Learning Disabilities: A Multidisciplinary Journal

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- higher and adult education;
- vocational and career education;
- cultural differences;
- public and private education;
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Since 1963, LDA has provided support to people with learning disabilities and their parents, teachers, and other professionals with cutting-edge information on learning disabilities, practical solutions, and a comprehensive network of resources. These services make LDA the leading resource for information on learning disabilities.
Identifying Specific Reading Disability Subtypes for Effective Educational Remediation

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The primary purpose of this study was to investigate the various neurocognitive processes concomitant to reading by attempting to identify various subtypes of reading disorders in a referred sample. Participants were 216 elementary school students in grades two through five who were given select subtests of the Woodcock Johnson-III Tests of Cognitive Ability. They were classified using a pattern of strengths and weaknesses (PSW) approach as having no SLD (control), 49 had an Associative Learning (Glr) SLD, 21 had a Gf-Gv SLD, 42 had a Gc SLD, 29 had a Learning Efficiency (Gs) SLD, and 40 had an Executive (Gsm) subtype SLD. Regressions completed for each of the six groups indicated that differing sets of cognitive skills were predictive of reading performance pertaining to letter and word identification skills, reading fluency skills, and passage comprehension skills. Rather than one, unique cognitive profile that represents all students with reading disorders, breakdowns in phonology, orthography, working memory, executive skills, and processing speed contribute in varying amounts to deficits in decoding, fluency, and deriving meaning from print. Viewing reading disorders from a subtype perspective allows us to more accurately classify, and most importantly, inform intervention decision making. Specific intervention recommendations are suggested for each cognitive subtype, and a discussion regarding limitations, and implications for future research are addressed as well.

Keywords: dyslexia; reading; remediation; subtypes

Introduction

According to the National Center for Learning Disabilities (2011), specific learning disability (SLD) prevalence rates among the U.S. population (ages 6+) are approximately 1.8%, totalling some 4.67 million American children. This translates to 5% of the public school population, or 2.5 million public school students are currently labeled as SLD, with an estimated cost of 1.6 times the expenditure of general education. The majority (80%) of children identified with SLD have reading skill deficits (U.S. Dept. Of Education, 2006) making this the largest category in special education (Grant & Grant, 2010) and the most prevalent learning disorder (Gabel, Gibson, Gruen, & Lo-Turco, 2010; Semrud-Clikeman, Fine, & Harder, 2005).

The learning outcomes for students with SLD remain problematic, and continue to present as an insurmountable challenge for most educators. For instance, only 35% of 4th grade students identified with SLD perform at the basic, proficient, or advanced reading levels, compared to 70% of students without disabilities (National Center for Educational Statistics, 2009). Furthermore, nearly half of those students identified with a reading disability (RD) are performing more than three grade levels behind their peers, resulting in heightened frustration and lower self-esteem. In fact, students with a SLD are twice as likely to suffer from mental health issues specifically related to their disability (O’Brien, 2004). These secondary emotional challenges further contribute to elevated dropout rates, poorer graduation rates, and meager employment options (Cortiella, 2011). Although graduation rates of students with SLD have improved significantly over the past decade, the drop-out rate remains at an unacceptable 22%, second only to students with an Emotional Disturbance. In fact, the graduation rate of students with SLD is 64%, well below that of non SLD students (NCLD or www.IDEAdata.org, Exiting by Disability, Ages 14-21+, 1999-2008). Within two years of leaving high school, only 33% of SLD students enroll in post secondary school and less than half (46%) of students with SLD had regular employment (NLTS2 www.nlts2.org). This information has far-reaching social and economic consequences, and must be addressed through policy and funding measures which significantly improve identification leading to appropriate educational remediation (Hale & Fiorello, 2004; Philpott & Cahill,
Learning Disabilities 19 2014, Volume 20, Number 1

Reading and Neuroscience

RD is a phenotypically complex developmental disorder with a neurobiological and genetic basis (Shaywitz & Shaywitz, 2005; Gabel et al., 2010). The neuropsychology literature suggests that children who have reading difficulties have deficits integrating orthography (alphabet system) with phonology (sound units), possibly due to microlesions in the left inferior parietal lobe (Cao, Bitan, & Booth, 2008; Heim, Eickhoff, & Amunts, 2008). Furthermore, neuroscience has suggested that there is a timing component to synthesizing the acoustical codes and neural correlates involved in the reading process (Tallal, 2012), and children who have not mastered the phonological code by age 10, may never acquire this skill (Rourke & Del Dotto, 1994). These findings were also consistent with the Collins and Rourke (2003) summary findings of PET, MEG, and fMRI studies on dyslexia which implicated deficits confined to linguistic processing systems in the left hemisphere.

Neuroscience may also be in an optimal position to inform intervention, since most children do not spontaneously remit or “catch up” in skills despite the claims of many educators (Shaywitz et al., 1999). In fact, a recent longitudinal study by Hoeft et al. (2011) revealed that greater right prefrontal activation during a reading task for students with learning disabilities was not only indicative of the brain being able to recruit additional neural pathways to support the reading process, but was also a better predictor of reading gains than standardized reading or behavioral tests. Nevertheless, general education teachers are often unaware of or confused by the definition of RD, the various subtypes of reading disorders, or the appropriate programs and strategies to use with students at various stages of the reading process. Nevertheless, studies are beginning to show that the correct intervention often leads to metabolic changes in the brain of learners with SLD (Shaywitz, 1998; Hoeft et al., 2007; Hoeft et al., 2010) and with the appropriate interventions in place, children can compensate for their weaknesses thus leading to academic and professional success. Further advancements in the identification of SLD and effective interventions are necessary to provide all students with quality special education services.

Recently, there has been a large body of research that not only differentiates structural brain differences in children with RD from their non-RD peers (Ekert et al., 2003; Shaywitz et al., 2004; Temple et al., 2003), but signifies increased brain activation associated with reading intervention (Aylward et al., 2003; Finn et al., 2013) In a structural imaging study, Eckert et al. (2003) identified volume differences in the right anterior lobe of the cerebellum and inferior frontal gyrus between dyslexic children and control subjects underlying the neuroanatomical differences correlated with RD. Subsequently, Aylward et al. (2003) demonstrated that brain activation patterns in RD subjects changed in response to 3 weeks of intervention to resemble patterns of normal control subjects. Prior to treatment, functional magnetic resonance imaging (fMRI) of children with RD showed very small regions of activation during two specific language processing tasks (phoneme and morpheme mapping) in comparison to controls without RD. Specifically, brain activation areas in the left middle and inferior frontal gyri, right superior frontal gyri, left middle and inferior temporal gyri, and bilateral superior parietal regions were reduced for phoneme mapping while left middle frontal gyrus, right superior parietal, and fusiform/occipital regions were decreased for morpheme mapping. Post treatment fMRI identified increased activation in these areas as well as additional areas of activation in the fusiform gyrus, left parietal lobe, and bilateral orbital, inferior, middle, and superior frontal gyrus. Furthermore, increased activation was noted in children with RD on morpheme mapping in the right fusiform gyrus and superior parietal lobe. Lastly, a recent study by Finn et al. (2013) also suggested that dyslexic readers had a reduction in functional connectivity in the visual word association areas due to utilizing inefficient reading strategies.

Identifying Reading Disorders

Historically, children with learning disabilities have primarily been identified as eligible for special education by the IQ–achievement discrepancy model. An accumulation of research has clearly demonstrated numerous shortcomings of and a lack of validity for this “discrepancy model,” including statistical imprecision (Stanovich, 2005), overreliance on a Full Scale IQ (leading to misdiagnosis or missed diagnosis; Hale & Fiorello, 2004), overrepresentation of minority groups (Macmillan & Hendrick, 1993), delay in services due to a “wait to fail” approach, and lack of discrimination between children who are low achievers and children with SLD (Fuchs, Fuchs, Mathes, Lipsey, & Roberts, 2001). The discrepancy model had been poorly operationalized and implemented across states, districts, schools, and individuals with a lack of agreement on the magnitude and meaning of the discrepancy across all ages (Feifer & DeFina, 2000; Hale et al., 2010). Additionally, the model remains less than helpful when assisting educators in developing appropriate remediation strategies. For instance, it is very difficult to develop a specific goal and objective for academic
learning based solely upon a global synopsis of a student's intellectual capacity (Feifer & Della Toffalo, 2007). In summary, the discrepancy model propagates an age-old educational myth that views learning disabilities along a one-dimensional continuum between those students with the disorder and those without. A congressional hearing was instrumental in changing federal criteria for identifying children with SLD. The 2004 reauthorization of the Individuals with Disabilities Education Act (IDEA, 2004) provided the paradigm shift when schools were no longer required to use the discrepancy model, and instead, a response-to-intervention (RTI) approach was advocated as a viable alternative to the traditional discrepancy model. Originally proposed as a school-wide prevention program, RTI as a process of service delivery has many benefits. It emphasizes evidence-based approaches to instruction, progress monitoring, early screening, and intervention for struggling readers (Feifer, 2008; Fletcher & Vaughn, 2009; Torgesen, 2009). In this respect, RTI is useful for early intervention for children at risk for SLD; however, as an instructional practice, it is not sufficient to identify or explain core learning deficits adequately. As such, RTI is not effective as a diagnostic model for SLD (Reynolds & Shaywitz, 2009).

While RTI may determine that a child is not reading adequately, without cognitive or neuropsychological assessment, it is unclear which cognitive component(s) or networks contribute to the deficit (i.e., phonological awareness, fluency, orthographic processing, working memory, or others) and which strengths can assist in remediation (i.e., vocabulary, conceptual reasoning, comprehension) (Semrud-Clikeman et al., 2005). In the absence of clear delineation of specific cognitive components, a one-size-fits-all intervention approach is assumed for all children.

Current research has demonstrated that not all students with reading disorders profit equally from remediation techniques (Heim et al., 2008), and therefore intervention approaches need to be individualized to address the child's deficit pattern. Ignoring the neurobiological underpinnings of reading can create a host of problems including further delay of appropriate and individualized services (Reynolds & Shaywitz, 2009) and a failure to acknowledge the extant research in cognition, neuropsychology, neurobiology, neuroimaging, and learning disabilities (Berninger, 2001; Fiorello, Hale, Snyder, 2006; Hale, Naglieri, Kaufman, & Kavale, 2004; Semrud-Clikeman, 2005). Further, wide variations in the conceptualization of RTI are problematic, leaving the guidelines, application, assessment criteria, and outcomes open to personal interpretation (Reynolds & Shaywitz, 2009), and lacking a needed consensus on standard protocol, measurement, curricula, and instructional methodology (Hale et al., 2010).

So the question remains, based on current research, what is the best approach to SLD identification and remediation? A third option defined as an "alternative research-based approach" emerged in the Federal Regulations, which allows for examination of a pattern of strengths and weaknesses (PSW) approach in the identification of SLD (Hale, Flanagan, & Naglieri, 2008; Hale, Naglieri, Kaufman, & Kavale, 2004); an approach advocated by eminent researchers within the field (Hale et al., 2010) and supported by expert consensus (Learning Disabilities Roundtable, U.S. Department of Education, 2002) and the SLD IDEA definition (34 C.F.R. 300.7). According to the ten professional organizations that made up the Learning Disabilities Roundtable, U.S. Department of Education (2002), "The identification of a core cognitive deficit, or a disorder in one or more psychological processes, that is predictive of an imperfect ability to learn, is a marker for a specific learning disability" (p. 5). These cognitive deficits are core psychological processes that require cognitive and neuropsychological evaluations to identify because children with SLD process information differently than their typically achieving peers (Semrud-Clikeman et al., 2005) and they have specific cognitive and neuropsychological deficits, not delays (Francis, Shaywitz, Stuebing, Shaywitz, & Fletcher, 1996). Given this variability, not all children with RD have the same deficits or require the same remediation (Ramus, 2004).

Consistent with many cognitive and neuropsychological studies now available in peer-reviewed publications, Hale et al. (2010) noted in their seminal LD White Paper that determining the cognitive and neuropsychological processing strengths and weaknesses of a child, coupled with extrinsic factors such as how a student has responded to previous interventions, constitutes the true foundation of a learning disorder. As Moats (2004) succinctly noted, conceptions of reading and writing instruction, curricular development, and ultimately learning disabilities should take their lead from the neurosciences in order to provide a scientific rationale for the selection, implementation, and monitoring of intervention approaches and programs designed to meet the specific needs of the child.

Cross-Battery Assessment and Cognitive Subtypes

The Cross-Battery Assessment (XBA) approach was introduced by Flanagan and her colleagues over 15 years ago (e.g., Flanagan & McGrew, 1997; Flanagan & Ortiz, 2001; McGrew & Flanagan, 1998). This approach is based on the Cattell–Horn–Carroll (CHC) theory and recently has been integrated with neuropsychological theory as well (Flanagan, Ortiz, & Alfonso, 2013). The XBA approach...
provides practitioners with the means to make systematic, reliable, and theory-based interpretations of any ability battery and to augment that battery with cognitive, achievement, and neuropsychological subtests from other batteries to gain a more psychometrically defensible and complete understanding of a child’s pattern of cognitive and neuropsychological strengths and weaknesses. Moving beyond the boundaries of a single cognitive or achievement battery or a fixed neuropsychological battery, by adopting the rigorous psychometrically and theoretically defensible principles and procedures of the XBA approach allows practitioners to focus on accurate and valid measures of specific cognitive processes and neurodevelopmental functions germane to referral concerns, such as reading (e.g., Decker, 2008; Flanagan, Ortiz, & Alfonso, 2013).

Research on the relationship among cognitive abilities, neuropsychological processes, and specific academic skills has grown over the years (see Flanagan, Ortiz, Alfonso, & Mascolo, 2006; McGrew & Wendling, 2010, for summaries). Much of the recent research on cognitive–academic relationships has been interpreted within the context of CHC theory (e.g., Flanagan, Alfonso, & Mascolo, 2011) and with specific instruments developed from CHC theory (e.g., McGrew & Wendling, 2010). In addition, statistical analyses, such as structural equation modeling, have been used to understand the extent to which specific cognitive abilities explain variance in academic skills above and beyond the variance accounted for by g (e.g., Floyd, McGrew, & Evans, 2008; McGrew, Flanagan, Keith, & Vanderwood, 1997; Vanderwood, McGrew, Flanagan, & Keith, 2002). Finally, many valuable resources summarize the research on cognitive and neurobiological processes associated with specific academic skill deficits and subtypes of learning disorders (e.g., Feifer & DeFina, 2005; Feifer & Della Toffalo, 2007; Flanagan & Alfonso, 2011; Fletcher-Janzen & Reynolds, 2008; Hale & Fiorello, 2004; Miller, 2010, 2013). Table 1 depicts the relationship between various CHC abilities and reading achievement.

Subtypes of Reading Disorders

Research is also starting to unveil that not only is RD a heterogeneous disorder consisting of various subtypes, but specific learning disorders’ subtypes are linked to specific cognitive deficits (Feifer & Della Toffalo, 2007; Crews & D’Amato, 2010). These deficits highly correlate with various neural systems underlying RD (Phinney et al., 2007) and include short-term memory (McDougal, Hulme, Ellis, & Monk, 1994), visuo-spatial abilities (Facoetti et al., 2009), integration of letters and speech sounds (Blau, van Atteveldt, Ekkebus, Goebel, & Blomert, 2009), phonological processing (Ramus et al., 2003; Shaywitz et al., 1999), and rapid automatic naming (Torgesen et al., 1997). However, it remains unknown as to whether all of these features are central to a core RD phenotype or are cognitively distinct, since underlying cellular neurobiological causes of RD have the capacity to affect multiple neural systems to varying degrees (Gabel et al., 2010; Phinney et al., 2007), therefore, a child may use a variety of these cognitive processes to complete a reading task (Hale & Fiorello, 2004).

Due to the diversity and range of reading related deficits, reading disabilities most likely have a multifocal origin within the brain. The phonological deficit hypothesis for reading and spelling implies that the cerebral cortex has distributed neural networks that contribute to the integration, binding, and relaying of phonological information throughout the brain (Cao, Bitan, & Booth, 2008). These distributed neural networks are dedicated to mapping out sounds to letters, and thus require more cross-modal associations between visual and verbal percepts. Specifically, the supramarginal gyrus, located at the juncture of the temporal and parietal lobes, appears to be a key brain region responsible for the highest levels of phonological processing (McCandliss & Noble, 2003; Sandak, Mencl, Frost, & Pugh, 2004; Shaywitz et al., 2004). It should be noted that the supramarginal gyrus is not necessarily involved in other types of linguistic processing tasks such as visual word recognition or semantic processing, but rather focuses primarily on the phonological nature of word assembly (Sliwinska et al., 2012).

Conversely, some students are readily able to sound out words but lack the ability to automatically recognize words in print. These students tend to be letter-by-letter and sound-by-sound readers, as there is an overreliance upon the phonological properties of the word, and an underappreciation of the orthographical or spatial properties of the visual word form. Most words are painstakingly broken down to individual phonemes and read very slowly and laboriously. Fluency tends to suffer the most, though phonological processing skills remain relatively intact. Neuroscience has identified multiple brain regions responsible for the rapid and automatic recognition of the printed word form. According to Cao et al. (2008), the left fusiform gyrus is particularly sensitive toward the orthographic representation of words and a key brain region involved in word automaticity. In addition, the angular gyrus is also involved in numerous functions involving the spatial assembly of linguistic information by relying upon the visual contour and shapes of letters.

Finally, some estimates have suggested that approximately 10% of all school-aged children have good decoding and fluency skills but possess specific difficulties comprehending the text (Nation & Snowling, 1998). In essence, these readers struggle to derive meaning from print despite good reading mechanics. Specific cognitive
constructs underlying reading comprehension includes **executive functioning**, which involve the strategies students use to organize incoming information with previously read material; **working memory**, which is the amount of memory needed to perform a given cognitive task; and **language foundation skills**, which represents the fund of words with which a student is familiar (Feifer & Della Toffalo, 2007). According to Cutting, Materek, Cole, Levin, & Mahone (2009), executive functioning skills influence reading comprehension by allowing students to effectively plan, organize, and continuously monitor a steady influx of verbal information. In fact, these **top-down** executive processes modulated primarily by frontal lobe functioning, coupled with reading fluency and language development skills, play a significant role in the comprehension process. Clearly, the ability to self-organize verbal information in a logical, sequential, and meaningful manner lies at the heart of effective recall.

**Purpose of Current Study**

It is the primary aim of the present study to identify major underlying neurologically-based functions that contribute to specific reading disability subtypes and patterns. It has long been argued that if RD (and other learning disorders) is defined more discretely via homogenous subtypes, the correspondences between diagnosis and treatment would be more clearly understood thus resulting in better reading outcomes.

**Method**

**Participants and Procedure**

Participants were 283 elementary school students who received comprehensive psychoeducational evaluations for learning and/or behavior problems in two Northeastern American school districts. The students were largely Caucasian (76%) and English-speaking and from largely middle-class socioeconomic backgrounds. The final sample included 194 males and 89 females, aged 6 through 16 years ($M = 9.6$ years, $SD = 2.3$), and in grades 2 through 12, which was the age and grade range focus for this study. For inclusion and exclusion criteria, only students with a Full-Scale IQ of 75 or higher were included in the sample to exclude children with intellectual disability. Children with known brain injury or other medical conditions affecting psychological functioning at the time of the evaluation were also excluded. The sample was divided into groups psychometrically following the conceptual similarities among PSW or third method approaches to SLD identification (Hale et al., 2008). Specifically, student reading skills were more than one standard deviation below grade level expectations and a minimum of one specific cognitive attribute was also approximately one standard deviation or more below expectations. Therefore, both reading achievement and a particular cognitive attribute were low and discrepant from the remainder of a child’s cognitive scores. Those with the same cognitive weaknesses were grouped together (see Table 1). Of these children, 35 were classified as having no SLD (control), 49 had an Associative Learning SLD, 21 had a Gf-Gv SLD, 42 had a Gc, 29 had a Learning Efficiency SLD, and 40 had an Executive subtype SLD.

**Materials**

Each participant was given select subtests of the Woodcock Johnson-III Tests of Cognitive Ability (WJ-III Cog; Woodcock, Mather, McGrew, 2001a) and the Woodcock-Johnson-III Tests of Achievement (WJ-III Ach; Woodcock, Mather, McGrew, 2001b).

**Results**

Three separate multiple regressions were run in each of the six groups using the following subtests from the WJ-III Ach as dependent variables: Letter-Word Identification, Reading Fluency, and Passage Comprehension. In each regression the independent variables were the following WJ-III Cog subtests: Verbal Comprehension, Visual–Auditory Learning, Spatial Relations, Sound Blending, Concept Formation, Visual Matching, Numbers Reversed, General Information, Retrieval Fluency, Picture Recognition, Auditory Attention, Analysis-Synthesis, Decision Speed, and Memory for Words. Exploratory analysis revealed individual subtest variations within WJ-III Cog cluster scores, therefore individual subtests were used as independent variables rather than cluster scores. These regressions were hierarchical in nature, allowing only for independent variables that added significantly to the prediction of the dependent variables into each equation. The mean Standard Score for each Woodcock Johnson-III subtest by subtype is provided in Table 2, and depicted graphically in Figure 1. Given that the sample was broken into six individual groups with smaller sample size, the results were limited when running multiple regression analysis and as a result were not corrected for when running multiple comparisons.

Within the no SLD clinical control group, both Sound Blending and Numbers Reversed were significant predictors of Letter-Word Identification ($R^2 = .449$), Numbers Reversed was a significant predictor of Reading Fluency ($R^2 = .239$), and Numbers Reversed and Picture Recognition were significant predictors of Passage Comprehension ($R^2 = .493$).

Within the Associative Learning group, Visual Matching and Numbers Reversed were significant predictors of Letter-Word Identification ($R^2 = .493$), Numbers Reversed was a significant predictor of Reading Fluency ($R^2 = .239$), and Numbers Reversed and Picture Recognition were significant predictors of Passage Comprehension ($R^2 = .493$).
predictors of Letter-Word Identification \( (R^2 = .187) \), there were no significant predictors of Reading Fluency, and Numbers Reversed was a significant predictor of Passage Comprehension \( (R^2 = .147) \).

Within the Gf-Gv group, Sound Blending and Auditory Attention were significant predictors of Letter-Word Identification \( (R^2 = .401) \), Visual Matching was a significant predictor of Reading Fluency \( (R^2 = .409) \), and General Information and Memory for Words were significant predictors of Passage Comprehension \( (R^2 = .406) \).

Within the Gc-Long-Term Memory group, Visual Matching was a significant predictor of Letter-Word Identification \( (R^2 = .100) \), Visual Matching and Decision Speed were significant predictors of Reading Fluency \( (R^2 = .286) \), and General Information was a significant predictor of Passage Comprehension \( (R^2 = .210) \).

Within the Learning Efficiency group, there were no significant predictors of Letter-Word Identification, Numbers Reversed was a significant predictor of Reading Fluency \( (R^2 = .229) \), and Numbers Reversed and Memory for Words were significant predictors of Passage Comprehension \( (R^2 = .391) \).

Within the Executive subtype group, Verbal Comprehension was a significant predictor of Letter-Word Identification \( (R^2 = .323) \), Visual Auditory Learning was a significant predictor of Reading Fluency \( (R^2 = .142) \), and Visual Auditory Learning and Picture Recognition were significant predictors of Passage Comprehension \( (R^2 = .399) \).

<table>
<thead>
<tr>
<th>Group Subtype</th>
<th>CHC Weakness</th>
<th>Reading Deficit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Associative Learning</strong></td>
<td>Long-Term Memory and Retrieval (Glr)</td>
<td>Letter-Word ID (M=78.39)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reading Fluency (M=80.59)</td>
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<tr>
<td></td>
<td></td>
<td>Passage Comprehension (M=76.08)</td>
</tr>
<tr>
<td><strong>Fluid/Visual Processing</strong></td>
<td>Fluid Intelligence (Gf)</td>
<td>Letter-Word ID (M=83.14)</td>
</tr>
<tr>
<td></td>
<td>Visual Processing (Gv)</td>
<td>Reading Fluency (M=84.62)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Passage Comprehension (80.48)</td>
</tr>
<tr>
<td><strong>Crystallized</strong></td>
<td>Crystallized Knowledge (Gc)</td>
<td>Letter-Word ID (M=79.19)</td>
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<td></td>
<td></td>
<td>Reading Fluency (M=79.89)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Passage Comprehension (78.17)</td>
</tr>
<tr>
<td><strong>Learning Efficiency</strong></td>
<td>Processing Speed (Gs)</td>
<td>Letter-Word ID (M=82.93)</td>
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<td></td>
<td></td>
<td>Reading Fluency (M=80.77)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Passage Comprehension (81.55)</td>
</tr>
<tr>
<td><strong>Executive Subtype</strong></td>
<td>Short-Term Memory (Gsm)</td>
<td>Letter-Word ID (M=83.35)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reading Fluency (M=82.03)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Passage Comprehension (81.68)</td>
</tr>
</tbody>
</table>
Table 2

Mean Standard Score by SLD Group across WJ-III Cog and Ach Subtests

<table>
<thead>
<tr>
<th>COG/ACH subtest</th>
<th>No SLD</th>
<th>Associative Learning Subtype</th>
<th>Gf-Gv Subtype</th>
<th>Ge Subtype</th>
<th>Learning Efficiency Subtype</th>
<th>Executive Subtype</th>
</tr>
</thead>
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<tr>
<td>Verbal Comprehension</td>
<td>91.14</td>
<td>88.51</td>
<td>88.14</td>
<td>77.26</td>
<td>93.03</td>
<td>94.08</td>
</tr>
<tr>
<td>Visual Auditory Learning</td>
<td>91.97</td>
<td>69.39</td>
<td>83.48</td>
<td>83.10</td>
<td>85.03</td>
<td>89.23</td>
</tr>
<tr>
<td>Spatial Relations</td>
<td>94.14</td>
<td>97.27</td>
<td>89.05</td>
<td>96.64</td>
<td>98.69</td>
<td>98.60</td>
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<td>Sound Blending</td>
<td>103.69</td>
<td>103.53</td>
<td>97.52</td>
<td>97.90</td>
<td>104.31</td>
<td>101.55</td>
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<td>Concept Formation</td>
<td>93.11</td>
<td>95.82</td>
<td>82.86</td>
<td>92.50</td>
<td>100.66</td>
<td>98.38</td>
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<td>Visual Matching</td>
<td>89.60</td>
<td>89.88</td>
<td>85.48</td>
<td>92.83</td>
<td>76.10</td>
<td>85.48</td>
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<td>Numbers Reversed</td>
<td>91.29</td>
<td>88.51</td>
<td>92.86</td>
<td>92.17</td>
<td>95.28</td>
<td>84.53</td>
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<td>General Information</td>
<td>89.23</td>
<td>87.43</td>
<td>90.95</td>
<td>76.19</td>
<td>90.41</td>
<td>91.98</td>
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<tr>
<td>Retrieval Fluency</td>
<td>92.26</td>
<td>78.98</td>
<td>84.05</td>
<td>85.95</td>
<td>85.41</td>
<td>86.18</td>
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<tr>
<td>Picture Recognition</td>
<td>99.86</td>
<td>100.78</td>
<td>92.76</td>
<td>100.19</td>
<td>101.66</td>
<td>102.73</td>
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<td>Auditory Attention</td>
<td>98.09</td>
<td>96.90</td>
<td>94.57</td>
<td>98.98</td>
<td>100.03</td>
<td>101.28</td>
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<td>Analysis-Synthesis</td>
<td>94.69</td>
<td>94.47</td>
<td>87.10</td>
<td>98.07</td>
<td>102.62</td>
<td>100.00</td>
</tr>
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<td>Decision Speed</td>
<td>102.11</td>
<td>100.90</td>
<td>96.29</td>
<td>100.90</td>
<td>90.03</td>
<td>98.10</td>
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<tr>
<td>Memory for Words</td>
<td>94.77</td>
<td>94.71</td>
<td>97.43</td>
<td>88.57</td>
<td>96.55</td>
<td>86.48</td>
</tr>
<tr>
<td>Passage Comprehension</td>
<td>86.26</td>
<td>76.08</td>
<td>80.48</td>
<td>78.17</td>
<td>81.55</td>
<td>81.68</td>
</tr>
<tr>
<td>Reading Fluency</td>
<td>86.24</td>
<td>80.59</td>
<td>84.62</td>
<td>79.89</td>
<td>80.77</td>
<td>82.03</td>
</tr>
<tr>
<td>Letter Word Identification</td>
<td>86.91</td>
<td>78.39</td>
<td>83.14</td>
<td>79.19</td>
<td>82.93</td>
<td>83.35</td>
</tr>
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</table>
Overall results suggest that the specific cognitive subtests that are predictive of Letter-Word Identification, Reading Fluency, and Passage Comprehension vary depending on the subtype of SLD.

**Discussion**

Current intervention practice tends to treat all children with SLD the same. That is, most children with reading disabilities receive similar instruction (i.e., phonological skills) with far greater intensity than general education can provide. This assumption provides the driving force for further subtyping of learning disorders (D’Amato, Dean, & Rhodes, 1998; Feifer & Della Toffalo, 2007; Crews & D’Amato, 2010). Such subtype research could improve our understanding of early “markers” of developmental RD thereby impacting positively early literacy for at-risk children. Once subtypes are identified, a secondary goal involves identification of the most effective interventions for the subtypes. Numerous empirical studies show that when the correct remedial intervention is used, it facilitates permanent neural change in RD learners (Shaywitz, 1998; Shaywitz & Shaywitz, 2005). An important implication of these findings is changing the RD definition from a lifelong condition to one that has the potential for remission due to neuroplasticity.

The overarching theme of this paper is that not all children with RD have the same deficits or require the same remediation (Ramus et al., 2003). Consistent with this notion was the finding that among the three core fundamental reading processes; namely letter and word...
identification, reading fluency, and passage comprehension, different cognitive profiles emerge with respect to processing strengths and weaknesses. This was even true for students in the control group who did not have a learning disability, as the Numbers Reversed test, a measure of working memory, was critical in the execution of all aspects of the reading process. Using the WJ III cognitive subtests, students who were in the Associative Learning SLD group demonstrated very poor long-term storage and retrieval skills as measured on a task requiring them to learn, store, and retrieve a series of rebuses representing words and phrases of various lengths (VAL M=69.39). With respect to their ability to effectively read letters and isolated words, nearly 19% of the variance of their reading performance was accounted for by scores from the Visual Matching (perceiving the visual contour and shapes of numbers quickly) and Numbers Reversed (working memory) subtests. This finding suggests that these students may have struggled with the orthographical representation of print, coupled with the working memory demands inherent in print knowledge. Reading performance was likely weak for these students because reading requires the ability to detect the symbolic representation of letters as making up individual words (i.e., orthographic processing), and holding and manipulating this information in the mind’s eye (i.e., working memory).

The educational implication for students who have orthographic processing and working memory difficulties is the requirement of teaching word identification skills by minimizing the demands of these processes on learning. For instance, the Horizons A-B Program uses a rather unique approach to teaching letters and words. In essence, orthographic prompts that color code sounds are used to guide the student in developing an appropriate strategy to decode words. These colors are gradually faded out once more advanced decoding activities are integrated into the lessons. By color coding these diacritical markers, Horizons essentially minimizes the orthographic and working memory demands of decoding words in print and avoids more abstract diacritical markers. Word attack activities emphasize orthographic decoding and critical vocabulary to prepare students for upcoming stories.

A second noteworthy finding was that students who had difficulty with more inductive and deductive reasoning types of tasks as represented by their poorer performance on the WJ III Concept Formation Task (M=82.86), had difficulty with passage comprehension skills. In fact, their scores from the General Knowledge subtest and Memory for Words subtest was able to account for over 40% of the variance in their reading scores. This finding suggests that having a general fund of information, coupled with auditory working memory for the sequential presentation of words is paramount to successful reading comprehension, but perhaps not enough. The ability to reason with verbal information is also important for reading comprehension. According to Cutting et al. (2009), executive functioning skills are particularly important attributes influencing comprehension, especially traits such as verbal and visual memory, as well as the capacity to plan, organize, and continuously monitor a steady influx of verbal information. Specific intervention efforts should therefore focus upon developing the inductive and deductive reasoning skills concomitant with self-organizing verbal information to facilitate later retrieval. For instance, the SQ3R method is a 5-step technique that teaches students how to Survey, Question, Read, Recall, and Review. Students are initially taught to scan and survey the content of the chapter and focus upon the introduction and summary sections to become familiar with the text. Next, students are encouraged to make a note of specific questions that in part, serve as study goals. Third, students begin to read through the chapter and to take notes in a mind map format. Next, students are asked to recall isolated facts about the passage. Lastly, the review stage involves re-reading the story, expanding notes, and then discussing with someone else.

A third noteworthy finding pertains to reading fluency skills, as students who demonstrated poor crystallized knowledge as measured by the General Information task (M=76.23), had nearly 29% of their variance in reading fluency accounted for by speeded tasks such as Visual Matching and Decision Speed. This suggests that measures of cognitive efficiency and speed of information processing are relevant to the types of attributes necessary for the rapid and automatic recognition of words in print. From an intervention perspective, specific reading programs designed to elevate pace, fluency, and automaticity to enhance the ability to recognize words in print without the need for systematic and slower paced decoding skills are critical. For instance, Read Naturally emphasizes reading fluency and speed, and also fosters more accurate comprehension skills. The program uses repeated exposures to modeled reading, and progress monitoring to increase overall fluency skill. All Read Naturally tasks follow a structured sequence whereby the student first selects a story of interest, subvocalizes vocabulary terms and meanings, and formulates a prediction about the story. Second, the student attempts a “cold-read” of the story, and graphs the number of words read correctly in one minute. Next, each student reads the story aloud three times along with the tape recording in order to hear proper pronunciation, expression, and phrasing. The rate of the recorded reading level increases with each successive reading. The student then attempts a “hot read” of the
passage as the teacher records errors, monitors prosody, and times the pace of reading. A variety of comprehension questions are presented as well.

Finally, students who made up the executive functioning subtype demonstrated poor performance on working memory types of measures, such as Numbers Reversed \( (M=84.53) \), and had slower Retrieval Fluency Skills \( (M=86.18) \). In theory, slower retrieval skills generally suggest a somewhat disorganized manner of storing words in knowledge bases, and thus these students require additional time to efficiently retrieve the information later. Furthermore, slower retrieval speed can also be associated with slower cognitive efficiency in general. For these students, there were reading deficits in multiple areas consistent with a mixed subtype of RD. For example, nearly 33% of the variance of reading performance in letter and word identification was accounted for by the Visual-Auditory Learning subtest, which measures long-term storage and retrieval. In addition, nearly 15% of the variance was also explained by this same subtest for students with reading fluency types of issues. Lastly, nearly 40% of the variance in reading comprehension for students with executive difficulties was accounted for by this same subtest, as well as the Picture Recognition subtest, a measure of visual short-term memory.

In terms of intervention selection, the Read 180 program is truly a balanced literacy program designed to meet the needs of students who are struggling on one or more of the five pillars of reading as outlined by the National Reading Panel (2000). The 90-minute instructional model begins with a 20-minute whole-group teacher directed instruction, and then students rotate between three smaller groups during the next 60 minutes. The first group involves small group instructional activities that allow teachers to better differentiate instruction. The second group is what makes the program unique, in that students use highly interactive and adaptive software which systemically directs the learner though the four learning zones. The Reading Zone includes phonics, fluency, and vocabulary instruction as students read through passages. The Word Zone provides systemic instruction in decoding and word recognition skills, as 6,000 words are defined and analyzed. The Spelling Zone allows students to practice spelling and receive immediate feedback, and the Success Zone focuses on comprehension once the other zones have been mastered. The software component of the program is highly adaptive as opportunities are provided for repeated oral reading, hearing models read with fluency, and using videos to provide background knowledge and introduce vocabulary.

One limitation of this study was the use of a single battery, the WJ III, to assess students who struggled in learning to read. Future research inquiry should consider exploring cognitive subtypes underscoring reading disorders by using testing batteries other than (or in addition to) the WJ III. Expanding assessment beyond the confines of the WJ III will aid practitioners in crafting assessment batteries that are more consistent with what is known about RD. Use of the XBA methodology is recommended as a psychometrically valid means of gathering and interpreting the breadth of abilities and processes that are related to reading acquisition and development. After all, one of the great challenges when studying children with learning disabilities remains the operational definition used to determine the sample in question. A second limitation of this study was not investigating the developmental nature of a particular psychological process over time. In other words, perhaps certain processing skills are particularly important to the reading process in the early years during letter and word acquisition, though not terribly important for more skilled readers in later grades (see McGrew & Wendling, 2010). Also, the small sample size for each group were limited and did not allow for correction in making multiple comparisons in the regression analyses. Lastly, future research efforts need to be directed toward the specific nature of the interventions themselves, and utilizing neuroimaging techniques to validate changes in brain circuitry and connectivity with more effective reading skills. Cognitive neuroscience is only beginning to provide the forensic evidence so often yearned for by educators to truly explain intrinsic barriers toward achieving academic success in all areas, especially reading.

References


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