# THE RELATIONSHIPS AMONG COGNITIVE CORRELATES AND IRREGULAR WORD, NON-WORD, AND WORD READING

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*This study explored four hypotheses: (a) the relationships among rapid automatized naming (RAN) and processing speed (PS) to irregular word, non-word, and word reading; (b) the predictive power of various RAN and PS measures, (c) the cognitive correlates that best predicted irregular word, non-word, and word reading, and (d) reading performance of typical and poor readers on irregular word, non-word, and word reading. Sixty participants in Grades 1-4 with and without reading disabilities were administered a measure of phonological awareness (PA) and a measure of working memory (WM), and several measures of RAN and PS. The findings indicated that PS had the strongest correlation with irregular word reading, whereas RAN had the strongest correlations with word reading and non-word reading. As with previous research RAN letters was the best predictor of reading skills. The best model for predicting reading was based on a combined measure of PA and RAN letters. An interesting finding was that the correlation between irregular and non-word reading was significant for students with typical reading, but insignificant for the poor readers. These findings provide support for both the dual-route and double-deficit theory of dyslexia that ascribes independent contributions of PA and RAN to the development of reading skills.*

Previous research has identified several cognitive and academic variables that are implicated as correlates or causes of reading disabilities (e.g., Badian, 2005; Bishop & League, 2006; Fawcett, Singleton, & Peer, 1998; Scarborough, 1998). Specifically, hypotheses about the causation of specific reading disabilities, or dyslexia, have been derived from theories regarding the relationships between and among basic reading skills and phonological awareness (PA), working memory (WM), rapid automatized naming (RAN), and processing speed (PS). The purposes of this study were to: (a) investigate the relationship of RAN and PS to various formats of word reading ability, (b) explore how various RAN and PS formats relate to reading, (c) identify which factors (PA, WM, RAN, and PS) best predict reading ability, and (d) investigate if differences exist between typical readers and poor readers' abilities to read irregular words, non-words, and words that are a mixture of phonically regular and irregular words (word reading). Because more research has focused on PA and WM, this study placed a greater emphasis on measures of RAN and PS.

*Phonological Awareness*

Research findings have suggested that poor PA is the main causal factor that underlies difficulties in the acquisition of word recognition skills (e.g., Abbott, Walton, & Greenwood, 2002; Catts, 1996; Foorman, Francis, Shaywitz, Shaywitz, & Fletcher, 1997; Reading & Van Duren, 2007; Savage & Frederickson, 2006; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997; Wagner &Torgesen, 1987). In fact, a few researchers have proposed a unitary theory of reading difficulty, claiming that all reading difficulties are caused by a phonological impairment alone (e.g., Lundberg, Frost, & Petersen, 1988). This unitary hypothesis does not, however, account for the fact that some students have adequate or even good phonological awareness, but still struggle to learn to read (Mather & Goldstein, 2008; Rack, Snowling, &

Olson, 1992; Wolf & Bowers, 1999). Because the phonological awareness hypothesiscannot account for all cases of reading failure, researchers must explore other possible factors that contribute to reading difficulties, such as working memory, RAN, and processing speed.

*Working Memory*

Many researchers have investigated he role of working memory (WM) as a contributing factor to reading disability (De Jong, 1998; Engle, Cantor, & Carullo, 1992; Swanson & Saez, 2003). Shankweiler and Crain (1986) found that WM resources are very taxed by underdeveloped PA. Students with poor phonics have impacted working memory systems and subsequent poor reading. In addition, Howes, Bigler, Lawson, and Burlingame (1999) confirmed that auditory sequential memory, more than WM, is often impaired in children with reading disabilities.

Although numerous studies have focused on the links between PA and WM and reading skills, fewer studies have explored the role of RAN and PS measures. Thus, questions still remain regarding which cognitive variables are the most critical for explaining the development of reading abilities and the causation of reading disabilities, as well as the nature of the interrelationships among these variables. Knowledge of the relationships among these cognitive abilities and basic reading skills can provide a better understanding of the cognitive patterns of weaknesses associated with reading problems and help guide the development and selection of more accurate and sensitive assessments.

*Rapid Automatized Naming (RAN) and Processing Speed (PS)*

Recently, investigators have begun to look more closely at the role of both RAN and PS in reading failure, as well as their relationships to word reading skill (e.g., Compton, 2003; Georgiou, Parrila, Kirby, & Stephenson, 2008; Urso, 2008). They have also explored how students with and without reading disabilities perform on measures of non-word and irregular word reading (Abbott et al., 2002; Coltheart, 2007; Reading & Van Duren, 2007; Savage & Frederickson, 2006). Findings from these studies have indicated that some students perform differently on measures of irregular word reading (words where one or more parts do not conform to English spelling rules, e.g., *said*), and non-word reading (made up words that conform to English spelling rules; also referred as to as pseudowords and nonsense words, e.g., *bup*). Thus, some students appear to have more difficulty reading non-words, whereas others have more difficulty reading irregular words.

*Rapid Automatized Naming*

Over the last decade, RAN has evolved as another possible correlate of reading disability, accounting for a significant amount of variance over and above what is explained by phonological awareness (Wolf & Bowers, 1999). Naming speed, or RAN, is defined as the speed at which names are retrieved in identifying colors, letters, digits and objects; slow RAN scores appear to differentiate readers with dyslexia from typical readers (Catts, Gillispie, Leonard, Kail, & Miller, 2002; Denckla & Cutting, 1999; Wolf, Bowers, & Biddle, 2000). For example, influenced by Denckla and Rudel's (1976a; 1976b) research that explored the importance of recall and automaticity in reading, Wolf et al. (2000) raised the possibility of a general timing deficit to explain the slow RAN scores among poor readers. Wolf et al. reported a strong correlation between the speed with which kindergarten children named familiar letters and digits and their subsequent performance on a word recognition task in Grade 2. Speed of naming a series of common pictures or symbols has been demonstrated to correlate both with kindergarten level reading achievement scores and future reading performance in first and second grade (Denckla & Rudel, 1976b; Wolf & Bowers, 1999).

A few researchers have addressed the contributions of both RAN and PA to reading failure. For example, Wolf and Bowers (1999) developed the *double-deficit hypothesis* to explain the relationship between PA, RAN, and slow reading development, explaining that a weakness in either ability could contribute to poor reading. The double-deficit theory indicates that if both routes are impeded, the reading problems will be more severe, and as a consequence, remediation will be more difficult.

Currently, a single widely accepted explanation of the reading skills predicted by RAN does not exist. Wolf and Bowers (2000) described RAN as including the sub-processes of reading associated with letter identification or the serial scanning of print, and the ease and rate at which children induce orthographic patterns from print exposure. Thus, RAN may impact the amalgamation of grapheme–phoneme connections, as well as the quality of orthographic codes stored in memory. RAN also appears to be more related to irregular word reading than to non-word reading (Denckla & Rudel, 1976a; Wolf & Bowers, 1999).

Researchers have also investigated the different formats of RAN tasks (objects, colors, numbers, letters) (e.g., Bowey, McGuigan, & Ruschena, 2005; Neuhaus, Foorman, Francis, & Carlson, 2001; Van den Bos, Zijlstra, & Broeck, 2003; Wolf & Bowers, 1999). As an additional procedure, Wolf and Denckla (2005) introduced Rapid Alternating Stimulus (RAS) tasks as promising predictors of reading ability. These tasks require students to name 2- and 3- set combinations of letters, numbers, and colors. The new RAN/RAS Tests (Wolf & Denckla, 2005) contain RAS tasks in the following formats: (a) 2-set letters and numbers, and (b) 3-set letters, numbers, and colors which may provide improved prediction of reading skill. Currently, little research exists regarding the utility and significance of RAS tasks. The following research substantiated findings exist, however, in regard to the relationship between RAN and reading skills: (a) RAN letters followed by RAN numbers are the strongest predictors of reading skills (Bowey et al., 2005; Compton, 2003; Neuhaus et al., 2001; Van den Bos et al., 2003); (b) RAN appears to be distinct from phonological skills in the sense that it accounts for independent variance in word reading and reading comprehension (Manis, Doi, & Bhadha, 2000; Wolf & Bowers, 1999); (c) the independent contribution of RAN to word reading and reading comprehension is larger for younger readers and students with RD (Manis et al., 2000; Wolf & Bowers, 1999); (d) RAN accounts for independent variance in both word-reading accuracy and speed, although the relations are stronger with speeded measures (Manis, Seidenberg, & Doi, 1999; Wolf & Bowers, 1999); (e) RAN is not an effective predictor of non-word reading skills (Manis et al., 1999; Wolf & Bowers, 1999); and (f) RAN has a strong correlation with orthographic skills (Cutting & Denckla, 1999; Manis et al., 1999; Sunseth & Bowers, 2002; Wolf & Bowers, 1999).

*Processing Speed*

To help explain other factors that may affect reading, Nicolson and Fawcett (1999) proposed a unified view of timing deficits and suggested that PS can also be a cause of poor reading. PS is highly related to tasks that measure speed at which individuals perceive, react to, and respond to incoming information. In addition, PS involves the ability to maintain focus and work quickly through automatic cognitive tasks. Nicolson and Fawcett (1999) found that individuals with dyslexia have slowed or limited ability to automatize skilled behaviors. Therefore, slow PS may cause difficulties in the development of reading, writing, and phonological skills. Kail, Hall, and Caskey (1999) suggested that cognitive processing speed would mediate age-related changes in phonological awareness, naming speed, and visual-spatial skills because each of these constructs may be directly affected by the speed of processing. An important component of this view is that a weakness in PS not only impacts reading but all other related language skills.

Unlike exploration of the various RAN formats, previous research has not investigated in-depth the different formats of PS measures to decide which measures best predict reading ability. The existing studies have three limitations: (a) they have sampled only one or two of the various formats of PS, typically tests of visual matching and visual elimination (e.g., the Test of Visual Matching and the Cross Out Test on the Woodcock-Johnson III Test of Cognitive Abilities);(b) they have focused on typically developing children or on different groups such as only students with dyslexia or students with Attention Deficit Hyperactivity Disorder (ADHD); and (3) they have attempted to determine whether or not students with reading difficulties have slow PS (e.g., Shanahan et al., 2006; Waber et al., 2001; Weiler, Bernstein, Bellinger, & Waber, 2000). In addition, some researchers have included RAN under the umbrella of PS because PS contributes significant variance to rapid naming (Ackerman & Dykman, 1993; Kail, 1991). This notion is supported by Kail and Hall (1994) who reported that 36% to 40% of the variance in rapid naming was explained by the WISC-IV Coding subtest (PS measure). RAN, however, exclusively measures naming facility which is just one of the narrow cognitive abilities subsumed under the broad cognitive ability of PS, that also includes reaction time, executive decision making, and quickness of motor response (Feldmann, Kelly, & Diehl, 2004).

*The Dual Route Theory of Reading*

The reading of real words (both phonically regular and irregular), and non-words is a defining component of the dual route theory. Researchers have explained the dual route theory as a way to subtype dyslexia by the characteristics exhibited by the reader (e.g., Bowey& Rutherford, 2007; Castles &Coltheart, 1993; Coltheart, 2007; Tree, 2008). The dual-route theory describes two subtypes of dyslexia: phonological dyslexia and surface dyslexia. Phonological dyslexia indicates difficulty using grapheme-phoneme correspondences to decode non-words and phonically regular real words. In contrast, surface dyslexia indicates difficulty with reading words that contain irregular spelling patterns (e.g., *once*). Some researchers have found that a small minority of children with dyslexia has pure surface dyslexia with intact phonological encoding, whereas a larger group of children has pure phonological dyslexia (Bowey & Rutherford, 2007; Castles & Coltheart, 1993). The majority of students with dyslexia, however, have difficulties in both areas.

*The Direct and Indirect Routes of Word Reading*

When pronouncing words, readers may use either the direct (lexical) route or the indirect (non-lexical) route. The direct route involves quick visual recognition of the word and is supported by semantic knowledge of the word. This route is used to read familiar words and is especially important in irregular word reading. The direct route cannot be used to read unfamiliar or non-words. The non-lexical, or indirect route, involves the following procedures: (a) the parsing of graphemes into component parts, (b) the application of grapheme to phoneme correspondence rules, and (c) the blending of the phonemes. Skills in the indirect route procedures are pertinent to pronouncing unfamiliar or non-words (Coltheart, 2007; Kendall, Conway, Rosenbek, & Gonzalea-Rothi, 2003). According to dual route theory, words activate both the direct visual route and the phonological route (see Coltheart, 1978, 1980; Morton & Patterson, 1980). Irregular words can be read correctly only through the visual route as there are no reliable orthographic rules to apply. Real words are said to benefit also from sub-lexical processing by the indirect phonological route. Non-words can only be read by this indirect route.

Clearly, additional research is needed to increase knowledge about the relationships among irregular word, non-word, and word reading, as well as RAN and PS measures. Further knowledge in regard to reading patterns among students may help enhance diagnostic efforts, and guide treatment to improve reading performance. The present study was carried out to provide further clarification of the relationships among RAN and PS measures and children's word reading abilities. The results of this study will add to the growing body of research examining the various cognitive correlates of reading ability and provide further information regarding children who do not have poor PA or WM as a major correlate of poor reading.

To the authors' knowledge, this study is the first to examine five different measures of PS and six different measures of RAN and determine the correlations of these measures to three different reading outcomes (irregular word, non-word, and word reading). In addition, the current study compared the predictive power of these measures, individually and when combined together, to predict word-reading skills. As previously noted, researchers have indicated that RAN letters and then RAN numbers were the strongest predictors of reading skills (Bowey et al., 2005; Compton, 2003; Neuhaus et al., 2001; & Van den Bos et al., 2003). However, none of these studies investigated the predictive power of RAN letters and RAN numbers combined when evaluating reading skill. According to Wolf and Denckla (2005), promising results may be found from integrating these two tasks.

Four major hypotheses were postulated. First, RAN Total (i.e., a score combining the six RAN measures together) would be a stronger predictor of reading ability than the PS Cluster, (i.e., a score combining the WJ III Cognitive [WJ III COG; Woodcock, McGrew, & Mather, 2001a] Visual Matching and Decision Speed tests) because RAN tasks share many common characteristics with reading ability compared with the visual scanning requirements of PS tasks. Second, RAN letters followed by RAN numbers would be the strongest predictors of word reading ability. For PS measures, the WJ III COG Visual Matching and Pair Cancellation tests would be the strongest predictors of word reading ability, as found by Urso (2008). Third, phonological awareness and RAN would have the strongest weight in the cognitive models in the prediction of all reading skills (Badian, 1993; Bowers & Swanson, 1991; Catts, 1996; Compton, Olson, DeFries, & Pennington, 2002; Manis, et al., 2000; Torgesen et al., 1997; Wolf & Bowers, 1999) whereas PS (Kail, 1991; Nicolson & Fawcett, 1999; Urso, 2008; Waber et al., 2001; Weiler et al., 2000) and WM (De Jong, 1998; Engle et al., 1992; Swanson & Saez, 2003) will compete to add a significant contribution for these models. Fourth, strong positive correlations will exist between word reading (a mixture of phonically regular and irregular words), irregular word reading, and non-word reading for students with typical reading, as well as students with poor reading. On the other hand, correlations of less magnitude were expected between irregular word reading and non-word reading because they rely on different reading routes (the direct and indirect routes), as well as different linguistic abilities (orthography vs. phonology).

*Study's Questions*

This study addressed the following four major questions:

Study Question 1: What are the relationships of PS and RAN to poor reading? What is the best predictor (RAN-Total or PS Cluster) for predicting irregular word, non-word, and word reading?

Study Question 2: How do different measures of RAN and different measures of PS correlate with irregular word, non-word, and word reading?

Study Question 3: Do the following cognitive variables (PA, RAN, WM, and PS) predict all reading skills (irregular word reading, non-word reading, and word reading)?

Study Question 4: Will participants have similar performance on tests that measure irregular word, non-word, and word reading? How do these tests (TIWRE, TOWRE-PDE, WA, and LWI) correlate?

## Method

### *Participants*

A total of 60 students from two separate schools in two separate locations in the Southwest United States participated in the study. The number of participants in this study was based on a power analysis using Cohen's (1977) approach to estimate the necessary sample size. Participants in the study were ages 6-1 to 10-0 years (M= 9-0 years, SD= 1.06 years). This age range was selected due to the trajectory of PS development at this time and the focus on the development of basic reading skills. Twenty-nine females and 31 males participated in the study. The participants were selected from a larger set of students who were assessed to meet the requirements for inclusion in the study: intelligence within the average range, native speakers of English, no noted emotional/behavioral disorder, no noted attention disorders, and no sensory impairments. Seventeen students with RD and 39 average readers (n = 56) comprised the normally distributed sample. Another sample consisted of 21 students with RD, 17 from the previous sample and four new participants.

Two school sites were purposefully selected to yield the population of participants who would allow for group analyses of both students with and without RD. Twenty one students were recruited from the first site school, a private school for students with learning disabilities in a metropolitan area. These students were all pre-identified as having reading disabilities and received small-group instruction throughout their core academic areas, as well as specialized reading instruction and related services administered by specialists. Thirty-nine students were recruited from the second site school, a small K-12 public charter school with a science focus in another metropolitan area. These students were not identified as having reading difficulties and did not receive remediation or special education services. Consent for participation was obtained from the participants and their parents/guardians.

### *Materials*

This section describes the tests used to measure both the criterion variables (irregular word, non-word, and word reading) and the predictor variables (PA measure, WM measure, RAN measures, and PS measures). TheWJ III COG (Woodcock et al., 2001a) and the Woodcock-Johnson III Tests of Achievement (WJ III ACH; Woodcock, McGrew, & Mather, 2001b) were used for several of the measures. The WJ III COG and WJ III ACH are a comprehensive, norm-referenced, individually administered assessment of cognitive abilities and achievement. In general, the internal consistency reliability estimates for all WJ III measures are uniformly high, most often with magnitudes in the .80s and .90s for individual tests, and in the .90s for clusters. In addition to tests from the WJ III, three other standardized tests (RAN/RAS, TOWRE-PDE and TIWRE) were used and are described below.

*PA and WM measures.* The Sound Blending test from the WJ III was administered to measure PA ability. This test requires listening to individual phonemes and then blending these sounds into familiar read words. The WJ III COG Numbers Reversed test was administered to measure WM. This test requires listening to a series of digits and then repeating the digits in reversed order.

### *PS measures*

Participants were administered the Woodcock-Johnson Tests of Cognitive Abilities III of Visual Matching, Decision Speed, Rapid Picture Naming, Pair Cancellation, and Cross Out to measure various formats of processing speed ability (WJ III COG; Woodcock, McGrew, & Mather, 2001a). Fairly extensive confirmatory factor analyses provided validity evidence for the WJ III COG measures of PS (see McGrew & Woodcock, 2001, p. 62-63). The PS Cluster score is determined from the administration of the Visual Matching and Decision Speed Tests on the WJ III COG (see Table 1 for all WJ III COG tests). The tests have administration times ranging from 2 to 3 minutes (Mather & Woodcock, 2001).

*RAN measures*

The Rapid Automatized Naming and Rapid Alternating Stimulus Tests (RAN/RAS; Wolf & Denckla, 2005) were used to assess naming speed ability. On all six test sections, the examinees were asked to recognize and name accurately and rapidly visual symbols, such as letters, numbers, objects, and/or colors. The Letters, Numbers, Colors, and Objects subtests are comprised of 50 items consisting of five high-frequency stimuli randomly repeated ten times in an array of five rows. The RAS tests are comprised of a mixture of the stimuli. One of the RAS tests, *2-Set Letters and Numbers*, consists of 50 stimulus items alternating five letters and numbers. The second RAS test, *3-Set Letters, Numbers, and Colors*, consists of 50 stimulus items of five alternating letters, numbers, and colors. Scores are based on the amount of time required to name all of the stimulus items on each test section. Wolf and Denckla (2005) reported test-retest corrected reliability coefficients ranging from .81 to .98 for different levels (i.e., elementary, middle, high school, and all ages). A second type of reliability, inter-scorer reliability, ranged from .98 to .99 for RAN/RAS tests.

**Table 1. WJ III COG Tests**

| Test | Stimuli | Test Requirement | Response |
|---|---|---|---|
| Visual Matching | Visual (numbers) | Rapidly locating and circling identical numbers | Motoric (circling) |
| Decision Speed | Visual (pictures) | Identifying and circling the two most conceptually similar pictures in a row | Motoric (circling) |
| Rapid Picture Naming | Visual (pictures) | Recognizing objects, then retrieving and articulating their names rapidly | Oral (words) |
| Pair Cancellation | Visual (pictures) | Identifying and circling instances of a repeated pattern rapidly | Motoric (circling) |
| Cross Out | Visual (objects) | Identifying and circling instances of a repeated pattern rapidly | Motoric (circling) |
| Sound Blending | Auditory (phonemes) | Synthesizing language sounds (phonemes) | Oral (word) |
| Numbers Reversed | Auditory (numbers) | Holding a span of numbers in immediate awareness while reversing the sequence | Oral (numbers) |

*Note.* The data in Table 1 are from the Woodcock-Johnson III Technical Manual: Normative Update (p. 58, 59, 65, 66) by McGrew, Schrank, & Woodcock, 2007, Rolling Meadows, IL: Riverside Publishing.

*Reading Measures*

*Irregular word reading*. The Test of Irregular Word Reading Efficiency (TIWRE; Reynolds & Kamphaus, 2007) was used to measure irregular word reading. The TIWRE offers a rapid assessment of the examinee's ability to pronounce words with irregular spelling patterns. The TIWRE is different from other word reading assessments because it presents only irregular words for pronunciation. Each form presents letters (uppercase and lowercase) and irregular words for a total of 50 items. The TIWRE takes approximately two minutes to administer. Reliability coefficients for all forms are in the mid-to-high .90s.

*Non-word reading*. Non-word reading was measured by the WJ III ACH Word Attack test (WA; Woodcock et al., 2001b). WA is an un-timed measure of an individual's ability to read phonically regular non-words accurately. The test/retest reliabilities are mostly .80 or higher. In addition, a timed measure of non-word reading, the Test of Word Reading Efficiency-Phonetic Decoding Efficiency subtest (TOWRE-PDE; Torgesen, Wagner, & Rashotte, 1999) was administered. This test includes 63 pronounceable non-words requiring the examinee to decode each non-word as quickly as possible. The test is timed (45 seconds) and has two alternate forms. The test/retest (time sampling) reliability coefficients ranged from .83 to .96.

*Word reading*. For word reading, all participants were administered the WJ III ACH Letter-Word Identification test (LWI; Woodcock et al., 2001b). This test involves identifying letters and then reading real words. The test/retest reliabilities are mostly .80 or higher.

*Procedures*

Tests were administered to all students individually in two 30- minute sessions by trained examiners. All testing was conducted as per the examiner's manuals and answers were recorded on test protocols. The test administration was counterbalanced to (a) avoid potential effects of practice in speeded tasks, (b) maintain children's concentration and interest, and (c) avoid learning effects (Fisher & Yates, 1963). The RAN Total was obtained by calculating the sum of RAN tests (Objects, Colors, Numbers, Letters, 2-set Letters and Numbers, and 3-set Letters, Numbers, and Colors) and then dividing by the number of the tests, in this case six. The WJ III COG provided the PS Cluster (Visual Matching and Decision Speed tests). The RAN Total score and PS Cluster were considered the most reliable measures since these scores reflect two or more measures of each ability. In terms of statistical analyses, descriptive statistics, Pearson product moment correlations, and hierarchical regression analyses were used to answer the study's questions.

**Results**

*Preliminary Data Analysis*

To begin analyzing the study data, all test variable raw scores were converted to standard scores (SS; M=100, SD=15) as displayed in Table 2. The Kolmogorov-Smirnov statistic was performed to test the hypothesis that the data were normally distributed. This test compares the set of scores to a normally-distributed set of scores with the same mean and standard deviation. Therefore, if the test is not significant ($p > 0.05$), it means that the distribution is not significantly different from a normal distribution. If, however, the test is significant ($p < 0.05$) then the distribution in question is significantly different from a normal distribution (Field, 2009).

The data displayed normal distributions for all predictors and criterion variables $D$ (55) statistics ranged from .062 to .126; all statistics were not significant ($p > 0.05$). Slightly lower performances (positively skewed distributions) were detected in the distributions. This finding was expected due to the fact that 17 students were identified as having a reading disability. To improve the shape of the distributions, the responses of outliers whose scores were ±2 SD or more from the group mean were replaced by a value equal to the next highest non-outlier-score plus 1 unit of measurement (Tabachnick & Fidell, 2001). This process is known as winsorization; winsorization preserves the rank of the outlier's score within the distribution without disturbing the distribution either by deleting the score, or by retaining it in its original form. The following sections present the results for each hypothesis explored in this study.

*Hypothesis 1: RAN Total would be a stronger predictor of reading ability than the PS Cluster*

*Correlations between irregular word reading, RAN-Total, and PS Cluster scores.*

To test this hypothesis, correlations between irregular word reading as measured by the TIWRE, and the RAN-Total, and PS Cluster score were conducted. Pearson correlations between the TIWRE test and both predictors –RAN Total and PS Cluster, were statistically significant (see Table 3). The PS Cluster had the strongest correlation with irregular word reading as measured by the TIWRE. The data set showed a moderate positive correlation between the PS Cluster and TIWRE test. To test if there was a significant difference between the two dependent correlation coefficients (RAN Total and TIWRE test and PS Cluster and TIWRE test), a $t$ test was performed (Steiger, 1980). No significant difference was found between the two correlations, $t\,(54) = .197$, $p > .05$, one-tailed.

*Correlations between non-word reading, RAN-Total, and PS Cluster scores.*

Pearson correlations among non-word reading as measured by the TOWRE-PDE and WA test of the WJ III ACH, and both predictors –RAN Total and PS Cluster, were statistically significant. The RAN Total had the strongest correlation with the TOWRE-PDE. The correlation between the RAN Total and WA tests was not as strong as the correlation with TOWRE-PDE test (see Table 3). When using the un-timed WA test to represent non-word reading, the RAN-Total had a stronger relationship with the TIWRE test than the WA test. On the other hand, no significant correlation was found between the PS Cluster and the WA test. To test if a significant difference existed between the two dependent correlation coefficients

(RAN Total and TOWRE-PDE test, and PS Cluster and TOWRE-PDE test), a *t* test was performed. No significant difference was found between the two correlations, $t$ (54) = 1.496, p > .05, one-tailed.

**Table 2. Means and Standard Deviations for all Study Variables**

| Variables | M | SD | Variables | M | SD |
|---|---|---|---|---|---|
| RAN Total | 93.38 | 12.73 | Visual Matching | 89.04 | 17.67 |
| RAN Objects | 90.78 | 13.19 | Decision Speed | 99.69 | 16.73 |
| RAN Colors | 91.59 | 16.39 | Rapid Picture Naming | 90.73 | 13.55 |
| RAN Numbers | 95.18 | 13.73 | Pair Cancellation | 98.51 | 7.21 |
| RAN Letters | 95.41 | 14.45 | Cross out | 93.08 | 14.79 |
| RAN 2-set Letters and Numbers | 93.76 | 14.98 | PS-Cluster | 89.98 | 16.86 |
| RAN 3-set Letters, Numbers, and Colors | 93.59 | 14.15 | TIWRE | 101.71 | 17.29 |
| Word Attack | 95.22 | 15.22 | Letter Word Identification | 97.45 | 14.77 |
| TOWRE-PDE | 92.92 | 10.94 | Number Reversed | 95.24 | 16.24 |
| Sound Blending | 110.92 | 14.52 | | | |

*Note*. N = 56, M = Mean, SD = Standard Deviation, TIWRE = Test of Irregular Word Reading Efficiency, RAN = Rapid Automatized Naming Test, TOWRE-PDE = Test of Word Reading Efficiency- Phonemic Decoding Efficiency test, PS = Processing Speed.

*Correlations between word reading, RAN-Total, and PS Cluster scores.*

The correlations between the LWI test and both predictors of RAN Total and PS Cluster were statistically significant. The RAN Total had the strongest correlation with the LWI test. A moderate positive correlation was found in the data set between RAN Total and the LWI test. To test if a significant difference existed between the two dependent correlation coefficients (RAN Total and LWI test, PS Cluster and LWI test) a *t* test was performed. No significant difference was found between the two correlations, $t$ (54) = .046, p > .05, one-tailed.

In summary, no significant differences were found among all of the dependent correlations. The PS Cluster had the strongest correlation with irregular word reading as measured by TIWRE test and no significant correlation was found with non-word reading as measured by WA test. RAN Total had the strongest correlation with both word reading as measured by the LWI test and non-word reading as measured by TOWRE-PDE test and the WA test.

**Table 3. Correlation Matrix for Question One and the Reading Variables**

| | TIWRE | TOWRE-PDE | WA | LWI | RAN-Total | PS-Cluster |
|---|---|---|---|---|---|---|
| TIWRE | 1.00 | | | | | |
| TOWRE-PDE | .672** | 1.00 | | | | |
| WA | .582** | .777** | 1.00 | | | |
| LWI | .798** | .867** | .763** | 1.00 | | |
| RAN-Total | .498** | .634** | .456** | .540** | 1.00 | |
| PS-Cluster | .522** | .463** | .237 | .533** | .470** | 1.00 |

*Note*. N = 56. ** Correlation is significant at the 0.01 level (1-tailed). TIWRE = Test of Irregular Word Reading Efficiency, TOWRE-PDE = Test of Word Reading Efficiency-Phonetic Decoding Efficiency test, WA= Word Attack test, LWI = Letter Word Identification test, RAN = Rapid Automatized Naming, PS = Processing Speed Cluster.

*Hypothesis 2: RAN letters followed by RAN numbers would be the strongest predictors of word reading ability. For PS measures, the WJ III COG Visual Matching and Pair Cancellation tests would be the strongest predictors of word reading ability.*
To test this hypothesis, Individual hierarchical multiple regression was performed to test the relative contributions of RAN/PS measures in the prediction various formats of word reading ability as measured by the TIWRE, TOWRE-PDE, WA, and LWI tests. Assumptions were tested by examining normal probability plots of residuals and a scatter diagram of residual versus predicted residual. Assumptions were tested by examining normal probability plots of residuals and a scatter diagram of residual versus predicted residual. No violations of normality, linearity, or homoscedasticity of residuals were detected. In addition, box plots revealed no evidence of outliers. RAN letters and then RAN numbers were entered in the first block. RAN colors, RAN objects, RAS 2-set letters and numbers, and RAS 3-set letters, numbers, and colors were entered in the second block.

Regression analyses revealed that the model significantly predicted all three dependent test variables as follows:

1. LWI test model, $F(6, 49) = 6.83$, $p < .05$. $R^2$ for the model = .48, and adjusted $R^2$ = .41;
2. WA test model, $F(6, 49) = 4.69$, $p < .05$. $R^2 = .39$, and adjusted $R^2 = .30$;
3. TOWRE-PDE test model, $F(6, 49) = 7.61$, $p < .05$. $R^2 = .50$, and adjusted $R^2 = .44$

Table 4 presents the hierarchical regression predicting LWI, WA, and TOWRE-PDE tests by the RAN/RAS tests.

Hierarchical multiple regression was conducted to predict the relative contributions of PS measures to irregular word reading as measured by the TIWRE. All related assumptions for the regression had been tested. The Visual Matching test and then the Pair Cancellation test were entered in the first block. Cross Out, Decision Speed, and Rapid Picture Naming tests were entered in the second block. Regression analysis revealed that the model significantly predicted TIWRE scores, $F(5, 50) = 4.298$, $p < .05$. $R^2$ for the model was .323, and adjusted $R^2$ was .248. Table 5 presents the hierarchical regression predicting TIWRE test by the PS measures.

To summarize, all RAN measures contributed 48%, 39%, and 50% in shared variability of LWI, WA, and TOWRE-PDE tests respectively; however, among all RAN measures, RAN letters had the strongest predictive power in the regression. In terms of PS measures, the full model contributed 32% in shared variability of TIWRE test; however, among all PS measures, the Visual Matching test had the strongest predictive power followed by the Pair Cancellation test in the regression model.

*Hypothesis 3: PA and RAN will have the strongest weight in the cognitive models in the prediction of all reading skills, whereas PS and WM will compete to add a significant contribution for these models.*
Hierarchical multiple regression was conducted to answer this question. All related assumptions for the regression had been tested. The Sound Blending (SB) test and then the RAN-Letters test were entered in the first block. Visual Matching (VM) and Number Reversed (NR) tests were entered in the second block. A model consisting of RAN-Letters, SB, and VM together was the most powerful one in predicting all reading skills. In separate multiple regression analyses tests their unique contributions for predicting TIWRE, TOWRE-PDE, and LWI tests were 44.7%, 66%, and 63.5%, respectively. However, when the untimed WA test was used to measure non-word reading, only SB and RAN-Letters tests had predictive power. These measures contributed 48% in shared variability of WA scores.

*Hypothesis 4: Strong positive correlations will exist between word reading (a mixture of phonically regular and irregular words), and irregular word reading and non-word reading with lower correlations between non-word and irregular word reading. The pattern of correlations will be similar for students with typical reading, as well as students with poor reading.*
Two group analyses were conducted to explore this hypothesis. One was for the normally distributed data and another one was for students with RD. In the normally distributed data, students' means performances on all three tests were comparable; average scores were 101, 95, 92, and 97 respectively for the TIWRE, WA, TOWRE-PDE, and LWI (see Table 2). Participants in general had similar average performances in non-word reading skills and word reading skills and slightly better performance in irregular word reading skills. High significant correlations were found among all reading variables (irregular word, non-word, and word reading) as demonstrated in Table 3. These correlations ranged from .58 between WA and TIWRE tests to .86 between LWI and TOWRE-PDE tests. In general, the

LWI test had higher correlations with TIWRE, TOWRE-PDE, and WA tests than the other reading tests had with each other.

**Table 4. Hierarchical Regression Predicting LWI, WA, and TOWRE-PDE Tests by RAN Measures**

| Analyses | Predictor Variables | Zero-order r | B | SEB | β | Block $\Delta R^2$ |
|---|---|---|---|---|---|---|
| | Step 1 | | | | | |
| Analysis-1 | Constant | | 38.43 | 11.71 | | |
| LWI | | .63 | | | .75** | |
| | RAN-Letters | .49 | .76 | .215 | -.139 | |
| | RAN-Numbers | | -.15 | .22 | | |
| | Step 2 | | | | | |
| | Constant | | 45.23 | 12.47 | | .07 |
| | | .49 | | | | |
| | RAN-Colors | .27 | .24 | .15 | .26 | |
| | RAN-Objects | .44 | -.41 | .19 | -.37* | |
| | RAN 2-Set | .48 | -.21 | .26 | -.21 | |
| | RAN 3-Set | | .21 | .27 | .20 | |
| | Step 1 | | | | | |
| Analysis-2 | Constant | | 34.89 | 12.921 | | |
| WA | | | | | | |
| | RAN-Letters | .55 | .362 | .237 | .34* | |
| | RAN-Numbers | .53 | .271 | .250 | .24 | |
| | Step 2 | | | | | |
| | Constant | | 44.80 | 13.95 | | .07 |
| | | .28 | | | | |
| | RAN-Colors | .19 | -.06 | .177 | -.07 | |
| | RAN-Objects | .42 | -.32 | .217 | -.28 | |
| | RAN 2-Set | .42 | -.25 | .300 | -.25 | |
| | RAN 3-Set | | .120 | .304 | .11 | |
| | Step 1 | | | | | |
| Analysis-3 | Constant | | 42.43 | 8.20 | | |
| TOWRE-PDE | | .68 | | | | |
| | RAN-Letters | .60 | .46 | .15 | .62** | |
| | RAN-Numbers | | .06 | .15 | .07 | |
| | Step 2 | | | | | |
| | Constant | | 45.29 | | | .04 |
| | RAN-Colors | .55 | .17 | .11 | .26 | |
| | RAN-Objects | .38 | -.20 | .14 | -.24 | |
| | RAN 2-Set | .54 | -.05 | .19 | -.06 | |
| | RAN 3-Set | .55 | .05 | .19 | .07 | |

*Note*. n = 56. ** β is significant at the 0.01 level, * β is significant at the 0.05 level, TOWRE-PDE = Test of Word Reading Efficiency-Phonetic Decoding Efficiency test, WA= Word Attack test, LWI = Letter Word Identification test, RAN = Rapid Automatized Naming tests, Zero-order r = The ordinary correlations coefficient, B = The unstandardized regression coefficients, SEB = The standard error of B, β = The standardized regression coefficients, $\Delta R^2$ = R square change.

To investigate if there was any special pattern on students' performance in word reading ability, only students with at least one low standard score (≤ 85 SS) on the TOWRE, WA, TIWRE, and LWI tests were included in the second data analysis. A total number of 21 participants were included in this data analysis. Eleven female and 10 male, age range from 6-1 to 9-8, mean of 8-6, and standard deviation of .98. Students' average performances on all three tests were similar; their average scores were between 84 and 85 with standard deviations between 9 and 15.

**Table 5. Hierarchical Regression Predicting TIWRE Test by PS Measures**

| Predictor Variables | Zero-order r | B | SEB | β | Block $\Delta R^2$ |
|---|---|---|---|---|---|
| Step 1 | | | | | |
| Constant | | 2.86 | 30.45 | | |
| Visual Matching | .50 | .29 | .15 | .31 | |
| Pair Cancellation | .50 | .73 | .38 | .30 | |
| Step 2 | | | | | |
| Constant | | 2.95 | 31.40 | | .01 |
| Cross Out | .38 | -.04 | .209 | -.03 | |
| Decision Speed | .45 | .05 | .20 | .04 | |
| Rapid Picture Naming | .38 | .16 | .19 | .12 | |

*Note*. n = 56. TIWRE = Test of Irregular Word Reading Efficiency, PS = Processing Speed Tests from WJ III COG, Zero-order r = The ordinary correlations coefficient, B = The un-standardized regression coefficients, SEB = The standard error of B, β = The standardized regression coefficients, $\Delta R^2$ = R square change.

The Pearson correlation of reading variables (TIWRE, TOWRE-PDE, WA, and LWI tests) indicated that the TOWRE-PDE test performance related highly to LWI test performance $r$ (20) = .806, $p< 0.05$, one-tailed. In contrast, the correlation between the TIWRE and TOWRE-PDE tests was insignificant within the reading difficulties group $r$ (20) = .08, $p > 0.05$. Furthermore, no significant correlation was found between the TIWRE and WA tests within the reading difficulties group as well $r$ (20) = -.01, $p > 0.05$ (see Table 6).

Additionally, data showed that 10 students (48%) presented problems in both non-word reading (TOWRE-PDE test) and irregular word reading (TIWRE test); 9 students (42%) presented problems just in non-word reading (TOWRE-PDE test), and 2 students (10%) presented problems only in irregular word reading (TIWRE test).

**Table 6. Correlation Matrix for Reading Variables among Students with Reading Difficulties**

| | TIWRE | TOWRE-PDE | WA | LWI |
|---|---|---|---|---|
| TIWRE | 1.000 | | | |
| TOWRE-PDE | .080 | 1.000 | | |
| WA | -.014 | .591** | 1.000 | |
| LWI | .411* | .806** | .541** | 1.000 |

Note. n = 21. * Correlation is significant at the 0.05 level (1-tailed), **Correlation is significant at the 0.01 level (1-tailed). TIWRE = Test of Irregular Word Reading Efficiency, TOWRE-PDE = Test of Word Reading Efficiency- Phonetic Decoding Efficiency test, LWI = Letter Word Identification test.

## Discussion

A growing body of evidence suggests that both RAN and processing speed can affect the development of reading skill. Taken together, the results of this study are in line with the result from prior research and also add support to the validity of the dual route theory of reading when analyzing the performance of poor readers. The questions addressed in this study were fourfold: (a) to examine how RAN and speed of processing are related to different reading measures; (b) to examine which of the RAN and speed of processing measures are the best predictors of the reading measures; (c) to find the best cognitive model for predicting all reading skills; and (d) to examine the performance of typical and poor readers on different reading measures. The results for each of these questions are discussed more fully below.

*Relationship of RAN and PS to Reading Skills*

As was hypothesized, the RAN Total was a stronger predictor of reading ability than the PS Cluster, but not for all types of word reading. The PS Cluster had the strongest correlation with irregular word reading, whereas the RAN Total had the strongest correlation with both word reading and non-word reading. These results suggested that RAN and PS predict different aspects of word reading. RAN tasks require speeded naming of serially presented stimuli and share key characteristics with reading such as paying attention, visual recognition, access to phonological codes, and articulation. PS tasks involve quick visual recognition, which is a similar requirement of irregular word reading.

One interesting finding was that the RAN measures had a stronger relationship with the non-word reading, as measured by the TOWRE-PDE, than with the irregular word reading, as measured by the TIWRE test (irregular words). Based on prior research, the opposite finding was expected (e.g., Manis et al., 1999; Wolf & Bowers, 1999). On the other hand, when the second Pearson correlation was performed using the WA test to represent non-word reading, the RAN measures had a stronger relationship with the TIWRE test. The second correlation was similar to the findings of Manis et al., (1999) and Wolf and Bowers (1999). Manis et al. suggested that RAN is not a good predictor of non-word-reading, and has a stronger relationship with orthographic skills, which was represented by irregular word reading in this study. Their non-word reading measure, however, was the WJ III ACH WA test, an untimed test. In this study, the researchers used the TOWRE-PDE, a timed test (45 seconds), as well as the untimed WA test to measure non-word reading. The higher correlation between these two measures is most likely because both the RAN-measures and the TOWRE-PDE test are both timed.

No significant correlation was found between the PS Cluster and WA test. It seems that WA and PS tests have completely different requirements. The PS measures required locating and circling identical numbers (Visual Matching test), or identifying and circling the two most conceptually similar pictures in a row (Decision Speed test) under timed conditions, a crucial condition to PS. On the other hand, the un-timed WA test requires reading non-words. The reading of non-words involves integration of visual information with stored phonological representations, access and retrieval of phonological labels, and non-word articulation.

*Predictive Power of RAN Measures*

In regard to the predictive power of RAN, the results of this study were in agreement with the findings of earlier studies: letters were the most powerful predictor of word reading skill (Bowey et al., 2005; Neuhaus et al., 2001; Van den Bos et al., 2003; Wolf & Bowers, 1999). The RAN letters task successfully predicted reading ability, whereas the other RAN measures did not. Results from other studies have indicated that other RAN formats do not reliably predict reading performance after kindergarten (Powell, Stainthorp, Stuart, Garwood & Quinlan, 2007; Wolf & Bowers, 1999). The results supported the view that reading performance is predicted by the rapid naming of letters, but not as well by the naming of objects, colors, numbers, or the RAS tasks. Although Wolf and Denckla (2005) demonstrated that the RAS tests are valid measures of the ability to perceive a visual symbol and name it accurately and rapidly, and that ability predicts reading facility, this study did not find any increased prediction of word reading ability by using the RAS tests.

The finding that RAN letters was the best predictor of reading skill is not surprising. RAN letters and word reading have many commonalities. Random letter strings and meaningful words are reported to be processed similarly, as both are subjected to intense lexical evaluation in classic language-related brain areas (Jessen et al., 1999; Misra, Katzir, Wolf, & Poldrack, 2004). RAN letters are presented in rows and demand left-to-right sequencing, as does reading. Furthermore, letter names provide anchors upon which to map acoustically similar phonemes (Treiman, Tincoff, Rodriguez, Mouzaki, & Francis, 1998). Both RAN tasks and reading demand efficient visual and verbal processing of letters.

*Predictive Power of PS Measures*

Compared to the other PS measures (Decision Speed, Rapid Picture Naming, and Cross Out), the Visual Matching test, followed by the Pair Cancellation test, were the best predictors of reading skills. In a recent study, Urso (2008) explored the role of various PS measures as predictors of reading difficulties. The results indicated that PS, as measured by the WJ III COG Cluster score, was strongly correlated with word reading, $r= .749$, $r^2 =.56$. The PS tests of Visual Matching, ($r = .663$, $r^2= .44$) and Pair Cancellation ($r = .520$, $r^2 =.27$) were most strongly correlated with poor word reading skill. Moreover, 37.5% of the poor readers also had low PS scores. Findings from the present study and the Urso (2008) study support the finding that PS measures are good predictors of reading.

*Cognitive Correlates and Reading*

Another finding was that the Numbers Reversed (NR) test, a measure of WM ability, did not increase the prediction of the cognitive model of reading skills in the normally distributed data. WM may have less power in predicting reading with normal readers. This interpretation is supported by Shankweiler and Crain (1986) who found that WM resources are very taxed by underdeveloped phonological awareness.

Students with poor phonics have impacted working memory systems and subsequent poor reading (Howes et al., 1999).

In reference to the double-deficit model, a main finding of this study was that the Sound Blending (SB) test, a measure of PA, and RAN-Letters were the best predictors of all reading skills. As was hypothesized the RAN-letters test contribution to the model of predicting irregular word reading was larger than the SB contribution. According to their meta-analysis, Wolf and Bowers (1999) reported correlations between RAN and PA as only .1 to .4, showing the independence of these skills. They proposed that PA was related to underlying auditory processing while RAN either relates to visual or temporal processing, a stance somewhat aligned to the dual route theory of Castles and Coltheart (1993). The results of this study lend more support to the double-deficit model and indicate that PA and RAN contribute independently to the variance of reading.

*Correlations among Reading Skills*

Significant correlations were found between irregular word and non-word reading in the normally distributed data. The dual-route model has provided a powerful theoretical framework for interpreting this finding. This suggests that the visual route and the phonological route are not completely independent. In contrast, the correlation between irregular word reading and non-word reading for the group of students with reading disabilities was insignificant. Thus, the results from this study are more in line with the modified dual-route theory (e.g., Paap, McDonald, Schvaneveldt, & Noel, 1987; Paap & Noel, 1991). This theory assumes that the two routes are somewhat dependent on one another in terms of both knowledge structure and processes, but the distinction between lexical and sub-lexical processing is still maintained. For typical readers, these two reading routes are dependent on one another. For students with reading disabilities, however, the pathways appear more independent.

Finally, this study confirmed the results from other studies supporting the distinction between phonological dyslexia and surface dyslexia (Bowey& Rutherford, 2007; Castles &Coltheart, 1993). A very small minority of children with dyslexia showed pure surface dyslexia with intact phonological encoding, whereas a larger group showed pure phonological dyslexia. The largest group of children with RD, however, had difficulties in both areas. Relatively few cases of either type of developmental dyslexia appeared to be *pure*.

*Limitations*

This study had several limitations. The sample size was small (n = 56) for normally distributed data and (n = 21) for students with RD. A larger sample size would have provided a stronger statistical power. Although the findings of this study indicated that some of the correlations were larger than the others, none of the differences between these dependent correlations were significant when *t* tests were performed. In future research, these findings should be validated with larger sample sizes to establish stronger power analysis and to find the differences between the two correlation coefficients in two independent samples. In addition, this study was limited to the exploration of irregular word reading, non-word reading, and word reading. Adding measures of reading comprehension would be useful to provide a more comprehensive overview of reading performance. Finally, this study had only one measure of PA and WM versus multiple measures of RAN and PS.

*Implications*

For both practitioners and researchers, this study provides direction for the assessment of reading. These findings support the need to assess all known cognitive correlates of reading ability to avoid specification error when predicting models of reading and diagnosing reading difficulties. The failure to not include a broad set of cognitive and linguistic abilities when attempting to examine the correlates of reading can lead to specification error where the included abilities appear to be more important than they really are (Pedhazur & Schmelkin, 1991).

Furthermore, researchers should continue to investigate the interrelationships among different types of measures of cognitive processing variables and reading skills. The data showing relationships among cognitive variables could help evaluators select the most appropriate assessment measures. Findings from the various RAN and PS measures in this study indicated that variability exists among the different measures and their predictive power of reading skills. Additionally, students have different types of reading difficulties (e.g., using phonics for reading non-words versus recognizing irregular words by sight). Therefore, it is important to measure both non-word reading and irregular word reading as part of a reading assessment. It is also essential to obtain a measure of reading fluency and reading comprehension as part of a comprehensive reading assessment.

**References**

Abbott, M., Walton C., & Greenwood, C. (2002). Phonemic awareness in kindergarten and first grade. *Teaching Exceptional Children, 34* (4), 20-26.

Ackerman, P. T., & Dykman, R. A. (1993). Phonological processes, confrontation naming, and immediate memory in dyslexia. *Journal of Learning Disabilities, 26*, 597–609.

Badian, N. (1993). Phonemic awareness, naming, visual symbol processing, and reading. *Reading and Writing: An Interdisciplinary Journal, 5*, 87–100.

Badian, N. (2005). Does a visual-orthographic deficit contribute to reading disability? *Annals of Dyslexia, 55*, 28-52.

Bishop, A. G., & League, M. B. (2006). Identifying a multivariate screening model to predict reading difficulties at the onset of kindergarten: A longitudinal analysis. *Learning Disability Quarterly, 29,* 235–252.

Bowers, P. G., & Swanson, L. B. (1991). Naming speed deficits in reading disability. *Journal of Experimental Child Psychology, 51*, 195–219.

Bowey, J., McGuigan, M., & Ruschena, A. (2005). On the association between serial naming speed for letters and digits and word-reading skill: Towards a developmental account. *Journal of Research in Reading, 28,* 400–422.

Bowey, J., & Rutherford, J. (2007). Imbalanced word-reading profiles in eighth-graders. *Journal of Experimental Child Psychology, 96*, 169–196.

Castles, A., & Coltheart, M. (1993). Varieties of developmental dyslexia.*Cognition, 47*, 149-180.

Catts, H. W. (1996). Defining dyslexia as a developmental language disorder: An expanded view. *Topics in Language Disorders, 16*, 14-29.

Catts, H., Gillispie, M., Leonard, L., Kail, R., & Miller, C. (2002). The role of speed of processing, rapid naming, and phonological awareness in reading achievement. *Journal of Learning Disabilities, 35*, 509-524.

Cohen, J. (1977). *Statistical power analysis for the behavioral sciences* (revised edition). New York, NY: Academic Press.

Coltheart, M. (1978). Lexical access in simple reading tasks. In G. Underwood (Ed.), *Strategies of information processing* (pp. 151–216). London, United Kingdom: Academic Press.

Coltheart, M. (1980). Reading phonological recording and deep dyslexia. In M. Coltheart, K. Patterson,& J. C. Marshall (Eds.), *Deep dyslexia* (pp. 197-226). London, United Kingdom: Routledge & Kegan Paul.

Coltheart, M. (2007). Modeling reading: The dual-route approach. In M. Snowling & C. Hulme (Eds.), *The science of reading* (pp. 6-23). London, United Kingdom: Wiley- Blackwell Publishing Ltd.

Compton, D. (2003). Modeling the relationship between growth in rapid naming speed and growth in decoding skill in first-grade children. *Journal of Educational Psychology, 95,* 225–239.

Compton, D. L., Olson, R. K., DeFries, J. C., & Pennington, B. F. (2002). Comparing the relationships among two different versions of alphanumeric rapid automatized naming and word level reading skills. *Scientific Studies of Reading, 6*, 343–368.

Cutting, L. E., & Denckla, M. B. (1999). The relationship of rapid serial naming and word reading in normally developing readers: An exploratory model. *Reading and Writing: An Interdisciplinary Journal, 14*, 673–705.

De Jong, P. F. (1998). Working memory deficits of reading disabled children. *Journal of Experimental Child Psychology*, *70*, 75–96.

Denckla, M. B., & Cutting, L. E. (1999). History and significance of rapid automatized naming. *Annals of Dyslexia, 49*, 29-42.

Denckla, M. B., & Rudel, R. G. (1976a). Naming of object-drawings by dyslexic and other learning-disabled children. *Brain and Language, 3*, 1-15.

Denckla, M. B., & Rudel, R. G. (1976b). Rapid automatized naming (R.A.N.): Dyslexia differentiated from other learning disabilities. *Neuropsychologia, 14*, 471-479.

Engle, R. W., Cantor, J., & Carullo, J. (1992). Individual differences in working memory and comprehension: a test of four hypotheses. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *18*, 972–992.

Fawcett, A., Singleton, C., & Peer, L. (1998). Advances in early years screening for dyslexia in the United Kingdom. *Annals of Dyslexia, 48,* 57-88.

Feldmann, G., Kelly, R., & Diehl, V. (2004). An interpretative analysis of five commonly used processing speed measures. *Journal of Psychoeducational Assessment, 22,* 151-163.

Field, A. P. (2009). *Discovering statistics using SPSS*. (3rd ed.). London: Sage publications.
Fisher, R. A., & Yates, F. (1963). *Statistical tables for biological, agricultural and medical research.* (6th ed.). Edinburgh, Scotland: Oliver and Boyd, Ltd.
Foorman, B., Francis, D., Shaywitz, S., Shaywitz, B., & Fletcher, J. (1997). The case for early reading intervention. In B. Blachman (Ed.), *Foundations of reading acquisition* (pp. 243-264). Mahwah, NJ: Erlbaum.
Georgiou, G., Parrila, R., Kirby, J., & Stephenson, K. (2008). Rapid naming components and their relationship with phonological awareness, orthographic knowledge, speed of processing, and different reading outcomes. *Scientific Studies of Reading, 12*, 325–350.
Howes, N. L., Bigler, E. D., Lawson, J. S., & Burlingame, G. M. (1999). Reading disability subtypes and the test of memory and learning. *Clinical Neuropsychology, 14*, 317–339.
Jessen, F., Erb, M., Klose, U., Lotze, M., Grodd, W., & Heun, R. (1999). Activation of human language processing brain regions after the presentation of random letter strings demonstrated with event-related functional magnetic resonance imaging. *Neuroscience Letters, 270***,** 13–16.
Kail, R. (1991). Developmental change in speed of processing during childhood and adolescence. *Psychological Bulletin*, *109,* 490–501.
Kail, R., & Hall, L. K. (1994).Processing speed, naming speed, and reading. *Developmental Psychology, 30*, 949-954.
Kail, R., Hall, L. K., &Caskey, B. J. (1999). Processing speed, exposure to print, and naming speed. *Applied Psycholinguistics, 20,* 303–314.
Kendall, D., Conway, T., Rosenbek, J., &Gonzalea-Rothi, L. (2003). Case study: Phonological rehabilitation of acquired phonological alexia. *Aphasiology, 17*, 1073-1095.
Lundberg, I., Frost, J., & Petersen, O. P. (1988). Effects of an extensive program for stimulating phonological awareness in preschool children. *Reading Research Quarterly, 33*, 263-284.
Manis, F. R., Doi, L. M., & Bhadha, B. (2000). Naming speed, phonological awareness, and orthographic knowledge in second graders. *Journal of Learning Disabilities, 33*, 325-333.
Manis, F. R., Seidenberg, M. S., & Doi, L. M. (1999). 'See Dick RAN': Rapid naming and the longitudinal prediction of reading sub-skills in first and second graders. *Scientific Studies of Reading, 3*, 129-157.
Mather, N., & Goldstein, S. (2008). *Learning disabilities and challenging behaviors: A guide to intervention & classroom management* (2nd ed.). Baltimore, MD: Paul H.Brookes.
Mather, N., & Woodcock, R. W. (2001). Examiner's Manual. *Woodcock-Johnson III Test of Cognitive Abilities.* Rolling Meadows, IL: Riverside Publishing.
McGrew, K. S., & Woodcock, R. W. (2001).Technical Manual.*Woodcock Johnson III.* Rolling Meadows, IL: Riverside Publishing.
McGrew, K.S., Schrank, F. A., & Woodcock, R.W. (2007).Technical Manual. *Woodcock-Johnson III Normative Update.* Rolling Meadows, IL: Riverside Publishing.
Misra, M., Katzir, T., Wolf, M., &Poldrack, R. A. (2004). Neural systems for rapid automatized naming in skilled readers: Unraveling the RAN-reading relationship. *Scientific Studies of Reading, 8,* 241–256.
Morton, J., & Patterson, K. E. (1980). A new attempt at an interpretation, or, an attempt at a new interpretation. In M. Coltheart, K. E. Patterson, & J. C. Marshall (Eds.), *Deep dyslexia* (pp. 91–118). London, United Kingdom: Routledge & Kegan Paul.
Neuhaus, G., Foorman, B. R., Francis, D. J., & Carlson, C. D. (2001). Measures of information processing in rapid automatized naming (RAN) and their relation to reading. *Journal of Experimental Child Psychology, 78*, 359-373.
Nicolson, R., & Fawcett, A. (1999). Developmental dyslexia: The role of the cerebellum. *Dyslexia, 5,* 155-177.
Paap, K. R., McDonald, J. E., Schvaneveldt, R. W., & Noel, R. W. (1987). Frequency and pronounceability in visually presented naming and lexical-decision tasks. In M. Coltheart (Ed.), *Attention& Performance*, (pp. 221–244). Hillsdale, NJ: Erlbaum.
Paap, K. R., & Noel, R. W. (1991). Dual-route models of print to sound, still a good horse race. *Psychological Research*, *53*, 13–24.
Pedhazur, E.J., & Schmelkin, L.P. (1991). *Measurement, design, andanalysis: An integratedapproach*. Hillsdale, NJ: Lawrence Erlbaum.
Powell, D., Stainthorp, R., Stuart, M., Garwood, H., & Quinlan, P. (2007). An experimental comparison between rival theories of rapid automatized naming performance and its relationship to reading. *Journal of ExperimentalPsychology,98*, 46-68.
Rack, J. P., Snowling, M. J., & Olson, R. K. (1992). The non-word reading deficit in developmental dyslexia: A review. *Reading Research Quarterly, 27*, 28–53.

Reading, S., & Van Duren, D. (2007). Phonemic awareness: When and how much to teach? *Reading Research and Instruction, 46,* 267-285.
Reynolds, C. R., & Kamphaus, R. W. (2007). *Test of Irregular Word Reading Efficiency (TIWRE).* Odessa, FL: PAR.
Savage, R.S., & Frederickson, N. (2006). Beyond phonology: What else is needed to describe the problems of below-average readers and spellers*? Journal of Learning Disabilities, 39,* 399-413.
Scarborough, H. S. (1998). Predicting the future achievement of second graders with reading disabilities: Contributions of phonemic awareness, verbal memory, rapid naming, and IQ. *Annals of Dyslexia, 48*, 115–136.
Shanahan, M., Pennington, B., Yerys, B., Scott, A., Boada, R., & Willcutt, E., et al. (2006). Processing speed deficits in Attention Deficit/Hyperactivity Disorder and reading disability. *Journal of Abnormal Child Psychology, 34,* 585–602.
Shankweiler, D. P., & Crain, S. (1986). Language mechanisms and reading disorder: A modular approach. *Cognition, 24*, 139–168.
Steiger, J. H. (1980).Tests for comparing elements of a correlation matrix. *Psychological Bulletin, 87*, 245–251.
Sunseth, K., & Bowers, P. G. (2002). Rapid naming and phonemic awareness: Contributions to reading, spelling, and orthographic knowledge. *Scientific Studies of Reading, 6*, 401–429.
Swanson, H. L., &Saez, L. (2003). Memory difficulties in children and adults with learning disabilities. In H. L. Swanson, K.R. Harris, & S. Graham (Eds.), *Handbook of learning disabilities* (pp. 182–198). New York, NY: Guilford.
Tabachnick, B. G., & Fidell, L. S. (2001). *Using multivariate statistics*. Boston, MA: Allyn & Bacon.
Torgesen, J. K., Wagner, R. K., & Rashotte, C. A. (1999). Examiner's manual. *Test of Word Reading Efficiency (TOWRE).* Austin, TX: PRO-ED.
Torgesen, J. K., Wagner, R. K., Rashotte, C. A., Burgess, S., & Hecht, S. (1997). Contributions of phonological awareness and rapid automatic naming ability to the growth of word-reading skills in second- to fifth-grade children. *Scientific Studies of Reading, 1,* 161-185.
Tree, J. (2008). Two types of phonological dyslexia – A contemporary review.*Cortex*, *44*, 698-706.
Treiman, R., Tincoff, R., Rodriguez, K., Mouzaki, A., & Francis, D. J. (1998). The foundations of literacy: Learning the sounds of letters. *Child Development, 69*, 1524–1540.
Urso, A. (2008). *Processing speed as a predictor of poor reading.* Unpublished doctoral dissertation, University of Arizona, Tucson.
Van den Bos, K., Zijlstra, B., & Broeck, W. (2003).Specific relations between alphanumeric-naming speed and reading speeds of monosyllabic and multisyllabic words. *Applied Psycholinguistics*, *24*, 407–430.
Waber, D. P., Wolff, P. H., Weiler, M. D.,Bellinger, D., Marcus, D. H., & Forbes, P., et al. (2001). Processing of rapid auditory stimuli in school-age children referred for evaluation of learning disorder. *Child Development, 72*, 37–49.
Wagner, R. K., & Torgesen, J. K. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological Bulletin, 101,* 192–212.
Weiler, M. D., Bernstein, J. H., Bellinger, D. C., &Waber, D. P. (2000). Processing speed in children with attention deficit/hyperactivity disorder, inattentive type. *Child Neuropsychology*, *6,* 218–234.
Wolf, M., & Bowers, P. (1999). The "double-deficit hypothesis" for the developmental dyslexia. *Journal of Educational Psychology, 91,* 1-24.
Wolf, M., & Bowers, P. (2000). The question of naming-speed deficits in developmental reading disabilities: An introduction to the special issue on the double-deficit hypothesis. *Journal of Learning Disabilities, 33*, 322-324.
Wolf, M., Bowers, P., & Biddle, K. R. (2000). Naming-speed processes, timing, and reading: A conceptual review. *Journal of Learning Disabilities, 33*, 387-407.
Wolf, M., & Denckla, M. B. (2005). *Rapid Automatized Naming and Rapid Alternating Stimulus tests (RAN/RAS).* Austin, TX: PRO-ED.
Woodcock, R. W., McGrew, K. S., & Mather, N. (2001a). *Woodcock-Johnson III Tests of Cognitive Abilities.* Rolling Meadows, IL: Riverside Publishing.
Woodcock, R. W., McGrew, K. S., & Mather, N. (2001b). *Woodcock-Johnson III Tests of Achievement*. Rolling Meadows, IL: Riverside Publishing.