency and reading comprehension?
2. What is the relationship between spelling recognition and reading skills, particularly passage comprehension, for average readers and dyslexic readers?

Overview

In order to examine the relationship of spelling recognition and reading related skills in dyslexic and nondyslexic children, the sample in the present study was administered a battery of cognitive and achievement tasks. We included measures of phonological processing, orthographic processing, cognitive ability, and reading at different levels: symbol level, word level, and connected text level. A short-term memory measure was included because it has been found to predict reading performance such as word reading and passage comprehension for average readers (Hansen & Bowey, 1994; Parrila, Kirby, & McQuarrie, 2004; Swanson, 1992; Swanson & Alexander, 1997), word attack skills of average readers (Hansen & Bowey, 1994), and reading comprehension for learning disabled children (Swanson & Alexander, 1997). As opposed to a measure of verbal short-term memory used in other studies with young children (e.g., Parrila et al., 2004), in the present study, we used memory for digits because working memory tasks are independent of specific academic domain.

Method

Subjects

The subjects were drawn from two sources: Morris, Lovett, and Wolf's (1995) National Institute of Child and Human Development (NICHD) data and Katzir's (2002) study. Out of the 269 dyslexic readers recruited from Boston, Atlanta, and Toronto for the NICHD study, 159 dyslexic readers who had complete data for all the experimental variables were considered for the present study.

Selection criteria

The participants in the NICHD study were identified as having reading disability if they had low achievement or they met an ability-achievement regression-corrected discrepancy criterion (Stanovich & Siegel, 1994). The children with low achievement met the following criterion: their composite score on the Kaufman Brief Intelligence Tests (K-BIT, Kaufman & Kaufman, 1990) was higher than 80 and their average achievement on multiple measures was equal to or less than a standard score of 85. Children who met the criteria for either low achievement or ability-achievement regression-corrected discrepancy definitions of reading disability (Stanovich & Siegel, 1994) were selected in the study. The children were identified as having ability-achievement discrepancy if their reading scores were one or more standard deviations of the estimate below their predicted scores. Participants' achievement level was determined based on their performance in one of the following tasks: (a) the average of the standard scores on the Woodcock Reading Mastery Tests-Revised (WRMT-R) (Woodcock, 1987, i.e., Word Identification subtest, Word Attack subtest, and Passage Comprehension subtest) and the Wide Range Achievement Test-3 (WRAT) (Wilkinson, 1993) Reading subtest; (b) the Basic Skills Cluster standard score of the WRMT-R (Word Identification and Word Attack); and/or (c) the Total Reading Cluster standard scores of the WRMT-R (Word Identification and Passage Comprehension).

Katzir's (2002) data had 30 nondyslexic readers who were recruited from the Boston area. The subjects in the original studies fit the following selection criteria: (a) their primary language was English, (b) hearing and vision were within normal range, (c) ethnicity was Caucasian or African-American heritage, and (d) their age was between 6;4 and 8;6 at the time of initial testing. Average readers and dyslexic readers were matched within half a standard deviation of raw word reading scores. The majority of the students' raw word reading scores were within ± 3 raw word reading scores (Woodcock Word Identification). Efforts were made to match gender whenever possible. A total of 34 children (17 pairs) were matched on word reading proficiency (Table 1). As Table 1 shows, the dyslexic readers were, on average, more than a year older than typical readers.

Instruments

Verbal ability

Verbal IQ measured by WISC-III (Wechsler, 1991) was used as a measure of verbal ability for the dyslexic children and an abbreviated version of the WISC-III, the WASI (Wechsler, 1999), for the controls. These two

Table 1. Sample size, gender, and age for each matched sample.

	Average readers	Dyslexic readers
Sample size	17	17
Gender	12 boys and 5 girls	6 boys and 11 girls
Age range	6.5–8.2	7.0–9.8
Mean age	7.05	8.3

measures are highly correlated. The verbal scale included information, similarities, arithmetic, vocabulary, and comprehension.

Working memory

Memory for digits in Comprehensive Test of Phonological Processes (CTOPP) (Wagner, Torgesen, & Rashotte, 1999) was used as a measure of working memory. It contains 21 items of a series of numbers that range from two to eight digits. It requires that children repeat numbers in the same order they heard.

Phonological measure

CTOPP, Elision (Wagner et al., 1999) was used as a measure for phonological processing. Early version of the Elision subtest with local norms was used with the dyslexic subjects; the recently published versions were administered to the controls. The measure generates standard scores ($M = 10$, $SD = 3$). The Elision subtest measures child's ability to repeat the word after deleting either a syllable or a phoneme specified by the experimenter, with the correct response forming a real word.

Symbol level reading

Rapid Automatized Naming test (Wolf & Denckla, 2005) was used. The letter naming subtest contains 50 stimuli each. The stimuli in each subtest are arranged randomly in a 10×5 matrix. The subject is required to name the stimuli in each subtest as quickly and accurately as possible. Speed and accuracy are measured.

Word level reading

For word recognition skills, Word Identification (Woodcock, 1987) and WRE (Wagner et al., 1999) were used. Word Identification requires the participant to identify regular and irregular sight words within a 5-s limit per word. An early version of Test of WRE with local norms was used with the dyslexic subjects while the published version was administered to the controls. This test contains 104 words of increasing level of difficulty arranged in four columns. The subject is required to read aloud as many words as possible within 45 s. This is a timed word recognition test which measures word reading fluency and accuracy. For word decoding proficiency, Word Attack (Woodcock, 1987) and NonWord Reading Efficiency (NWRE) (Wagner et al., 1999) were used. Word Attack assesses a child's ability to apply grapheme-phoneme rules and word analysis skills to pronounce unfamiliar printed words (i.e., phonetically regular nonwords or low-frequency words in the English language). Errors are recorded and standardized according to both grade and age norms. An early version of NWRE with local norms was used with the dyslexic subjects while the published version was administered to the controls. This test contains 63 successively more difficult pseudowords arranged in four columns. The subject is required to read as many pseudowords as possible within 45 seconds. This is a timed nonword decoding test which measures word decoding fluency and accuracy.

Reading comprehension

Woodcock Passage Comprehension (Woodcock, 1987) was used as a measure of reading comprehension. This subtest uses a cloze procedure that requires the subject to read sentences that are missing a word that is important to the meaning of the passage. Subjects must supply a word that fits the meaning of each sentence or passage.

Spelling recognition

The spelling subtest of the Peabody Individual Achievement Test (PIAT) (Markwardt, 1989) was used as a measure of spelling recognition. PIAT is a measure of spelling recognition of standard spelling in which the subjects are asked to select a correct standard spelling out of four choices (e.g., *time*, *teim*, *tihm*, *tiem*). This spelling measure was shown to have the highest loading for the orthographic processing factor (Cunningham et al., 2001).

Results

Descriptive statistics

Table 2 shows the summary statistics and *t*-test results in all the measures using raw scores and Table 3 shows results using standardized scores in comparing average readers and dyslexic readers. When raw scores are used (see Table 2), average readers significantly outperformed dyslexic readers on memory for digits, word attack, and NWRE. In addition, the difference in mean performance of the RAN latency approached significance ($p = .07$), while the difference in accuracy was not significant. This indicates that dyslexic readers are significantly slower, but not less accurate, in the RAN letter name task. However, as seen in Table 3, when students' standardized scores on these measures were used for comparison, although students were matched on word reading skills, dyslexic children's performance was significantly lower than that of nondyslexic children in most of the study's measures. This can be explained by the higher mean age of the dyslexic readers because participants' ages are

Table 2. Descriptive statistics and *t*-test results using raw scores ($N = 34$, 17 in each group).

		Average readers		Dyslexic readers		
	Instruments	Mean (SD)	Range	Mean (SD)	Range	*t* Statistics
Orthographic processing	PIAT	34.06 (10.66)	20–48	34.67 (10.18)	19–54	−.16
Cognitive processing	Memory for digits	10.38 (2.53)	6–15	8.47 (1.55)	6–11	2.63*
	Verbal IQ+	95.94 (6.89)	77–108	91.53 (8.77)	76–110	1.63
Phonological processing	Elision	8.50 (4.13)	2–18	11.00 (5.15)	0–20	−1.53
Symbol level reading	RAN LT++	36.31 (8.65)	26–56	45.53 (19.91)	23–104	−1.71~
	RAN LT accuracy	.29 (.59)	0–2	.53 (.87)	0–3	−.92
Word level reading	Word Identification	31.00 (18.60)	6–57	29.82 (17.36)	6–55	.19
Word level decoding	WRE	30.53 (20.24)	7–61	21.65 (14.38)	3–49	1.45
	Word attack	12.71 (8.11)	1–25	6.29 (8.09)	0–27	2.31*
	NWRE	13.82 (9.70)	1–38	5.69 (6.40)	0–17	2.83**
Connected text reading	Comprehension	15.88 (11.31)	1–31	13.12 (8.24)	2–26	.82

Note: ~ $p < .10$; *$p < .05$; **$p < .01$; + For Verbal IQ, raw scores were not available so standardized scores are used; + + RAN LT: RAN letter names.

Table 3. Descriptive statistics and *t*-test results using standardized scores ($N = 34$, 17 in each group).

		Average readers		Dyslexic readers		
	Instruments	Mean (SD)	Range	Mean (SD)	Range	*t* Statistics
Orthographic processing	PIAT	110.24 (8.17)	95.00–126.00	89.00 (8.52)	78.00–113.00	7.31***
Cognitive processing	Memory for digits	9.35 (2.09)	6.00–13.00	10.35 (4.15)	5.00–19.00	−.89
	Verbal IQ	95.94 (6.89)	77.00–108.00	91.53 (8.77)	76.00–110.00	1.63
Phonological processing	Elision	10.43 (2.01)	4.99–15.01	7.16 (3.87)	−3.65–1.35	3.21**
Symbol level reading	RAN LT+	99.95 (14.88)	66.42–119.45	73.06 (29.19)	25.00–110.00	3.38**
Word level reading	Word identification	102.12 (12.32)	82.00–131.00	86.59 (9.72)	69.00–113.00	4.08***
Word level decoding	WRE	100.53 (11.80)	77.00–117.00	75.91 (9.54)	62.00–97.00	6.69***
	Word Attack	100.88 (8.80)	82.00–116.00	78.94 (11.09)	59.00–100.00	6.39***
	NWRE	103.88 (9.72)	87.00–122.00	82.47 (5.33)	75.00–97.00	7.78***
Connected text reading	Comprehension	99.75 (10.08)	83.00–121.00	82.59 (8.50)	68.00–108.00	5.30***

Note: $*p < .05$; $**p < .01$; $***p < .001$; + RAN LT: RAN letter names.

factored in standardized scores. The higher mean age of the dyslexic readers meant that their relative standing, as reflected in standard scores, was significantly lower, as would be expected. In the subsequent analyses, raw scores were used in order to examine relationships between students' proficiency levels in these skills without the age factored in the scores. Finally, only RAN latency, not accuracy, was used.

Correlation analysis

Tables 4 and 5 show the correlations between measures in the sample. The spelling recognition task, PIAT, was consistently and highly correlated with all the reading and comprehension tasks in both groups. However, PIAT was significantly correlated with RAN letter names for average readers, but not for dyslexic readers. Relationships between PA (Elision task), word reading, and comprehension show the same pattern for both the average readers and dyslexic readers in the sample. Specifically, children's performance in the Elision task was highly and significantly correlated with their performance in all the word reading and comprehension tasks for both groups (correlation coefficients range from .64** to .80***). Furthermore, average and dyslexic readers' performance in word reading tasks (word recognition and word decoding tasks) was highly and significantly correlated with each other and with reading comprehension.

Consistent with previous studies of young children, Verbal IQ was not significantly correlated with any of the reading-related measures in both groups, (Stothard & Hulme, 1992) while different findings have been found in older children in fourth and fifth grade. For example, Torgesen, Rashotte, and Alexander (2001) found that Verbal IQ accounted for unique variance in text fluency scores for children whose fluency scores were below average. The correlations between reading measures and memory for digits show different patterns of relationships for average readers and dyslexic readers. For dyslexic readers, memory for digits was only significantly correlated with RAN letter names, but this disappeared when two extreme outliers in RAN letter names were excluded (see next paragraph). In contrast, for average readers, memory for digits approached significance for PIAT, Elision, Word Attack, and NWRE. These results are not consistent with Swanson and Alexander's (1997) findings, which showed significant relationships between working memory and reading related skills for both average readers and reading disabled children. The discrepant results may due to task effects (Swanson & Alexander, 1997) and age differences in the subjects studied: the present

Table 4. Correlations between measures for dyslexic readers ($N = 17$).

		PIAT	Memory for digits	Verbal IQ	Elision	RANLT	Word ID	WRE	Word Attack	NWRE
Orthographic processing	PIAT	—								
Cognitive processing	Memory for digits	.12	—							
	Verbal IQ	.001	.10	—						
Phonological processing	Elision	.80***	.14	.17	—					
Symbol level reading	RAN LT	−.23 (−.59*)	−.59* (−.25)	−.07 (−.57*)	−.33 (−.61*)	—				
Word level reading:	Word ID	.82***	.003	−.01	.77**	−.08 (−.44~)	—			
word recognition	WRE	.82***	.08	−.02	.72***	−.18 (−.47~)	.96***	—		
Decoding	Word Attack	.90***	.003	.02	.72**	−.25 (−.40)	.76***	.77***	—	
	NWRE	.87***	−.16	−.01	.74**	−.15 (−.41)	.72**	.69**	.91***	—
Connected text level reading	Comprehension	.83***	.02	.03	.70**	−.16 (−.44~)	.96***	.93***	.79***	.71**

Note: The values in parentheses are correlation coefficients yielded without two children whose RAN LT scores were extreme; Word ID represents Word Identification, RAN LT: RAN letter names and NWRE: NonWord Reading Efficiency.
$\sim p < .10$; $*p < .05$; $**p < .01$; $***p < .001$.

Table 5. Correlations between measures for average readers ($N = 17$).

		PIAT	Memory for digits	Verbal IQ	Elision	RANLT	Word ID	WRE	Word Attack	NWRE
Orthographic processing	PIAT	—								
Cognitive processing	Memory for digits	.45~	—							
	Verbal IQ	−0.02	−0.17	—						
Phonological processing	Elision	.67**	.43~	0.19	—					
Symbol level reading	RAN LT	−.75**	−0.15	−0.24	−.72**	—				
Word level reading:	Word ID	.97***	.03	−0.09	.64**	−.78**	—			
word recognition	WRE	.97***	0.38	−0.06	.74**	−.78**	.97***	—		
Decoding	Word Attack	.90***	.50~	−0.18	.71**	−.76**	.87***	.89***	—	
	NWRE	.84***	.45~	−0.15	.80***	−.68**	.84***	.89***	.84***	—
Connected text level reading	Comprehension	.96***	0.4	−0.004	.66**	−.69**	.95***	.95***	.85***	.80***

Note: Word ID represents Word Identification, RAN LT: RAN letters, and NWRE: NonWord Reading Efficiency.
~$p < .10$; *$p < .05$; **$p < .01$; ***$p < .001$.

study used memory for digits while Swanson and Alexander (1997) used a variety of tasks including sentence and counting span and their skilled and reading disabled subjects were older by approximately 2 years. Future studies are warranted to clarify this result.

Another notable trend was differential relationships between RAN letter names and literacy measures for dyslexic readers and average readers. While RAN was correlated with all word-level and comprehension scores in the average-achieving readers, it was not correlated with these measures in the dyslexic readers. However, this result was driven by two dyslexic children whose RAN reaction time was extremely slow and whose deviant results greatly skewed the distribution. As seen in Table 2, the range of the RAN latency scores for dyslexic children is much wider than that of average readers. This is because one child's RAN latency in seconds was 104 and the other's was 74, which are beyond one and half standard deviations from the mean. When the two outliers[1] were removed, the mean and standard deviation of RAN latency of the dyslexic group is similar to those of nondyslexic group (M = 39.73, SD = 10.73). When correlation analysis was performed without these two dyslexic children (see the correlation coefficients in parentheses in Table 4), the relationships between RAN and other measures changed, similar to those of average readers. Specifically, RAN letter names are significantly correlated with PIAT, verbal IQ, and Elision task, and approached significance with word identification, WRE, and reading comprehension. However, relationships between other measures in the dyslexic group minimally changed in terms of significance and direction and magnitude of relationships.

Hierarchical regression analysis

Hierarchical regression analyses were performed in order to determine the unique variance contributed to reading comprehension by spelling recognition, controlling for children's reading status (dyslexic vs. nondyslexic), phonological processing, and symbol level and word reading proficiency. Due to the small sample size, we were not able to include as all the control variables simultaneously. Thus four different hierarchical regression models were constructed with different control variables. In the first model (Table 6), the Elision task and reading status was entered in the first step and PIAT was added in the second step. In the next two models (see Tables 7, 8), RAN letter name was used as a control variable along with children's reading disability status in order to examine whether students' spelling recognition explains variance in reading comprehension controlling for their symbol level reading skills. Table 7 shows results

Table 6. Multiple regression results: unique variance in passage comprehension explained by spelling recognition, controlling for phonological processing (Elision) and reading status ($N = 34$).

Step	Variable	R	R^2 change	F change
1.	Elision & Reading disability status	.71	.51	14.49***
2.	PIAT	.91	.31	48.76***

***$p < .001$.

Table 7. Multiple regression results: unique variance in passage comprehension explained by spelling recognition, controlling for symbol level reading (RAN letter) and reading status ($N = 34$).

Step	Variable	R	R^2 change	F change
1.	RAN letter & Reading disability status	.37	.14	2.18
2.	PIAT	.91	.69	103.86***

***$p < .001$.

Table 8. Multiple regression results: unique variance in passage comprehension explained by spelling recognition, controlling for symbol level reading (RAN letter) and reading status excluding two outliers in RAN letter ($N = 32$)

Step	Variable	R	R^2 change	F change
1.	RAN letter & Reading disability status	.62	.38	7.90**
2.	PIAT	.93	.48	85.35***

**$p < .01$; ***$p < .001$.

including all the children in the sample while in Table 8 two dyslexic children who had extreme scores in RAN letters were excluded for comparison. The last model (see Table 9) examined the relationship between PIAT and reading comprehension while controlling for word reading proficiency and reading status. WRE was chosen as the word reading proficiency control variable because of its consistent, highly significant relationship with reading comprehension for both average and dyslexic readers and its high correlations with the other word-level reading proficiency measure, word identification. In addition, WRE incorporates both word reading accuracy and speed. The results in Tables 6–9 show that PIAT uniquely explained a significant portion of

Table 9. Multiple regression results: unique variance in passage comprehension explained by spelling recognition, controlling for WRE and reading status ($N = 34$).

Step	Variable	R	R^2 change	F change
1	WRE & Reading disability status	0.94	0.88	110.58***
2	PIAT	0.95	0.02	4.55*

*$p < .05$; ***$p < .001$.

variance in passage comprehension after controlling for the reading disability status and Elision, RAN letter names and word reading proficiency,[2] respectively. Table 8 shows that the role of PIAT in reading comprehension did not change when analysis was performed excluding two dyslexic children whose RAN letter naming were extremely slow. There were no significant interaction effects.

Discussion

The results from the present study confirm and expand our knowledge on the complex relationship of phonological and orthographic processes to reading: Phonological processing is critical for word reading and reading comprehension while there is an additional significant relationship between spelling recognition and reading skills at the word, and connected reading level for both nondyslexic *and* dyslexic children beyond phonological processing. The highly significant associations between word reading and PA, particularly between nonword reading (i.e., Word Attack and NWRE) and PA ($r = .74$** for dyslexic readers and $r = .80$*** for average readers), confirm the relationship between phonological processing and decoding found in many previous studies (Gayán & Olson, 2003; Hulme, 1995; Lonigan, Burgess, & Anthony, 2000). These findings continue to affirm the role of phonological processing in reading acquisition for both average and dyslexic readers (Torgesen, Wagner, & Rashotte, 1994; Wagner & Torgesen, 1987).

The results from the present study also contribute new information about the role of spelling recognition in fluent reading and comprehension. In relation to our first research question, the findings demonstrate that average readers outperformed dyslexic readers only in word and nonword decoding skills and memory for digits, but not in spelling recognition, when they were matched on word identification skills. This result fails to support a hypothesis that dyslexic readers compensate for their poor phonological skills to some extent with visual reading, or orthographic strategies. In contrast to findings in previous studies (Pennington et al., 1986; Siegel, Share, & Geva, 1995), dyslexic children in the present study, matched to controls on the word reading proficiency, did not outperform their controls in spelling recognition.[3] This is consistent with the findings of Swanson and Alexander (1997), who reported that learning disabled readers did not outperform controls on a measure of orthographic processing. These discrepant findings may be attributed to a wider age gap between average readers and their controls in previous studies (Pennington et al., 1986; Siegel et al., 1995) than exist in the present study and Swanson and Alexander's (1997) study. It should be noted that matching older individuals with dyslexia with controls on word reading proficiency presents the confound that they still tend to have more reading experience. In the research in this area, age gaps between dyslexics and controls range from almost 20 years (Pennington et al., 1986) to 1 year (present study), and even less than 6 months (Swanson & Alexander, 1997).

The main focus of the study was to examine the relationship between spelling recognition and reading skills, particularly reading comprehension, for average readers and dyslexic readers. The overall results suggest convergent evidence for the potential importance of orthographic processing in reading development. It also indicates that the relationship between spelling recognition and reading skills appears to be similar for both average readers and dyslexic readers. The present study confirms previous findings associating spelling recognition with reading skills at the letter name, word, and connected reading level for nondyslexic readers (Barker, Torgesen, & Wagner, 1992). It also extends the findings to dyslexic readers. Spelling recognition was consistently correlated with reading measures in both dyslexic and average readers. The trend suggests that spelling recognition plays an additional important role for both average and dyslexic readers in reading development and in the reading processes. Moreover, the results demonstrated that receptive spelling recognition was significantly associated with reading comprehension, even beyond phonological processing, symbol level reading skills, and word reading accuracy and speed. Spelling recognition may be conceptualized as a higher order integration task. The task requires mapping phonological information to visual representation, searching and selecting a permissible letter string and matching it to a memorized word template. This integration aspect of the task may be the reason why it explains additional independent variance in higher order reading that demands more than proficiency in lower level component skills such as decoding (Katzir et al., in press).

The results confirm findings from Hansen and Bowey's study (1994) regarding the role of phonological processing in reading comprehension for both average readers and dyslexic readers. Furthermore, an interesting finding in the present study is the different relationship between RAN and reading skills for the dyslexic group than for the average reading group. Children's performance on RAN letter names was not correlated with any reading measures for the dyslexic group whereas it was significantly correlated with spelling recognition and all reading measures for the average reading group. The result for the average group corresponds to findings by Parrila et al.'s study (2004), in which naming speed was a significant predictor of word reading and passage comprehension for average readers even after controlling for the augo-regressive effect. However, once two dyslexic children whose RAN was extremely high were removed, the results for the dyslexic readers are consistent with previous studies (McBride-Chang & Manis, 1996; Meyer, Wood, Hart, & Felton, 1998), in which a strong association was found between naming speed and word identification for poor readers. These findings suggest the importance of incorporating different subtypes of reading disability to accurately understand the reading process for children with reading disability. For instance, the two children with high RAN latency scores may have a fluency deficit and thus aggregating them with other dyslexic children into one category in analysis may obscure potentially different nature of relationships between reading related processing and reading skills for different subgroups. However, as this is a small sample, a larger sample is needed to verify the findings. Particularly, a larger sample would reveal clearer relationships between reading related processing and different level of reading skills, for example, by allowing regression analysis with more predictors in the model simultaneously.

The significant relationship between spelling recognition and reading comprehension supports the proposed role of spelling recognition in efficient word recognition (Wolf & Bowers, 1999). Spelling recognition is speculated to have an indirect relationship with reading comprehension through shared variance of comprehension with WRE. The results of the present study appear to provide evidence for this. First, the relationships between receptive spelling recognition and reading fluency measures such as naming speed, WRE, and NWRE were consistently significant for both average readers and dyslexic readers. Second, the role of efficient word recognition in reading comprehension (Rashotte & Torgesen, 1985) is confirmed by significant correlations between real word and NWRE and reading comprehension. Third, spelling recognition and reading comprehension were significantly correlated for both average and dyslexic readers. Finally, spelling recognition explained a small, yet significant proportion of variance in reading comprehension, even after the effects of symbol level reading and WRE were accounted for. Therefore, we speculate that the development of proficient orthographic knowledge beyond single letter units and the rapid recognition of orthographic patterns facilitate automatic word recognition, which is a requisite for successful reading comprehension. In other words, automatic word recognition which enables good comprehension is facilitated by both the rapid retrieval of information tapped by WRE and RAN as well as the accurate recognition of this information by a well-specified orthographic representation system tapped by the PIAT. This supports Wolf and Bowers' (1999) hypothesis that rapid retrieval (i.e., naming speed) contributes to the rate of spelling recognition at the word level. Wolf and Bowers further suggested that slow retrieval and recognition of single letters may inhibit the acquisition of spelling patterns that occur in print. Furthermore, according to Perfetti's (1991) verbal efficiency model, slow word recognition inhibits one's reading comprehension due to large demands on working memory. Therefore, students' proficiency in spelling recognition, mediated by speedy sight reading to some extent, affords them more cognitive attention to the extraction of meaning from text.

The main limitation of this study was that the spelling recognition task was untimed. Investigation of the interactions among rate of spelling recognition, WRE, and reading comprehension would better reveal the nature of the relationships. This possibility is explored in a couple of studies that examined the role of automaticity in spelling recognition for reading comprehension (Gray, Mulhern, & Neil, 2000; Mulhern, Wylie, & Sawey, 1997). Mulhern et al. (1997) developed a chronometric estimate of automaticity for spelling words as a measure of spelling recognition. Results showed that automaticity of spelling recognition was highly correlated with reading comprehension. Gray et al. (2000) replicated the findings with French language learners who participated in a computerized correct spelling recognition task and other language proficiency measures, including reading comprehension. The correlations between the latency in orthographic task and aural and reading comprehension were significant. In other words, students who were more efficient in the spelling recognition task performed better in reading comprehension in French as a second language.

Implications and future directions

Available literature and the results of the present study suggest the importance of incorporating orthographic training in reading intervention programs. Children with and without dyslexia will benefit from instruction with an emphasis on orthographic knowledge and strategies. In a fluency-based reading program, developed by Wolf, Miller, and Donnelley (2000), they describe activities such as computer games to increase speed of spelling recognition. They also recommend other activities such as wall charts of irregular words and sublexical units and their roles in words as well as visually highlighting the orthographic–phonological relationships in word families. In addition, they recommend working on reading fluency from the word identification level to the reading comprehension level. This should be done through repetitive efforts to increase processing speed at the lexical and sublexical levels with an emphasis on work on spelling recognition along with phonological, semantic, and syntactic processing.

With much remaining to be studied regarding the role of orthographic knowledge for both typically developing readers and dyslexic children, more attention should be paid in future studies to specific components of reading that orthographic skill tests measure (Vellutino, Scanlon, & Chen, 1995). Many studies do not distinguish receptive and expressive aspects or fluency and accuracy aspects of orthographic knowledge and reading skills. In order to tease out components of orthographic knowledge that facilitate different aspects of reading skills, researchers need to use specific, precise measures for both orthographic processing and reading comprehension. For example, orthographic measures that assess both accuracy and rate should be incorporated in the study of reading fluency development (Katzir, 2002). In future studies, the nature of the role of orthographic knowledge in reading development beyond correlational relationships should be investigated because there are only a few experimental studies that have examined a causal relationship between orthographic knowledge and reading skills (Ehri & Wilce, 1987).

Finally, the small sample of the study did not allow for the investigation of different subtypes of orthographic and phonological deficits. Some researchers have argued that some children who appear to have mastered alphabetic skills, but have difficulties with irregular spelling patterns have ‘‘surface dyslexia’’(Castles & Coltheart, 1993, 1996; Seymour, 1986; Temple & Marshall, 1983). For example, Castles and Coltheart (1996) reported a student whose reading is extremely poor on irregular word reading tasks while normal on nonword and regular reading tasks. These children tend to write phonetically, and have hard time distinguishing homophones (e.g., *pear – pair*). The existence of these children is argued as a support for two channel system in the dyslexia: one subtype with phonological deficit and the other with visual, orthographic deficit. While the sample as a whole in this study did not seem to overcompensate orthographically, future subtyping studies should include multiple types of orthographic tasks with larger samples to address these issues developmentally.

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Notes

1. The two outliers, although they were of similar age (about 8 years and 6 months old), verbal IQ, differed in their profiles: One had RAN latency of 74 with average word reading skills (Word Identification and WRE) but poor word decoding (Word Attack and NWRE). The other had RAN latency of 104, but above average word reading and word decoding skills.
2. The results remained the same when all the control variables were included. That is, even after controlling for reading disability status, PA, RAN, and WRE, PIAT added significant amount of variance to reading comprehension for both average readers and dyslexic readers. These results were not reported due to the over-specification problem from a small sample size in the study.
3. We also conducted regression analyses separately for average and dyslexic readers in order to examine whether dyslexic children overcompensate their lack of phonological skills with their orthographic processing. The results showed that orthographic processing was significant in explaining variance in reading comprehension after controlling for their phonological processing (Elision) for both average and dyslexic readers. However, orthographic processing contributed larger amount of unique variance to reading comprehension for average readers than dyslexic readers after controlling for their phonological processing. These results are not reported here because we are cautious about the overspecification problem due to the small sample size in the study.

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