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Sequential Prediction of Literacy Achievement for Specific Learning Disabilities Contrasting in Impaired Levels of Language in Grades 4 to 9

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Abstract

Sequential regression was used to evaluate whether language-related working memory components uniquely predict reading and writing achievement beyond cognitive-linguistic translation for students in grades 4–9 ($N=103$) with specific learning disabilities (SLDs) in subword handwriting (dysgraphia, $n=25$), word reading and spelling (dyslexia, $n=60$), or oral and written language (OWL LD, $n=18$). That is, SLDs are defined on basis of cascading level of language impairment (subword, word, and syntax/text). A 5-block regression model sequentially predicted literacy achievement from cognitive-linguistic translation (Block 1); working memory components for word form coding (Block 2), phonological and orthographic loops (Block 3), and supervisory focused or switching attention (Block 4); and SLD groups (Block 5). Results showed that cognitive-linguistic translation explained an average of 27% and 15% of the variance in reading and writing achievement, respectively, but working memory components explained an additional 39% and 27% variance. Orthographic word form coding uniquely predicted nearly every measure, whereas attention switching only uniquely predicted reading. Finally, differences in reading and writing persisted between dyslexia and dysgraphia, with dysgraphia higher, even after controlling for Block 1 to 4 predictors. Differences in literacy achievement between students with dyslexia and OWL LD were largely explained by the Block 1 predictors. Applications to identifying and teaching students with these SLDs are discussed.

Keywords

cognitive-linguistic translation; working memory components; specific learning disabilities; dyslexia; dysgraphia; oral and written language learning disability (OWL LD); reading and writing achievement

Ample prior research has shown that components of working memory are strongly related to reading and writing achievement for typically developing elementary school students (e.g., Bourke & Adams, 2010; Decker, Roberts, Roberts, & Stafford, 2016; Niedo, Abbott, & Berninger, 2014; Swanson & Howell, 2001) as well as individuals with learning difficulties (e.g., Peng & Fuchs, 2016; Swanson, Zheng, & Jerman, 2009). Evidence for the positive

relationship between working memory capacities and academic achievement also includes cross-cultural studies of languages with different orthographies (e.g., Georgiou, Parrila, & Papadopoulos, 2008; Vaessen et al., 2010), as well as studies of adults with dyslexia (e.g., Nergård-Nilssen & Hulme, 2014; Swanson & Hsieh, 2009) and studies of children from language minority backgrounds (e.g., Swanson, Orosco, & Kudo, in press). Moreover, similar links between working memory and achievement have also been found in mathematics (e.g., Geary, Hoard, Nugent, & Bailey, 2012; Swanson, 2014; Swanson & Jerman, 2006).

Despite the wealth of studies, most of the prior research has either focused on a limited set of working memory components or has not controlled for cognitive-linguistic translation, which we define as an individual's ability to orally express cognitive understandings, when the research aim is testing the unique relationships between working memory and achievement. In addition, with few exceptions, the prior research has also tended to neglect research on writing outcomes and research. Also, there are fewer studies of persisting specific learning disabilities (SLDs) in written language despite early intervention, which was the focus of the current study. Taken together, the present study extends previous work by testing the unique contributions of numerous language-related working memory components on both reading and writing achievement with a sample of students in grades 4 to 9 with language-related specific learning disabilities (SLDs), including handwriting (dysgraphia), word reading and spelling (dyslexia), and syntax in oral and written language (OWL LD).

Role of Cognitive-Linguistic Translation in Language-Related Learning Disabilities

Cross-site brain research has identified evidence of different neural bases for individuals with language-related learning disabilities who either are responsive to early intervention or who do not respond, despite early intervention (Leonard, Eckert, Given, Berninger, & Eden, 2006). Genetics research has identified genetic mechanisms that regulate neural migration after conception and early wiring of the brain versus pruning at two years of age versus myelination of fibers during adolescence and adulthood (Galaburda, LoTurco, Ramus, Fitch, & Rosen, 2006). Thus, the poor achievement of students with SLDs in reading and writing in the upper elementary and middle school grades is not the necessarily the result of a lack of appropriate instruction.

Currently one of the most widely used assessment tools for cognitive ability to identify children at risk for learning disabilities is the Wechsler Scales. However, the authors of this test, which has a version for ages 3 to 6, 6 to 18, and adolescents and adults age 16 and older, do not recommend using the full scale score as a global measure of intelligence for learning disabilities assessments (Prifitera, Weiss, Saklofske, Rolfhus, 2005). Factor analytic studies have shown that of the four scales on the Wechsler Scales, the Verbal Comprehension Index is the best predictor of academic achievement in both referred (Greenblatt, Mattis, & Trad, 1990) and non-referred samples (Vellutino, Scanlon, & Tanzman, 1991), especially in reading. Because many students with SLDs often have

working memory problems or processing speed problems, their scores on one or both of the Working Memory and Processing Speed Index scores may lower the overall full scale score.

Also, advances in psychometric measurement have made it obsolete to interpret results of the Wechsler Scales or other cognitive assessment tools as intelligence quotients (IQ). The term IQ has been obsolete since 1939 when the practice of taking a person's mental age and dividing it by the person's chronological age to generate the "quotient" ended. Instead, standard norm-referenced scores are used, which allow comparison of an individual with others of the same age or grade at a given time point in development and across ages or grades as an individual develops over time (Anastasi, 1955 reviewed in Guilford, 1955; Pfeiffer, 2015).

There have been multiple perspectives on what the Wechsler Scales measure. Anastasi, author of the highly influential book on psychological testing and measurement first published in 1955 and now in its seventh edition (Anastasi & Urbina, 1997), questioned how scores were being misinterpreted as measures of intelligence. She introduced the alternative concept of scholastic aptitude as more viable than intelligence (Anastasi, 1983). Another perspective is that the Verbal Comprehension Index assesses *cognitive-linguistic translation*. Clinical neuropsychologists analyze the processes required for taking specific tests on a battery. For Verbal Comprehension Index such task analysis shows the tasks require explaining orally what words mean (Vocabulary subtest), how two words are alike in meaning (Similarities), or why things are the way they are in the world. That is, individuals have to translate their cognitions into oral words (see Stahl & Nagy, 2005). The field of the cognitive psychology of writing has a long tradition of studying translation from the cognitive domain into the written language domain and even the oral language domain, for example, in thinking aloud while planning to compose (Fayol, Alamargot, & Berninger, 2012). Berninger, Swanson, and Griffin (2014) showed how translation is a higher-order executive function for cross-domain communication, which is supported by working memory. Further, Hayes and Berninger (2014) offered a model for linking the translation research in cognitive psychology with clinical psychology assessment that included cognitive-linguistic translation.

Finally, Niedo et al. (2014) studied typically developing readers and writers in second and fifth grade and found that the Verbal Comprehension Index, interpreted as a measure of cognitive-linguistic translation because of the task requirements as described above, accounted for significant variance in reading and writing outcomes, but not for as much variance as the working memory components did. Similar results were found with even younger children as well (Alloway & Alloway, 2009). Thus, one aim of the current study is to evaluate whether the finding by Niedo et al. (2014) that cognitive-linguistic translation explains unique variance in typical children's reading and writing outcomes can be replicated in students who have language-related SLDs. Further, we extend the construct of cognitive-linguistic translation to include both verbal comprehension as well as oral language syntax (measure to be described in the forthcoming methods section) because syntax plays an important role in Chomsky's (1965) language learning device model. In sum, the present study models cognitive-linguistic translation as having the goal of creating

oral syntax as well as understanding and using words and word combinations to orally express cognitive understandings (also see Stahl & Nagy, 2005).

Baddeley's Working Memory Model & Cascading Levels of Language Framework

According to Baddeley (1986; 2000; 2002; 2003) and others (e.g., Daneman & Carpenter, 1983; Swanson, 1992; 2000; Swanson & Siegel, 2001), working memory comprises a three-part system involving a multi-component central executive (coordination of sensory stimuli for retrieval of information from long term memory storage as well as formation of new memory); sub-word verbal processors, including the phonological loop (short-term phonological information manipulation and capacity system, also known as the “inner ear” and “inner voice”); and finally, the visuo-spatial sketch pad (short-term visual information manipulation and capacity, also known as visuo-spatial working memory involving the “inner eye” and recently thought to involve movement and motor control). These three multi-component systems are conceptualized as having interactions with longer-term memory storage (multi-sensory information storage). Whereas executive functions (focused/selective attention and switching attention) have been shown to be related to multiple academic domains (reading, writing, and arithmetic), so have domain-specific working memory components been. Specifically, verbal working memory has been more strongly associated with achievement in the reading and writing domains, whereas visuo-spatial working memory and processing (as well as motor speed) have been more often associated with the mathematics domain (Peng & Fuchs, 2016; Swanson, 2012; Swanson & Jerman, 2006).

Research on Specific Working Memory Components

Over the past two decades, literacy research on working memory has identified multiple components of the verbal working memory system, including: (a) *word form coding* for storing and processing heard and spoken words (phonological), read and written words (orthographic), and transformation of base words with affixes (morphological) (e.g., Cahill, Tiberius, & Herring, 2013; Richards et al., 2006); (b) *phonological loop* for orally naming visual/orthographic stimuli (e.g., Baddeley, Gathercole, & Papagno, 1998; Swanson, 2006) and *orthographic loop* for serial finger movements for producing the ordered strokes of letter formation in serial order (e.g., Berninger & Richards, 2010); and (c) *supervisory attention/executive functions* (e.g., Posner, & Rothbart, 2007; Stuss, 2011; Swanson, 1993, 2000) for selective attention (e.g. Delis, Kaplan, & Kramer, 2001) and switching attention (e.g., Wolf & Denckla, 2005). Measures of word-form coding, loops, and supervisory attention working memory components are sometimes referred to as phenotypes because interdisciplinary research in a multi-generational family genetics study validated them as behavioral markers of the genetic and brain bases of these working memory components (e.g., Berninger & Richards, 2010). These measures were used in the current study because each may contribute to different reading or writing achievement measures in students with persisting specific learning disabilities during middle childhood and early adolescence.

Word form coding—phonological, orthographic, and morphological

Venezky (1970, 1999), who specialized in linguistics, psycholinguistics, and educational linguistics, explained how speech is represented in the English morphophonemic orthography of written words and how both subword and word units of language are involved in learning to read and spell. That is, learning to spell and read English requires coding and processing in memory heard and spoken words, read and written words, and the morphemes in both the phonological and orthographic word forms, respectively. Morphemes include the bases and (a) affixes at the beginning (prefixes) that transform meaning of bases, and (b) affixes at the end (suffixes) that transform tense, number, and comparison (inflectional suffixes) or part of speech (derivational suffixes) of bases. The developing speller/reader also needs to learn to interrelate the three word forms for phonology, orthography, and morphology (Nunes & Bryant, 2006, 2009) and to learn to do so for words of different origin—Anglo-Saxon, French and Latinate, and Greek (Henry, 2010).

Loops

The phonological loop enables oral naming (word level) of visual or orthographic stimuli and thus plays an important role in learning oral vocabulary and also oral reading of words, especially if the phonological loop operates rapidly and automatically (e.g., Baddeley et al., 1998; Swanson, 2006). The orthographic loop enables the fingers to perform sequential movements to produce the letter form (ordered strokes) or the written word (ordered letters) stored in the “mind’s eye” and thus write letters, words, sentences and text, especially if finding, accessing, and producing the letter forms operates rapidly and automatically (Berninger, 2009).

Supervisory attention/lower level executive functions

In addition to higher-level executive functions such as cross-domain translation, there are lower level executive functions that provide the supervisory attention to regulate the working memory system—focused/selective and switching attention (Berninger, Swanson, & Griffin, 2014). Selective attention requires focusing on what is relevant and inhibiting or ignoring what is irrelevant. Switching attention requires flexibility because what was relevant becomes irrelevant and what was irrelevant becomes relevant.

Cascading Levels of Language Framework: Language Learning Profiles

Research by developmental linguistics and psycholinguists has shown that each of the functional language systems—language by ear (listening comprehension), language by mouth (oral expression), language by eye (reading comprehension), and language by hand (written expression) involves multiple levels of language processing (subword, word, syntax, and text levels); students with and without different kinds of SLDs differ in their profiles across adjacent levels of language (e.g., Richards, Nagy, Abbott, & Berninger, 2016). Students with an SLD in written language (SLD-WL) exhibit learning profiles that depend on which level of language is impaired: *subword* handwriting (dysgraphia), *word* reading and spelling (dyslexia), or *syntax* and *text* level listening and reading comprehension and oral and written expression (oral and written language learning disability, OWL LD); see

Silliman & Berninger (2011) for a comprehensive review that supports these contrasting learning profiles across levels of language and age of onset of language learning difficulties.

Language learning profiles for reading and/or writing contrast in cascading levels of language (Berninger, Richards, & Abbott, 2015). Each profile may have subword handwriting problems, but students with dysgraphia only have no word reading or sentence/text reading comprehension problems. Students with both dyslexia and OWL LD may have word reading and spelling problems or handwriting problems, but only students with OWL LD have reading comprehension problems related to processing syntax and composing problems related to constructing sentence syntax. Dyslexia is not only a word decoding/reading problem (Lovett, Barron, & Frijters, 2013; Lyytinen et al., 2004; Moll, Kunze, Neuhoﬀ, Bruder, & Schulte-Körne, 2014; Roeske et al., 2011) but also an encoding/spelling problem (e.g., Lefly & Pennington, 1991). OWL LD, also known as specific language impairment (SLI), tends to be associated with failure to meet oral language milestones in the preschool years (e.g., Bloom & Lahey, 1978) and struggles with written and oral language learning during school age years (Bishop, 2009; Bishop & Snowling, 2004; Catts, Bridges, Little, and Tomblin, 2008; Nelson, 2010; Pennington & Bishop, 2009; Scarborough, 2005; Silliman, 2008; Scott, 2010, 2011; Troia, 2009).

Current Study

Drawing from a cascading levels of language framework (subword, word, and syntax/text), the present study seeks to extend prior research on students who have one of three types of language-related specific learning disabilities (SLDs). Specifically, we test whether specific language-related working memory components are uniquely associated with literacy achievement beyond cognitive-linguistic translation for a cross-sectional sample of students in grades 4 to 9 with hallmark (defining) impairments in handwriting (dysgraphia), word reading and spelling (dyslexia), or oral and written language learning disability (OWL LD). Our research questions were as follows.

1. What are the direct relationships between cognitive-linguistic translation and language-related working memory components and literacy achievement?
2. What are the incremental contributions of language-related working memory components to explaining individual differences in literacy achievement, beyond cognitive-linguistic translation? Relatedly, which working memory components are uniquely predictive?
3. Do differences between language-related SLD profiles on literacy achievement remain present even after controlling for cognitive-linguistic predictors?

We hypothesized that we would replicate earlier findings such as those by Niedo et al. (2014) in that working memory would significantly account for reading and writing achievement beyond cognitive-linguistic translation measures, but potentially to a lesser degree in terms of magnitude of variance accounted for in our sample with SLDs compared to the prior work with typical readers and writers. We also anticipated there would be little difference left between SLDs once the cognitive-linguistic predictors were taken into

account since these measures were taken into consideration for identifying SLD groups, albeit in varying ways.

Method

Participants

Recruitment and eligibility—Participants were recruited through flyers distributed to local elementary and middle schools in school districts within driving distance of the university where the research was conducted. The flyers announced an opportunity to participate in a study of oral and written language learning for students with persisting specific learning disabilities (SLDs) in grades 4 to 9. Educational professionals referred parents who were interested in learning more about the study to the university researcher heading the study. For those who did, an initial interview was conducted over the phone using a scripted set of questions approved by the university's institutional review board. The purpose of the initial interview was to determine if conditions other than an SLD might account for any reported language learning problems; for example, exclusion criteria included pervasive developmental disability, neurogenetic disorders like fragile-X, neurofibromatosis, or phenylketonuria, sensory disorders like significant hearing or visual impairment, motor disorders like cerebral palsy or muscular dystrophy, spinal cord or brain injuries, substance abuse, and medical conditions like epilepsy or other seizure disorders, etc. (see Batshaw, Roizen, & Lotrecchiano (2013). Attention deficit and/or hyperactivity disorder (ADHD), however, was not an exclusion criterion because it can co-occur with dysgraphia, dyslexia, and oral and written language learning disability (OWL LD). Also, questions were asked about developmental and educational history, including whether the child in past or currently showed signs of persisting struggle with some aspect of oral language (i.e., listening comprehension or oral expression) or written language (i.e., reading words, reading comprehension, handwriting, spelling, or composition) despite help at and/or outside school.

Assessment and SLD diagnostic groups—If, based on the phone screening, it seemed likely that a child's reading, writing, or oral language problems were related to an SLD rather than to another condition, and the parent granted informed consent and the child granted assent, as approved by the Institutional Review Board (IRB) at the university, the child was scheduled for assessment at the university. That assessment with a test battery was conducted in keeping with the ethical principles of the American Psychological Association, and took approximately four hours, with refreshment and movement breaks interspersed (detailed descriptions forthcoming in Measures section). While the participating student completed the test battery given in a standard order across participants, the parent completed questionnaires about developmental, medical, family, and educational histories and child's current functioning at and outside school.

Participants whose cognitive-linguistic translation fell at least within the lower limit of the normal range (standard score of 80 or above) and met other inclusion criteria described next were assigned to one of three SLD groups (dysgraphia, dyslexia, or OWL LD) based on (a) the student's learning profile describing test scores for aural/oral language, reading, and

writing; and (b) the student's and parent's reported educational history (timing and nature of observed learning difficulty and whether the learning difficulty was present consistently or variably over time from preschool to each grade to date during school years). That is, this was not a self-referred clinical sample but rather a carefully screened and diagnosed sample.

Students were assigned to the **dysgraphia** group if their performance on at least two handwriting measures fell below the 25th percentile ($-2/3$ *SD*, the lower limit of the average range), there was reported evidence of persisting handwriting problems despite prior help at and/or outside school, and there was a history of handwriting problems persistent over time but not of reading problems. Students were assigned to the **dyslexia** group if their performance on at least two word-level reading (real words or pseudowords) or spelling measures fell below the population mean and at least one standard deviation below their Verbal Comprehension Index (Berninger & Abbott, 2013), their listening comprehension and oral expression fell at or above the 25th percentile and there was no history of receptive or expressive oral language problems, and there was reported evidence of persisting word reading and/or spelling problems despite prior help at and/or outside school. Finally, students were assigned to the **OWL LD** group if: their performance on least two syntactic measures for listening or reading comprehension and/or oral or written expression fell below the 25th percentile, they had oral language problems that emerged during the preschool years, and there was reported evidence of persisting listening or reading comprehension and/or oral or written expression problems despite prior help at and/or outside school.

Note that neither the Verbal Comprehension Index alone nor oral sentence construction alone was ever used to assign participants to SLD diagnostic groups, and the working memory components were also not employed for determining assignment to SLD diagnostic groups. Further, no student met hallmark criteria for more than one group (evidence of handwriting without reading impairment, evidence of word reading and spelling impairment without syntax impairment, or evidence of syntax impairment and early emerging oral language problems). Thus, levels of language, rather than the sets of predictors, were used to assign participants to SLD diagnostic groups: group assignment was based on a *profile* of scores (pattern or constellation of test scores and current and past history of responding to or not responding to instructional intervention) and never based on one of the achievement measures alone. In addition, students who did not meet inclusion criteria for any of the SLD diagnostic groups were excluded from analyses.

Sample characteristics—Our initial sample size included $N = 113$ students in grades 4 to 9 ($n = 29$ dysgraphia, $n = 65$ dyslexia, and $n = 19$ OWL LD); however, only $N = 103$ had sufficient working memory predictor data available for analyses ($n = 25$ dysgraphia, $n = 60$ dyslexia, and $n = 18$ OWL LD). Of these students, two with OWL LD were missing one of the measures of reading, and five with dyslexia were missing one of the measures of writing (these students are included in all analyses except those in which they were missing an outcome). Demographic characteristics for the analytic sample of $N = 103$ are provided in Table 1; these data show that most students were enrolled in middle school grades (63%) (average age was $M = 11.85$ years, $SD = 1.34$), and that most were male (64%), from majority heritage backgrounds (74% European American), and from homes in which both

parents completed at least a 4-year college degree (83% and 73% of mothers and fathers, respectively).

Measures: Predictors

Cognitive-linguistic translation measures—Three subtests of *Wechsler Intelligence Scale for Children, 4th Edition* (WISC IV) (Wechsler, 2003) were given to obtain a *Verbal Comprehension Index Score*: Similarities, Vocabulary, and Comprehension. Raw scores were converted to scaled scores, which were combined to obtain a standard score ($M = 100$ and $SD = 15$) for which the test-retest reliability is 0.93 to 0.95. In addition, a measure of translating word meaning into sentence syntax was given: *Formulated Sentences* subtest of *Clinical Evaluation of Language Function 4th Edition* (CELF IV) (Semel, Wiig, & Secord, 2003). The task is to construct an oral sentence from a provided word. The score is number correct across multiple items, which is converted to a scaled score ($M = 10$ and $SD = 3$) for which the test-retest reliability ranges from 0.62 to 0.71.

Working memory components—word form storage and processing for morphophonemic orthography—To assess the word form storage and processing for heard and spoken words (*phonological coding*), the *Comprehensive Test of Phonological Processing* (CTOPP) (Wagner, Torgesen, & Rashotte, 1999) Nonword Repetition (test-retest reliability is 0.70) was given. The task is to listen to an audio recording of nonwords, which are pronounced one at a time and then repeat exactly the heard oral nonword, which contains English sounds but has no meaning. The raw score is converted to a standard score ($M = 100$ and $SD = 15$).

To assess word form storage and processing for affixes signaling derivation of a word from another word (*morphological coding*) in heard and read words, a version of the widely used *Comes-From test* developed by Nagy was given (Nagy, Berninger, & Abbott, 2006; Nagy, Berninger, Abbott, Vaughan, & Vermeulen, 2003). The task is to judge whether or not a word is derived from a base word. Examples include the following: Does *corner* come from *corn*? Does *builder* come from *build*? In both cases the first word contains a common spelling (*er*), but only in the second example does it function as a morpheme (a suffix that transforms a verb or action word into a noun or person word). Raw scores are transformed to *z*-scores ($M = 0$ and $SD = 1$) based on research norms for elementary and middle school grades (test-retest reliability for a one-year period is 0.67).

To assess the word form storage and processing for detecting written words in letter strings read silently (*orthographic coding*), the *Test of Silent Word Reading Fluency* (TOSWRF) (Mather, Hammill, Allen, & Roberts, 2004) was given. The task is to mark the word boundaries in a series of letters arranged in rows. The score is the number of correctly detected and marked word boundaries in 3 minutes, which is converted to standard score for age ($M = 100$ and $SD = 15$) for which test-retest reliability is 0.92.

Working memory components—loops for cross-code integration—For integrating visual/orthographic and oral/name codes (*phonological loop*), *Rapid Automatic Letter Naming* (RAN) (Wolf & Denckla, 2005) was given. The task is to name lower case printed letters arranged in rows. The total score is the time required to name all the letters in all the

rows. It is converted to a standard score ($M = 100$ and $SD = 15$) for which test-retest reliability is 0.90.

For integrating internal representations of alphabet letters and their production through sequential finger movements (*orthographic loop*), alphabet 15, a rapid automatic letter writing task, was given. The task is to print the alphabet in lower case manuscript (unconnected) letters so that others can recognize the letters but write as quickly as possible. The score is the number of legible letters in correct alphabetic order in the first 15 seconds, which is converted to a z-score based on research norms for grade. Interrater reliability is 0.98. The number of letters in the first 15 seconds is an indicator of *automatic* access, retrieval, and production, after which controlled, strategic processing regulates access, retrieval, and production. See Shiffrin and Schneider (1977) for distinction between initial automatic and subsequent controlled processing.

Working memory components—supervisory attention—To assess *focused attention*, that is, the ability to inhibit irrelevant information and attend only to relevant information, the *Color Word Form Inhibition* subtest of the *Delis Kaplan Executive Functions* (D-KEFS) (Delis, Kaplan, & Kramer, 2001) was given. The task, based on the classic Stroop task, is to read orally a color word in black ink and then name the ink color for a written word in which the color of the ink conflicts with the color name of the word (e.g., the word red written in green ink). The difference in time for reading the words in black and naming the color of the ink that conflicts with the name of the color word is an index of focused/selective attention. Raw scores are converted to scaled scores for age ($M = 10$ and $SD = 3$), for which the test-retest reliability is 0.62 to 0.76.

To assess *switching attention* from one focus of attention to another focus of attention, *Rapid Automatic Switching (RAS) letters and numerals* (Wolf & Denckla, 2005) was given. The task is to name alternating lower case printed letters and written numerals arranged in rows. The score is the total time required to name all the alternating letters and numerals in all the rows and provides a measure of switching attention from one category to another of visual symbols while naming them. The raw score is converted to a standard score ($M = 100$ and $SD = 15$) for which test-retest reliability is 0.90.

Outcome Measures: Multi-Leveled Reading Achievement

Reading real words—accuracy (word level)—The *Word Identification* subtest of the *Woodcock Psychoeducational Battery 3rd Edition* (WJ III) (Woodcock, McGrew, & Mather, 2001) was given. The task is to pronounce a list of written real words without context clues. Total accuracy is converted to a standard score ($M = 100$, $SD = 15$) (test-retest reliability is 0.95).

Reading real words—rate (word level)—*Sight Word Efficiency* on the *Test of Word Reading Efficiency* (TOWRE) (Torgesen, Wagner, & Rashotte, 1999) was given. The task (test-retest reliability is 0.91) is to pronounce a list written real words on list without context clues accurately and quickly within 45-second time limit. The total correct within the time limit (indicator of automatic word reading) is converted to a standard score ($M = 100$ and $SD = 15$).

Reading pseudowords—accuracy (word level)—The WJ III *Word Attack* subtest (Woodcock et al., 2001) was given. The task is to pronounce a list of written pseudowords within a 45-second time limit. The total accuracy (an indicator of accuracy of decoding) is converted to a standard score ($M = 100$ and $SD = 15$) for which test-retest reliabilities range from 0.73 to 0.81.

Reading pseudowords—rate (word level)—*Pseudoword Efficiency* on the *TOWRE* (Torgesen et al., 1999) was given. The task (test-retest reliability is 0.90) is to read a list of printed pronounceable non-words accurately within a 45-second time limit. Total accuracy within time limit (an indicator of decoding efficiency) is converted to a standard score ($M = 100$ and $SD = 15$).

Reading comprehension—cloze task (syntax and text level)—The *WJ III Passage Reading Comprehension* subtest (Woodcock et al., 2001) was given. The task (test-retest reliability is 0.85) is to supply orally a missing word in the blank that fits the accumulating context of the sentence and preceding text. Total accuracy is converted to standard score ($M = 100$ and $SD = 15$).

Measures: Multi-Leveled Writing Achievement

Handwriting (subword level)—The *Detailed Assessment of Speed of Handwriting (DASH)* Best (Barnett, Henderson, Scheib, Schulz, 2007) was given. The task is to copy a sentence with all the letters of the alphabet in one's best handwriting as many times as possible until time is called at 1 minute and then again 1 minute later (total time 2 minutes of sustained copying). Students choose to use their usual writing—manuscript (unconnected) or cursive (connected) or a combination. The score is the total legibility (interrater reliability was 0.99) for single letters within the time limits converted into an age-normed standard score ($M = 10$, $SD = 3$). *DASH Copy Fast* was also given but the results were essentially the same as for *Copy Best* and are not reported here.

Spelling—dictated words (word-level)—The *Spelling* subtest of the *Wechsler Individual Achievement Test, 3rd Edition (WIAT III)* (Pearson, 2009) was given. The task is to spell in writing dictated real words, which the examiner first pronounced alone, then in a sentence, and then alone. The total accuracy score is a standard score ($M = 100$ and $SD = 15$) for which test-retest reliability is 0.92.

Spelling—recognition (word-level)—The *Homophone Choice* (ages 9–12) or *Word Choice* (ages 13–16) subtest of the *Test of Orthographic Competence (TOC)* (Mather, Roberts, Hammill, & Allen, 2008) was given. The task is to identify the correct spelling for a specific word among options that are all pronounced the same but only one spelling is associated with a vocabulary meaning and the morphology for a real word spelling (Ehri, 1980; Olson, Forsberg, Wise, & Rack, 1994). Even though there are different norms, according to age of child, the scaled scores for age are comparable and were analyzed to assess *word-specific spelling*. The score is a scaled score ($M = 10$ and $SD = 3$) for which test-retest reliability is 0.72 to 0.75.

Composition—sentence writing fluency (word and syntax levels)—*The WJ III Writing Fluency* subtest of the (Woodcock et al., 2001) was given. The task is to compose a written sentence for each set of three provided words, which are to be used without changing them in any way. There is a 7 min time limit. The score, which is the total number of syntactically correct sentences composed in writing within the time limit, is converted to a standard score ($M = 100$ and $SD = 15$) for which test-retest reliability is 0.88.

Composition—sentence combining (syntax level)—*The WIAT III Sentence Combining* subtest (Pearson, 2009) was given. The task is to combine two provided sentences into one well written sentence that contains all the ideas in the two separate sentences (Myhill, 2008), that is, translate thoughts into one well written syntactic structure. The total accuracy score is a standard score ($M = 100$ and $SD = 15$) for which test-retest reliability is 0.81.

Data Analyses

To test the first research question, we used multiple regression with simultaneous (or “standard”) predictor entry to determine percent of variance each set of predictors explained (i.e., using R^2 values). In this way, we could determine whether a given set of predictors had a direct relationship with the outcome, even if the set shared variance with another set of predictors.

To test the second research question, we used multiple linear regression with sequential (also known as “hierarchical” predictor entry, but to avoid confusion with multilevel modeling, we use the term “sequential”). Sequential predictor entry specifically allows testing the significance of the incremental variance in each outcome accounted for by sets of predictors, after controlling for previously entered predictor sets. Five blocks or “steps” of predictors were used to replicate and extend prior research on links between predictors and reading and writing achievement for students with SLDs in contrasting levels of language impairment in grades 4 through 9. Specifically, Block 1 tested the contribution of cognitive-linguistic translation measures; Block 2 tested the incremental variance accounted for by three working memory word form coding measures beyond cognitive-linguistic translation; Block 3 tested the added variance explained by the two working memory loops (above and beyond cognitive-linguistic translation and word-form coding); and Block 4 tested the contribution of two supervisory attention to explaining individual achievement differences, above and beyond the other measures in Blocks already entered. (Essentially, Blocks 1–4 replicate similar regressions with typically developing younger students in Nieto et al. (2014); but the current Block 1 also includes a measure of oral sentence syntax construction and Blocks 2–4 are entered sequentially rather than simultaneously to evaluate whether specific working memory components explain unique variance.

Finally, in the last Block 5, to test our third research question in determining whether the differences in SLDs remained even after controlling for Blocks 1–4, we added two dummy-coded predictors to represent the three SLD profiles for which dyslexia was coded 0 as the reference group. Dyslexia was selected as the reference group since it is the most researched and was the largest group in the dataset. Of interest was whether this set of two predictors

accounted for a significant proportion of variance in the achievement measures above and beyond the predictors already entered into the model. If it did account for significant variance, it would mean that any differences between groups on the measure were due to the profile or pattern of levels of language impairment associated with the SLDs being compared.

In all analyses, scores based on published norms for age or for grade on measures validated in research on large samples and multiple studies were used and an alpha level of 0.05 was adopted. Norm-referenced scores for predictors used in multiple regression analyses were further standardized into *z*-scores for ease of interpretation of model results. Finally, we note that students who were individually assessed at the university research center came from a wide array of schools and grade levels across the urban and suburban counties near to the university; as such, non-independence did not pose an issue for these data.

Results

Descriptive Statistics

SLD profiles—Table 2 provides means and standard deviations for each group of specific learning disability (SLD) profiles, as well as the sample as a whole. As can be seen, the OWL LD group was substantially lower than both the dysgraphia and dyslexia groups on cognitive-linguistic translation measures, as expected given their history of oral expression problems both before and after school entry. Nevertheless, students were not assigned to groups solely on the basis of their verbal comprehension or oral syntax construction scores alone. In particular, on word form coding measures (used in Block 2 of our regression models), the dysgraphia group was essentially at the mean, but the dyslexia group was below the mean on phonological and orthographic coding. The OWL LD group, on the other hand, was more than a standard deviation below the dyslexia group on morphological coding and below both of the other groups on phonological and orthographic coding. The dysgraphia group was below the mean only on the orthographic loop and neither of the supervisory attention measures. Both the dyslexia and OWL LD groups were below the mean on both working memory loops (used in Block 3 of our regression models) and both supervisory attention measures (used in Block 4).

With respect to our reading achievement measures, the OWL LD group was substantially lower than the dyslexia group, especially in reading comprehension but not only in reading comprehension, and the dyslexia group who had history of reading problems was generally lower than the dysgraphia group without history of reading problems. With regard to the writing achievement measures, all three groups were below the mean on handwriting, but only the dyslexia and OWL LD groups were below the mean on spelling measures. Further, the OWL LD group was notably lower than the dysgraphia and dyslexia groups on both sentence level written composing tasks, consistent with syntax problems persisting in those with history of early emerging oral language problems in the preschool years. Overall the profiles for the three diagnostic groups were consistent with cascading levels of language impairment across different SLDs in written language (Berninger et al., 2015; Richards et al., 2016).

We note that, although the means on the various achievement measures can differ statistically when diagnostic groups are compared on one measure at a time, as we mention earlier, our three SLD diagnostic groups were defined on the basis of profiles of hallmark impairments along a distribution of scores, rather than using a single measure alone. As also previously noted, past and current history of each child's response to instruction was also taken into account in assignment to diagnostic group (e.g., oral language problems emerging in the preschool years rather than reading and writing problems emerging at transition to school years). Additionally, we emphasize that the current study is a correlational study in which the research questions focus on whether each of the sets of predictors, entered sequentially (four sets of predictors in Tables 3, 4, 5, and 7, and five sets in Table 6), entered sequentially, explains additional unique variance in the achievement measures (see next section). To reiterate, we were not focused on whether the SLD diagnostic groups statistically differed from each other on individual achievement measures.

Zero-order correlations among measures—Zero-order correlations between each of the sets of predictors (cognitive-linguistic translation and working memory components) and each of the literacy achievement measures are provided in Table 3. As can readily be observed, the strongest correlates of achievement included orthographic word form coding (mean correlation with achievement measures was 0.56, which translates to 32% shared variance), supervisory attention switching (mean correlation of 0.45, 20% shared variance), and verbal comprehension (mean correlation of 0.42, 17% shared variance). Notably, the correlations among predictors and literacy achievement were somewhat lower for writing (average correlation was 0.30, or 9% shared variance) compared with reading (average correlation of 0.39, or 15% shared variance); additionally, the correlations among the predictors themselves (given in Table 4) were sizable, so it was unclear which of the predictors would explain *unique* (non-overlapping) variance in literacy achievement once entered together in a model.

RQ1: What are the Direct Relationships among Predictors and Literacy Achievement for Students with SLDs in Cascading Levels of Language?

To test research question 1, we conducted a series of simultaneous multiple regressions relating each particular *set* of predictors with each literacy measure. In other words, we conducted isolated tests of the percent of variance each construct shared with each achievement measure (four separate regressions). Results of these models (Table 5 provides R^2_{total} and associated F -test p -values) showed that cognitive-linguistic translation measures together accounted for an average of 27% and 15% of the variance in reading and writing, respectively (across all measures, averaging 21%); working memory word form coding measures together accounted for 46% and 34% of the variance in reading and writing, respectively (across all measures, averaging 40%); working memory loops accounted for 17% in reading and 11% in writing (averaging 14% across all); and working memory supervisory attention measures accounted for 38% and 17% in reading and writing, respectively (averaging 28% across all). In other words, each of the predictors was related to reading and writing achievement, but for handwriting, spelling choice, and sentence combining – the predictors accounted for markedly less variance than the other writing measures.

RQ2: (a) What are the Incremental Contributions of Working Memory Components to Literacy achievement, beyond Cognitive-Linguistic Translation? (b) Relatedly, which working memory components are uniquely predictive?

To test research questions 2a and 2b, we conducted multiple sequential predictor entry with each block of predictors entered in a specific order for the different working memory components related initially to storing a heard or read word form in working memory, next for integrating these with oral name or written letter via loops, and finally for a supervisory attention mechanism for regulating all the working memory components. In the last (fifth) block, we tested for any remaining differences in SLD profiles; findings for this block will be discussed in the next section as it relates to our final research question 3. Table 6 summarizes the model results for the incremental variance in the reading and writing achievement measures accounted for by each block after controlling for previous blocks (R^2_{change}) as well as the total variance accounted for at that point, much like filling a measuring cup (R^2_{total}); Table 7 summarizes which of the predictors had significant unique relationships with reading and writing achievement, respectively, when all predictors except SLD language profiles were entered (i.e., all predictors through Block 4).

Reading measures—Not surprisingly given our findings for research question 1 and because it was entered first into the model, cognitive-linguistic translation accounted for significant variation in all reading outcomes (averaging 27% variance accounted for), with less variance explained in pseudoword reading accuracy and rate (11–15%) relative to real word reading accuracy and rate (19% and 28%) and reading comprehension (60%). More interestingly, working memory components each contributed unique variance above and beyond shared variance with cognitive-linguistic translation (averaging a total of 38% more variance explained). Word form coding explained an additional 32–33% of the variance in measures of reading accuracy and 23–25% more variance in reading rate; only 6% additional variance was explained in reading comprehension. Controlling for both cognitive-linguistic translation and word form coding, working memory loops accounted for added variance in reading rate (14–22% more) and reading accuracy (5–6% more); however, they did not account for additional significant variance in reading comprehension (only 2%, F -test $p > 0.05$). Finally, working memory supervisory attention accounted for an average of 5% more variance in reading comprehension, controlling for all three prior blocks. In summary, all three working memory predictors accounted for unique variance in reading accuracy and rate in particular, far beyond cognitive-linguistic translation; however, reading comprehension was explained almost entirely by cognitive-linguistic translation (60%), with only 10% more explained by working memory components. Examination of the pattern of significant coefficients (Table 7) shows that the predictors that were *consistently* and *uniquely* predictive of individual differences in reading for this sample were supervisory switching (all five reading measures), orthographic word form coding (four of five reading outcome measures – all but reading comprehension), and the working memory orthographic loop (three of five measures – all but reading comprehension and pseudoword reading rate).

Writing measures—Results for the writing measures differed somewhat from the patterns observed in the reading measures (see again Table 6). First, it was notable that the average percentage of total variance in writing accounted for by all of the predictors was 42%,

markedly lower than 65% observed for reading measures. (Even when we take handwriting out of this calculation, the average variance in writing achievement accounted for by the cognitive correlates was 46%.) Nevertheless, across both reading and writing, working memory components as a whole appeared to account for approximately 10% more variance than did cognitive-linguistic translation measures: whereas 15% of the variance in writing was accounted for by cognitive-linguistic translation (compared to 27% explained in reading), 27% more variance was accounted for by working memory components (compared to 38% in reading).

Another notable finding was that only working memory word form coding accounted for significant variation in writing; working memory loops and supervisory attention accounted for little if any variance. Examination of the pattern of significant coefficients (see again Table 7) shows that the only predictor that was *consistently, uniquely* predictive of individual differences in writing for this sample of language-related SLD students was orthographic word form coding.

RQ3: Do Differences among SLD Profiles Remain After Controlling for the Cognitive-Linguistic Translation Predictor?

Block 5, the final step in our sequential predictor entry regression models (see again Table 6), tested whether any differences between the SLD groups persisted (remained unexplained) after controlling for the other predictors (measures of cognitive-linguistic translation and working memory components in Blocks 1–4). Recall that dyslexia, with impairment at the word level, was the reference group that was compared to dysgraphia, with impairment at a lower level of language–subword, and OWL LD, with impairment at a higher level of language–multi-word syntax.

Dysgraphia compared to dyslexia—Across the ten reading and writing achievement measures, six simple (unadjusted) mean differences advantaging dysgraphia SLD over dyslexia SLD were detected (t -test $ps < 0.05$, see Table 2 for means), including all measures of reading and two measures of writing (both spelling). However, these groups also differed significantly on two measures of working memory word form coding (dysgraphia performed much higher than dyslexia), one type of working memory loop (phonological), and one type of working memory supervisory attention (switching). Results from Block 5 of the regression models, which adjusted for SLD differences on the Block 1 predictors, revealed that differences continued to persist between the dysgraphia and dyslexia on all of the measures previously showing differences (percent of variance accounted for summarized in Table 6; individual model results available upon request from the first author); indeed, SLD differences accounted for an additional 3% of the variance, on average, beyond what the Block 1 predictors explained.

For word and pseudoword reading accuracy, the dysgraphia group was predicted to be significantly higher than the dyslexia group (6.10 and 5.23 points, respectively), although these magnitudes are quite diminished in comparison with the original simple mean differences of 12.17 and 12.61 points (see again Table 2), respectively. For reading comprehension, the predicted difference was 5.18 points, which did not decrease

substantively in comparison with the original simple mean difference of 5.51 points. For word and pseudoword reading fluency, the results show that the dysgraphia group continued to be predicted to be higher than the dyslexia group (8.31 and 9.74 points, respectively). Again, these magnitudes are smaller than the original simple mean differences of 17.40 and 20.75 points, respectively. Finally, for spelling, the dysgraphia group was predicted to outperform the dyslexia group by 8.92 and 1.90 points on spelling dictated words and spelling word choice, respectively; the original simple mean differences were 15.94 and 2.95 points.

Overall, despite the diminished differences observed, the fact that students with dysgraphia remained significantly higher than those with dyslexia after controlling for associated cognitive factors supports the plural form in SLDs. There are differences among the diagnostic profiles for impaired subword handwriting (dysgraphia) and impaired word reading and spelling (dyslexia) beyond those processes captured in the cognitive-linguistic translation and working memory components for word form storage and processing, phonological and orthographic loops, and supervisory attention. These findings are consistent with brain imaging findings showing differences between dyslexia and dysgraphia as well (Richards et al., 2015).

OWL LD compared to dyslexia—Only four simple mean differences between the OWL LD and dyslexia groups were detected across the 10 reading and writing achievement measures (p s > 0.05, see Table 2 for means), which included word reading accuracy, reading comprehension, and both sentence writing measures; however, they also differed significantly on all measures of cognitive translation and working memory word form coding (OWL LD performed much lower than dyslexia). After controlling for these cognitive correlates (along with working memory loops and supervisory attention), only two differences remained between these two groups: sentence writing fluency and word reading rate. On sentence writing fluency, the OWL LD group was predicted to be 11.56 points lower than the dyslexia group (compared with original mean difference of 17.36 points, this is much lower). On word reading rate, the simple mean difference between groups showed the OWL LD group was not significantly different from the dyslexia group (the difference was 6.51 points). However, after controlling for group differences on the predictors, the OWL LD group was predicted to be higher than the dyslexia group by 7.40 points. This last finding may be due to the fact that the OWL LD group was relatively less impaired in word- than syntax-level processing, and that the word reading rate task is likely to be more sensitive to word-level processing. Overall, the initial (simple) differences between OWL LD and dyslexia on literacy outcomes given in Table 2 were largely explained by their differences in measures of cognitive-linguistic translation and working memory word form coding components. These results are consistent with findings in Richards et al. (2016) and Berninger, Richards, and Abbott (2015).

Discussion

Building on a legacy of prior work on working memory contributions to academic achievement for students with and without learning disabilities, the present study tested the unique contributions of cognitive-linguistic translation and working memory components to

individual differences in reading and writing achievement for children in grades 4–9 with language-related specific learning disabilities (SLDs), including dysgraphia, dyslexia, and oral and written language learning disability (OWL LD). Our findings clearly showed that working memory components as a whole (including word form coding, phonological and orthographic loops, and supervisory attention) accounted for substantial unique variance in reading and writing achievement (averaging 39% and 27%, respectively) beyond that of cognitive-linguistic translation (which averaged 27% and 15% of the variance accounted for, respectively). Indeed, the findings in the present paper are consistent with those found in Niedo et al. (2014) with typically developing elementary students – in other words, both cognitive-linguistic translation and working memory components are key factors to understanding achievement differences in early adolescents with language-related SLDs.

Further, although all of the working memory components in our study were found to have significant direct relationships with reading and writing achievement, only orthographic word form coding consistently *uniquely* predicted both reading and writing achievement (supervisory attention switching did, however, uniquely predict reading measures). These results are consistent with prior findings for other studies (Berninger & Richards, 2010). Finally, results from our models showed that differences in reading and writing achievement between dyslexia and OWL LD were largely explained by their differences in cognitive-translation and working memory components; differences between dyslexia and dysgraphia groups, on the other hand, were not.

Differences in Percent of Variance Explained for Reading and Writing Outcomes

One of the unanticipated findings in the present study is that, while we were able to predict between 55% and 70% (average of 65%) of the variance in individual differences in reading achievement measures using cognitive-translation and working memory components (Blocks 1–4 of our models), the same set of predictors accounted for between 27% and 56% (average of 42%) of the variance in writing achievement measures, a sizable amount of variance even though less than for reading. There may be two reasons for predicting less variance in writing measures. First, prior research showed that cognitive-linguistic translation is not a significant predictor of handwriting problems (Berninger, 2009). Second, writing at the word and syntax levels tends to be generative in English, that is, there is more than one way to spell words pronounced the same, more than one meaning associated with the same spelling, or more than one way to pronounce the same word across dialects, or to combine words in sentence syntax to express ideas. Also, higher order executive functions, which are not components of working memory, may play a role in writing (e.g., planning, reviewing, and revising) (Berninger, Swanson, & Griffin, 2014), but were not assessed in the current study.

Educational Implications

In the present study, parents of participating children wanted to know *why* their children were continuing to struggle in learning to read and write, despite the various kinds of help they had received over the years, as well as *what could be done instructionally* to help their child in further developing their literacy skills. In making such recommendations for linking instruction to assessment we consider the current findings in the context of over two decades of programmatic, interdisciplinary research on SLDs, including multiple family genetic,

brain imaging, diagnostic assessment, and instructional intervention studies early and later in schooling (e.g., Berninger & Richards, 2010).

Diagnosing SLDs and cognitive-linguistic translation—In the current study cognitive-linguistic translation (the first set of predictors) did account for substantial variance in all reading and most writing measures, but it was not found to account for as much unique variance as the subsequently entered working memory components. Thus, the evidence from this study, which is consistent with prior programmatic research, is that the IQ-achievement discrepancy, which simply subtracts current academic achievement from the Weschler Full Scale score, is not evidence-based; however, this does not mean that the Verbal Comprehension Index and other measures of cognitive-linguistic translation are not relevant to diagnosing SLDs if component working memory measures and profiles of measures organized by levels of language are also considered.

For example, those with OWL LD may be low in verbal comprehension, not because they are not intelligent, but because they have difficulty translating their ideas into oral language, especially at the syntactic level. If schools use the discrepancy definition of SLD, students with OWL LD are likely to be missed because their low achievement in reading and writing, especially reading comprehension and written expression, is not sufficiently discrepant from their Full Scale score, deflated by their low Verbal Comprehension Index. Yet, assessment using the sets of predictors as in the current study can be used to design specialized instruction to help the student learn to express thinking in oral language as well as to improve their reading and writing skills at the morphological and syntax levels of language. Assessments that do not include morphological coding and reading and writing measures at the syntax level are likely to not identify OWL LD and provide necessary instruction in morphological coding and syntax awareness that students with OWL LD require (see Berninger & O'Malley-May, 2011).

In contrast cognitive-linguistic translation is not relevant to identifying dysgraphia (handwriting impairment), but component working memory components like orthographic coding and orthographic loop are. Also, if cognitive-linguistic translation is superior or very superior and writing skills are near the mean rather than below the average range, that does not mean a student does not have an SLD in written language. For students who are twice exceptional – both verbally gifted and meeting diagnostic criteria for dysgraphia – the dysgraphia may be masking student's talent in translating thought into oral language because of difficulty in then translating the oral language into written language (e.g., Lyman, Sanders, Abbott, & Berninger, 2016).

Phonological awareness and coding are necessary, but not sufficient—For this sample of students with persisting SLDs beyond the early grades, orthographic word form coding and the orthographic loop were more impaired relative to the population mean than any of the other predictors. Although phonological awareness, phonological coding, and phonological decoding may be necessary in early literacy, so too are orthographic awareness, orthographic coding, and orthographic encoding (spelling); and if the latter orthographic skills are not developed adequately, that may result in ongoing persisting literacy problems beyond the early grades. Indeed, all three SLD groups had difficulty with

handwriting, which has been shown in research to draw on orthographic skills (Berninger, 2009). However, because handwriting tends not to be emphasized as much in current educational practices as it was in the past (and never has been beyond fourth grade), instructional practices may account for some of these difficulties for all students with language-related SLDs. However, it is unlikely that instruction explained all of the observed handwriting difficulties in the present study, since studies with typically developing students show no difficulty with handwriting (e.g., Niedo et al., 2014).

Implications for the language learning mechanism—The results of our study showed that both cognitive-linguistic translation and working memory were significantly related to all of our reading measures, and some of our writing measures, providing evidence for a “language learning mechanism” system not unlike Chomsky’s (1965) original vision of a language learning device involving syntax. The current results, however, show that more components are involved in the language learning mechanism than Chomsky envisioned. Even after cognitive-linguistic translation was controlled for in Block 1, the working memory components in Blocks 2–4 explained additional unique variance – and when working memory components were combined, they accounted for more variance than cognitive-linguistic translation. However, for the handwriting outcome, only orthographic word form coding and the orthographic loop were uniquely related, showing that subword level language skills should also be assessed and taught.

Importance of assessing profiles of multi-leveled reading and writing—One of the new findings in the present study is the demonstrated need to assess learning profiles across levels of language for students with language-related learning disabilities. Indeed, the current findings are consistent with characterizing dysgraphia, dyslexia, and OWL LD in terms of cascading levels of language impairment (subword to word to syntax levels, such that each SLD has an identifiable profile/pattern, but nevertheless may share some common impairments with those at a lower level of language as well as unique impairments for the level of language that is defining for a particular diagnosis: subword for dysgraphia, word for dyslexia, and syntax for OWL LD (c.f., Berninger et al., 2015; Catts, Adlof, Hogan, Ellis, & Weismer, 2005; Richards et al., 2015). Thus, it is unlikely that a one-size-fits-all instructional approach would be fitting for these three language-related SLDs. Interestingly, once the cognitive-linguistic translation and working memory predictors were controlled for, differences between the dyslexia and OWL LD group were largely explained in Block 5 of our model. Our results showed that the dysgraphia group, with only subword level of written language impairment, outperformed the dyslexia group in both word-level reading and writing (spelling) achievement. Again, a one-size-fits-all intervention would be inappropriate.

If practitioners were to measure both cognitive-linguistic translation and working memory components in concert with achievement, they could develop learning profiles and design or coordinate instructional plans tailored to the individual student. For example, for all three SLDs in the present study, intervention to support the orthographic loop may be an important part of the plan. For children with dyslexia who exhibit a phonological processing impairment, phonological word form coding support seems warranted; and, for children with

OWL LD, a multi-pronged plan to bolster cognitive-linguistic translation (practice in translating ideas into verbal and written form) and working memory strategies interventions may be the fruitful (c.f., Swanson et al., 2010; Swanson et al., 2015; Swanson et al., 2016).

Finally, although it is often assumed that the primary impairment in dyslexia is related to reading, especially decoding unfamiliar words, the current study serves as yet another reminder that individuals with dyslexia are impaired in spelling too—and spelling is often the persisting impairment over reading. In the present study, those with dyslexia were more impaired than those with dysgraphia on both spelling tasks. In addition, the OWL LD group was more impaired in sentence writing than the dyslexia group, illustrating the word-level impairment in dyslexia and the syntax-level impairment in OWL LD. Additionally, the OWL LD group was more impaired in morphological coding than the dyslexia group, who was impaired mainly in phonological and orthographic coding.

Limitations and Future Directions

The trade-off for a very careful acquisition and differential diagnosis of SLDs in levels of language during the upper elementary and middle school grades was that our sample size was relatively small. Note that this was not a sample of convenience or a sample of self-referred as in clinic samples. Rather, both parents and educators and other professionals referred children and youth who were carefully screened and assessed, and only those who met diagnostic criteria were included. Nevertheless, our power was sufficient to detect modest effect sizes and our sample is representative of the broader urban area in which the study was conducted. Future research might apply the present study's model to larger samples in schools, and analyze whether social emotional, self-concept, and motivational issues (e.g., avoidance through discouragement) may be other unique contributing factors in predicting literacy outcomes for upper elementary and middle school students, both with and without SLDs. Use of a larger scale study would also allow for the inclusion of a more diverse sample, including language minority students; however, prior research has found consistent results implicating working memory deficits in learning disabilities even in language minority students (e.g., Swanson, Sáez, & Gerber, 2006; Swanson, Sáez, Gerber, & Leafstedt, 2004).

The finding that morphological and orthographic word form coding contributed to literacy achievement in addition to phonological coding should not be surprising because English is a morphophonemic orthography (Venezky, 1970, 1999). Thus, although the National Reading Panel emphasizes the importance of phonological coding based on typically developing students, the current results provide further evidence to support that orthographic and morphological coding are also important (consistent with other research, including Niedo et al., 2014), especially for those with language-related SLDs. More research is needed on implementing instructional interventions for SLDs for teaching students in grades 4 to 9 to read and spell words in English morphophonemic orthography who can learn to do so despite not past struggles (Tanimoto, Thompson, Berninger, Nagy, & Abbott, 2015).

Summary

The present study extends prior research for typically developing students to those with three profiles of language-related SLDs, and provides a better framework than the IQ-achievement discrepancy model for predicting expected reading and writing achievement for SLD learning profiles relevant to diagnosing and individually tailoring instruction. Unlike disabilities involving a sensory system such as blindness or deafness, or a motor system impairment such as speech and communication, when an otherwise typically developing child struggles to learn because of an SLD, the reason for the struggle is not nearly as visible. Impaired cognitive-linguistic translation and/or working memory components can easily be completely misunderstood as just achievement gaps stemming from poor classroom instruction, deficient parental involvement, or student apathy. Without a deep understanding of the nature of profiles of disabilities interfering with learning, practitioners may miss the mark and fail to seize an opportunity to change the course of action for the student; of even greater concern is that students who struggle with language-related SLDs may simply give up on themselves. Thus, our first step requires developing learning profiles using evidence-based identification; and our next step is tailored interventions that not only teach skills but also offer hope to the struggling readers and writers that they can learn to read and write.

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Table 1

Demographic Characteristics for SLD Profiles and Combined Sample

Characteristic	Dysgraphia (<i>n</i> = 25)		Dyslexia (<i>n</i> = 60)		OWL LD (<i>n</i> = 18)		Combined Sample	
	<i>n</i>	(%)	<i>n</i>	(%)	<i>n</i>	(%)	<i>N</i>	(%)
<i>Gender</i>								
Male	20	(80%)	34	(57%)	12	(67%)	66	(64%)
Female	5	(20%)	26	(43%)	6	(33%)	37	(36%)
<i>Grade Level</i>								
Elementary (4 – 5)	7	(28%)	21	(35%)	6	(33%)	34	(33%)
Middle School (6 – 8)	17	(68%)	35	(58%)	11	(61%)	63	(61%)
High School (9)	1	(4%)	4	(7%)	1	(6%)	6	(6%)
<i>Ethnicity</i>								
Non-Minority	18	(72%)	47	(78%)	11	(61%)	76	(74%)
Minority	6	(24%)	12	(20%)	5	(28%)	23	(22%)
Hispanic	1	(4%)	0	(0%)	1	(6%)	2	(2%)
Black	0	(0%)	2	(3%)	0	(0%)	2	(2%)
Asian	0	(0%)	2	(3%)	2	(11%)	4	(4%)
Native/Pac Isl	0	(0%)	0	(0%)	1	(6%)	1	(1%)
Mixed	5	(20%)	8	(13%)	1	(6%)	14	(14%)
Missing/Unspecified	1	(4%)	1	(2%)	2	(11%)	4	(4%)
<i>Mother's Education</i>								
< High School	0	(0%)	0	(0%)	1	(6%)	1	(1%)
High School	1	(4%)	1	(2%)	1	(6%)	3	(3%)
Some College	0	(0%)	3	(5%)	2	(11%)	5	(5%)
Bachelor's Degree	11	(44%)	24	(49%)	7	(39%)	42	(41%)
> Bachelor's	12	(48%)	26	(43%)	5	(28%)	43	(42%)
Missing	1	(4%)	6	(10%)	2	(11%)	9	(9%)
<i>Father's Education</i>								
< High School	0	(0%)	1	(2%)	2	(11%)	3	(3%)
High School	1	(4%)	1	(2%)	1	(6%)	3	(3%)
Some College	3	(12%)	5	(8%)	2	(11%)	10	(10%)

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Characteristic	Dysgraphia (n = 25)		Dyslexia (n = 60)		OWL LD (n = 18)		Combined Sample	
	n	(%)	n	(%)	n	(%)	N	(%)
Bachelor's Degree	8	(32%)	28	(47%)	6	(33%)	42	(41%)
> Bachelor's	12	(48%)	19	(32%)	2	(11%)	33	(32%)
Missing	1	(4%)	6	(10%)	5	(28%)	12	(12%)

N = 103 students grades 4–9.

Table 2

Descriptive Statistics for SLD Profiles and Combined Sample on Predictors and Literacy Measures

Dysgraphia (DG) (<i>n</i> = 25)			Dyslexia (DL) (<i>n</i> = 60)			OWL LD (<i>n</i> = 18)			Combined Sample			DG vs. DL			OWL LD vs. DL			DG vs. OWL LD		
Variable	<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)	<i>d</i>	<i>p</i>	<i>d</i>	<i>p</i>	<i>d</i>	<i>p</i>				
<i>Predictors</i>																				
<i>1. Cognitive-Linguistic Translation</i>																				
Verbal Comp	110.24	(16.18)	114.45	(11.43)	90.56	(14.35)	109.25	(15.79)	-.32		-1.97 ***		.70 ***							
Oral Lang	9.92	(3.07)	11.20	(2.55)	5.89	(1.97)	9.96	(3.23)	-.47		-2.18 ***		2.11 ***							
<i>2. WM Word Form Coding</i>																				
Phono Process	10.76	(2.40)	9.30	(2.11)	7.78	(1.93)	9.39	(2.34)	.66 *		-.74 *		1.75 ***							
Morpho Process	-0.08	(0.76)	-0.06	(0.74)	-1.11	(1.17)	-0.25	(0.92)	-.03		-1.22 ***		1.38 ***							
Ortho Process	100.04	(13.74)	92.40	(9.90)	84.44	(8.85)	92.86	(11.81)	.69 *		-.82 *		.71 ***							
<i>3. WM Loops</i>																				
Phono Loop	107.76	(12.33)	96.78	(13.75)	97.56	(11.45)	99.58	(13.74)	.82 **		.06		.48 *							
Ortho Loop	-1.58	(0.63)	-1.20	(0.88)	-1.46	(0.63)	-1.34	(0.79)	-.46		-.32		-.31							
<i>4. WM Supervisory Attention</i>																				
Focusing	10.36	(3.13)	9.12	(2.74)	7.78	(2.98)	9.18	(2.97)	.43		-.48		1.06 *							
Switching	109.56	(9.88)	95.98	(11.85)	93.33	(8.96)	98.82	(12.49)	1.20 ***		-.24		.95 ***							
<i>Literacy Measures</i>																				
<i>Reading</i>																				
Word Read Acc	109.00	(11.79)	96.83	(9.63)	87.00	(10.90)	98.18	(12.54)	1.18 ***		-.99 **		1.07 ***							
Pseudoword Acc	106.76	(11.83)	94.15	(8.58)	88.39	(9.29)	96.20	(11.42)	1.31 ***		-.66		.92 ***							
Passage Comp	104.84	(11.31)	99.33	(9.78)	79.71	(12.16)	97.41	(13.35)	.54		-1.90 ***		1.27 ***							
Word Read Rate	110.68	(15.02)	93.28	(12.96)	86.78	(13.06)	96.37	(15.83)	1.28 ***		-.50		.92 ***							
Pseudoword Rate	108.48	(17.52)	87.73	(12.80)	78.28	(17.47)	91.12	(18.10)	1.45 ***		-.68		.99 ***							
<i>Writing</i>																				
Handwriting	8.76	(3.14)	9.33	(3.48)	8.61	(3.74)	9.07	(3.43)	-.17		-.20		.00							
Spell Dictated	100.84	(19.52)	84.90	(11.35)	78.44	(10.95)	87.64	(15.69)	1.12 ***		-.57		.72 ***							
Spell Choice	10.88	(3.35)	7.93	(3.78)	5.78	(2.73)	8.28	(3.88)	.81 **		-.60		2.12 ***							
Sent Fluency	98.12	(11.09)	95.36	(10.26)	78.00	(14.50)	92.97	(13.22)	.26		-1.53 ***		1.03 ***							
Sent Combining	100.96	(17.69)	98.45	(14.75)	87.94	(11.48)	97.22	(15.52)	.16		-.75 *		.46 *							

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Note. $N = 103$ students grades 4–9. Verbal Comp = Verbal Comprehension Index Standard Score; Oral Lang = CELF4 Formulated Sentences Standard Score; WM = Working Memory; Phono = CTOPP Nonword Repetition Standard Score; Morpho = Nagy et al. (2006) Comes From Scaled Z-Score; Ortho = TSWRF Standard Score; Phono Loop = Wolf and Denckla RAN Rapid Letter Naming Standard Score; Ortho Loop = Berninger (2009) Rapid Automatic Letter Writing Scaled Z-score; Focusing Attention = DK-EFS Color Word Form-Inhibition Standard Score; Switching Attention = Wolf and Denckla RAS Letters and Numbers Standard Score; Word Read Acc = WJ III Letter-Word Identification Standard Score; Pseudoword Acc = WJ III Word Attack Standard Score; Passage Comp = WJ III Passage Comprehension Standard Score; Word Read Rate = TOWRE Phonemic Decoding Efficiency Standard Score; Pseudoword Rate = TOWRE Sight Word Efficiency Standard Score; Handwriting = DASH Copy Sentence Best Standard Score; Spell Dictated = WIAT3 Spelling Standard Score; Spell Choice = TOC Homonym/Word Choice Standard Score; Sent Fluency = WJ III Writing Fluency Standard Score; Sent Combining = WIAT3 Sentence Combining Standard Score.

Table 3

Zero-Order Correlations among Predictors and Literacy Measures

Predictor	Reading Measures				
	Word Read Acc	Pseudoword Acc	Read Comp	Word Read Rate	Pseudoword Rate
<i>1. Cognitive-Linguistic Translation</i>					
Verbal Comp	.50 ***	.33 ***	.75 ***	.43 ***	.38 ***
Oral Lang	.43 ***	.21 *	.59 ***	.29 **	.26 **
<i>2. WM Word Form Coding</i>					
Phono Process	.41 ***	.48 ***	.32 ***	.35 ***	.34 ***
Morpho Process	.49 ***	.34 ***	.42 ***	.29 **	.29 **
Ortho Process	.70 ***	.55 ***	.60 ***	.61 ***	.61 ***
<i>3. WM Loops</i>					
Phono Loop	.29 **	.28 **	.23 *	.60 ***	.51 ***
Ortho Loop	-.02	-.08	.11	.02	.02
<i>4. WM Supervisory Attention</i>					
Focusing	.40 ***	.34 ***	.45 ***	.36 ***	.46 ***
Switching	.51 ***	.48 ***	.37 ***	.70 ***	.67 ***
Predictor	Writing Measures				
	Handwriting	Spell Word	Spell Choice	Sent Fluency	Sent Comb
<i>1. Cognitive-Linguistic Translation</i>					
Verbal Comp	.13	.39 ***	.39 ***	.46 ***	.41 ***
Oral Lang	.12	.27 **	.34 ***	.40 ***	.14
<i>2. WM Word Form Coding</i>					
Phono Process	.11	.43 ***	.28 **	.29 **	.17
Morpho Process	.10	.29 **	.14	.39 ***	.46 ***
Ortho Process	.33 ***	.69 ***	.63 ***	.57 ***	.33 ***
<i>3. WM Loops</i>					

Predictor	Reading Measures					
	Word Read Acc	Pseudoword Acc	Read Comp	Word Read Rate	Pseudoword Rate	
Phono Loop	.21	.32 ***	.18	.29 **	.22 *	
Ortho Loop	.41 ***	.07	-.07	.16	.16	
<i>4. WM Supervisory Attention</i>						
Focusing	.14	.38 ***	.23 *	.28 **	.30 **	
Switching	.28 **	.44 ***	.27 **	.43 ***	.35 ***	

Note. $N = 103$ students grades 4–9. Verbal Comp = Verbal Comprehension Index Standard Score; Oral Lang = CELF4 Formulated Sentences Standard Score; WM = Working Memory; Phono = CTOPP Nonword Repetition Standard Score; Morpho = Nagy et al. (2006) Comes From Scaled Z-Score; Ortho = TSWRF Standard Score; Phono Loop = Wolf and Denckla RAN Rapid Letter Naming Standard Score; Ortho Loop = Beminger (2009) Rapid Automatic Letter Writing Scaled Z-score; Focusing Attention = DK-EFS Color Word Form-Inhibition Standard Score; Switching Attention = Wolf and Denckla RAS Letters and Numbers Standard Score; Word Read Acc = WJ III Letter-Word Identification Standard Score; Pseudoword Acc = WJ III Word Attack Standard Score; Passage Comp = WJ III Passage Comprehension Standard Score; Word Read Rate = TOWRE Phonemic Decoding Efficiency Standard Score; Pseudoword Rate = TOWRE Sight Word Efficiency Standard Score; Handwriting = DASH Copy Sentence Best Standard Score; Spell Dictated = WIAT3 Spelling Standard Score; Spell Choice = TOC Homonym/Word Choice Standard Score; Sent Fluency = WJ III Writing Fluency Standard Score; Sent Combining = WIAT3 Sentence Combining Standard Score. Pearson's bivariate (zero-order) r values shown.

* $p < 0.05$,

** $p < 0.01$,

*** $p < 0.001$.

Table 4

Zero-Order Correlations among Predictors with Each Other

Predictor	1a.	1b.	2c.	2d.	2e.	3f.	3g.	4h.	4i.
<i>1. Cognitive-Linguistic Translation</i>									
a. Verbal Comp	--								
b. Oral Lang	.59 ***	--							
<i>2. WM Word Form Coding</i>									
c. Phono Process	.27 **	.24 *	--						
d. Morpho Process	.47 ***	.33 ***	.07	--					
e. Ortho Process	.49 ***	.38 ***	.32 ***	.40 ***	--				
<i>3. WM Loops</i>									
f. Phono Loop	.09	-.04	.15	-.07	.28 **	--			
g. Ortho Loop	.18	-.01	.03	.17	.17	.02	--		
<i>4. WM Supervisory Attention</i>									
h. Focusing	.40 ***	.13	.10	.28 **	.44 ***	.31 **	.05	--	
i. Switching	.15	.06	.28 **	.11	.42 ***	.81 ***	.11	.31 **	--

Note. $N = 103$ students grades 4–9. Verbal Comp = Verbal Comprehension Index Standard Score; Oral Lang = CELF4 Formulated Sentences Standard Score; WM = Working Memory; Phono = CTOPP Nonword Repetition Standard Score; Morpho = Nagy et al. (2006) Comes From Scaled Z-Score; Ortho = TSWRF Standard Score; Phono Loop = Wolf and Denckla RAN Rapid Letter Naming Standard Score; Ortho Loop = Berninger (2009) Rapid Automatic Letter Writing Scaled Z-score; Focusing Attention = DK-EFS Color Word Form-Inhibition Standard Score; Switching Attention = Wolf and Denckla RAS Letters and Numbers Standard Score. Pearson's bivariate (zero-order) r values shown.

* $p < 0.05$,

** $p < 0.01$,

*** $p < 0.001$.

Table 5

Total % Variance each Block Accounts for in Literacy Measures, in Isolation of Other Blocks

	Cognitive-Linguistic Translation	WM Word Form Coding	WM Loops	WM Supervisory Attention
Literacy Measure	R^2_{total}	R^2_{total}	R^2_{total}	R^2_{total}
<i>Reading</i>				
Word Read Acc	.28 ***	.59 ***	.09 **	.34 ***
Pseudoword Acc	.11 ***	.43 ***	.08 *	.27 ***
Read Comp	.61 ***	.43 ***	.06 *	.28 ***
Word Read Rate	.20 ***	.42 ***	.36 ***	.51 ***
Pseudoword Rate	.15 ***	.41 ***	.26 ***	.51 ***
<i>Writing</i>				
Handwriting	.02(ns)	.12 **	.21 ***	.09 **
Spell Word	.14 ***	.54 ***	.10 **	.27 ***
Spell Choice	.17 ***	.42 ***	.03(ns)	.11 **
Sent Fluency	.23 ***	.38 ***	.11 **	.22 ***
Sent Combining	.18 ***	.25 ***	.08 *	.17 ***

Note. $N = 103$ students grades 4–9. Block 1 Cognitive-Linguistic Translation includes Verbal Comprehension Index Standard Score and CELF4 Formulated Sentences Standard Score; Block 2 Working Memory (WM) Word Form Coding includes CTOPP Nonword Repetition Standard Score, Nagy et al. (2006) Comes From Scaled Z-Score, and TSWRF Standard Score; Block 3 WM Loops includes Wolf and Denckla RAN Rapid Letter Naming Standard Score and Berninger (2009) Rapid Automatic Letter Writing Scaled Z-score; Block 4 WM Supervisory Attention includes DK-EFS Color Word Form-Inhibition Standard Score and Wolf and Denckla RAS Letters and Numbers Standard Score; Word Read Acc = WJ III Letter-Word Identification Standard Score; Pseudoword Acc = WJ III Word Attack Standard Score; Passage Comp = WJ III Passage Comprehension Standard Score; Word Read Rate = TOWRE Phonemic Decoding Efficiency Standard Score; Pseudoword Rate = TOWRE Sight Word Efficiency Standard Score; Handwriting = DASH Copy Sentence Best Standard Score; Spell Dictated = WIAT3 Spelling Standard Score; Spell Choice = TOC Homonym/Word Choice Standard Score; Sent Fluency = WJ III Writing Fluency Standard Score; Sent Combining = WIAT3 Sentence Combining Standard Score. Significance of R^2 values based on multiple linear regression F -tests of each set of predictors, ignoring other predictor sets.

* $p < 0.05$,

** $p < 0.01$,

*** $p < 0.001$.

Table 6
Incremental % Variance each Block Accounts for in Literacy Measures, Controlling for Prior Blocks

Literacy Measure	Block 1		Block 2		Block 3		Block 4		Block 5	
	Cognitive-Linguistic Translation	WM Word Form Coding	WM Word Form Coding	WM Word Form Coding	WM Loops	WM Supervisory Attention	SLD Differences	SLD Differences	SLD Differences	SLD Differences
	R^2_{total}	R^2_{change}	R^2_{total}	R^2_{change}	R^2_{total}	R^2_{change}	R^2_{total}	R^2_{change}	R^2_{total}	R^2_{change}
<i>Reading</i>										
Word Read Acc	.28 ***	.32 ***	.60 ***	.05 **	.65 ***	.05 **	.69 ***	.03 *	.72 ***	.03 *
Pseudoword Acc	.11 ***	.33 ***	.44 ***	.06 **	.49 ***	.05 **	.55 ***	.02 ***	.57 ***	.02 ***
Read Comp	.60 ***	.06 ***	.66 ***	.02 ***	.67 ***	.03 *	.70 ***	.03 *	.73 ***	.03 *
Word Read Rate	.19 ***	.23 ***	.42 ***	.22 ***	.65 ***	.04 **	.69 ***	.04 **	.72 ***	.04 **
Pseudoword Rate	.15 ***	.25 ***	.40 ***	.14 ***	.55 ***	.08 ***	.62 ***	.03 *	.65 ***	.03 *
<i>Writing</i>										
Handwriting	.02	.10 *	.11 *	.16 ***	.27 ***	.00	.27 ***	.03 ***	.30 ***	.03 ***
Spell Word	.15 ***	.38 ***	.53 ***	.02 ***	.55 ***	.01	.56 ***	.04 *	.59 ***	.04 *
Spell Choice	.17 ***	.26 ***	.44 ***	.02 ***	.46 ***	.01	.47 ***	.03 ***	.50 ***	.03 ***
Sent Fluency	.24 ***	.16 ***	.40 ***	.04 *	.44 ***	.01	.45 ***	.05 **	.50 ***	.05 **
Sent Combining	.18 ***	.11 **	.29 ***	.03 ***	.33 ***	.03	.36 ***	.00	.36 ***	.00

Note. $N = 103$ students grades 4–9. Block 1 Cognitive-Linguistic Translation includes Verbal Comprehension Index Standard Score and CELF4 Formulated Sentences Standard Score; Block 2 Working Memory (WM) Word Form Coding includes CTOPP Nonword Repetition Standard Score, Nagy et al. (2006) Comes From Scaled Z-Score, and TSWRF Standard Score; Block 3 WM Loops includes Wolf and Denckla RAN Rapid Letter Naming Standard Score and Berninger (2009) Rapid Automatic Letter Writing Scaled Z-score; Block 4 WM Supervisory Attention includes DK-EFS Color Word Form-Inhibition Standard Score and Wolf and Denckla RAS Letters and Numbers Standard Score; Word Read Acc = WJ III Letter-Word Identification Standard Score; Pseudoword Acc = WJ III Word Attack Standard Score; Passage Comp = WJ III Passage Comprehension Standard Score; Word Read Rate = TOWRE Phonemic Decoding Efficiency Standard Score; Pseudoword Rate = TOWRE Sight Word Efficiency Standard Score; Handwriting = DASH Copy Sentence Best Standard Score; Spell Dictated = WIAT3 Spelling Standard Score; Spell Choice = TOC Homonym/Word Choice Standard Score; Sent Fluency = WJ III Writing Fluency Standard Score; Sent Combining = WIAT3 Sentence Combining Standard Score. Significance of R^2 values based on multiple linear regression F -tests that incrementally account for sets of predictors as each block is added to the model.

* $p < 0.05$,

** $p < 0.01$,

*** $p < 0.001$.

Table 7

Significant Unique Links between Predictors and Literacy Measures

Reading										
Predictor	Word Read Acc		Pseudoword Acc		Read Comp		Word Read Rate		Pseudoword Rate	
	Pattern	sr ²	Pattern	sr ²	Pattern	sr ²	Pattern	sr ²	Pattern	sr ²
1. Cognitive-Linguistic Translation										
Verbal Comp			(+) ***	.10	(+) *	.02				
Oral Lang			(+) **	.03						
2. WM Word Form Coding										
Phono Process	(+) *	.02	(+) ***	.07						
Morpho Process	(+) **	.03								
Ortho Process	(+) ***	.08	(+) **	.04	(+) ***	.04	(+) **	.04		.04
3. WM Loops										
Phono Loop										
Ortho Loop	(-) **	.03	(-) **	.04			(-) *	.01		.01
4. WM Supervisory Attention										
Focusing										
Switching	(+) ***	.04	(+) **	.05	(+) *	.02	(+) ***	.04	(+) ***	.07
Writing										
Handwriting										
Predictor	Pattern	sr ²	Pattern	sr ²	Pattern	sr ²	Pattern	sr ²	Pattern	sr ²
1. Cognitive-Linguistic Translation										
Verbal Comp									(+) *	.04
Oral Lang										
2. WM Word Form Coding										
Phono Process			(+) **	.03						

Reading										
Predictor	Word Read Acc		Pseudoword Acc		Read Comp		Word Read Rate		Pseudoword Rate	
	Pattern	sr ²	Pattern	sr ²	Pattern	sr ²	Pattern	sr ²	Pattern	sr ²
Morpho Process										
Ortho Process	(+)	*	.03	.16	(+)	***	.21	(+)	**	.07
3. WM Loops										
Phono Loop										
Ortho Loop	(+)	***	.13							
4. WM Supervisory Attention										
Focusing										
Switching									(+)	*
										.03

Note. $N = 103$ students grades 4–9. Verbal Comp = Verbal Comprehension Index Standard Score; Oral Lang = CELF4 Formulated Sentences Standard Score; WM = Working Memory; Phono = CTOPP Nonword Repetition Standard Score; Morpho = Nagy et al. (2006) Comes From Scaled Z-Score; Ortho = TSWRF Standard Score; Phono Loop = Wolf and Denckla RAN Rapid Letter Naming Standard Score; Ortho Loop = Berninger (2009) Rapid Automatic Letter Writing Scaled Z-score; Focusing Attention = DK-EFS Color Word Form-Inhibition Standard Score; Switching Attention = Wolf and Denckla RAS Letters and Numbers Standard Score; Word Read Acc = WJ III Letter-Word Identification Standard Score; Pseudoword Acc = WJ III Word Attack Standard Score; Passage Comp = WJ III Passage Comprehension Standard Score; Word Read Rate = TOWRE Phonemic Decoding Efficiency Standard Score; Pseudoword Rate = TOWRE Sight Word Efficiency Standard Score; Handwriting = DASH Copy Sentence Best Standard Score; Spell Dictated = WIAT3 Spelling Standard Score; Spell Choice = TOC Homonym/Word Choice Standard Score; Sent Fluency = WJ III Writing Fluency Standard Score; Sent Combining = WIAT3 Sentence Combining Standard Score.

* $p < 0.05$,

** $p < 0.01$,

*** $p < 0.001$;

Positive sign (+) indicates positive unique relationship; negative sign (–) indicates negative unique relationship; sr^2 = squared semipartial correlation (% variance uniquely accounted for by the predictor).