Relationship of Word- and Sentence-Level Working Memory to Reading and Writing in Second, Fourth, and Sixth Grade

Virginia W. Berninger
Robert D. Abbott
University of Washington, Seattle
H. Lee Swanson
University of California, Riverside
Dan Lovitt
Pam Trivedi
Shin-Ju (Cindy) Lin
Laura Gould
Marci Youngstrom
Shirley Shimada
Dagmar Amtmann
University of Washington

Increasingly, speech and language specialists are expected to address the written language disabilities of elementary schoolchildren who are referred for assessment of their school learning problems. Speech and language specialists routinely assess oral language at different levels of language but should also assess each level of written language and the related working memory mechanisms that support language learning at that language level. Some, but not all, phonological measures assess working memory because a single spoken name or series of names of digits or nonwords has to be stored in memory while analyzing the spoken word(s), preparing to repeat the word(s), and then producing the word(s) verbatim. Some, but not all, measures of syntactic awareness in oral language may also assess working memory in that a syntactic structure has to be held in working

ABSTRACT: **Purpose:** The purpose of this study was to evaluate the contribution of working memory at the word and sentence levels of language to reading and writing outcomes.
Method: Measures of working memory at the word and sentence levels, reading and writing, were administered to 2nd (*N* = 122), 4th (*N* = 222), and 6th (*N* = 105) graders. Structural equation modeling was used to evaluate whether the 2 predictor working memory factors contributed unique variance beyond their shared covariance to each of 5 outcome factors: handwriting, spelling, composing, word reading, and reading comprehension.
Results: At each grade level, except for handwriting and composing in 6th grade, the word-level working memory factor contributed unique variance to each reading and writing outcome. The text-level working memory factor contributed unique variance to reading comprehension in 4th and 6th grade.
Discussion: The clinical significance of these findings for assessment and intervention is discussed.

KEY WORDS: working memory, levels of language, orthographic, phonological, reading, writing

memory, analyzed, and then reproduced in a specified way to show precise processing of it.

The current study addressed the issue of whether word-level or syntactic-level working memory measures for both oral and written language explain variance in children's reading and writing skills that differ in their level of language (e.g., word or text). For written language, syntactic level corresponds to the sentence level. Whether word-level or sentence-level working memory measures uniquely predict written language skills only at the same level of language or across levels of language has clinical significance but has not been well researched. Word-level working memory tasks may be more appropriate for assessing word-level written language skills (reading and spelling), but sentence-level working memory tasks may be more appropriate for assessing sentence- and text-level reading and writing skills (reading comprehension and composition, that is, written expression of ideas).

Only measures of the word and sentence levels of language that also had working memory requirements for storage and processing were employed in the current study. The rationale for this study is best understood in reference to (a) the historical context in which working memory research and clinical application of the research has evolved, and (b) existing research findings about the role of working memory in reading and writing in children with typical development and children with specific learning disabilities.

Historical Context

Baddeley and colleagues' model of working memory. The original Baddeley and Hitch (1974) working memory model had three mechanisms: an articulatory loop with a phonological store, a visual–spatial scratch pad, and a central executive for attention regulation. Baddeley and Hitch's original model has since been revised in three ways. First, an episodic buffer for storing novel stimuli has been added. Second, the articulatory loop has been renamed and reconceptualized as a phonological loop. This phonological loop serves as an oral language learning device for pairing names (phonological buffer) with objects (visual–spatial scratch pad) or situations (episodic buffer) in early vocabulary learning (Baddeley, 2002; Baddeley, Gathercole, & Papagno, 1998). Third, instead of a single supervisory attentional mechanism, recent models specify multiple executive functions for regulating working memory functions such as inhibition, mental set shifting, self-monitoring, and updating (e.g., Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000). Jarrold and Towse's (2006) definition of working memory—the process of holding information in mind, despite potentially interfering distraction—captures this insight that executive dysfunction can contribute to inefficient working memory functioning. This revised working memory model (Baddeley, 2002) has been investigated for its relevance to oral language learning in preschoolers (e.g., Baddeley et al., 1998) and written language learning in school-age children (e.g., Gathercole, Tiffany, Briscoe, Thorn, & The ALSPAC Team, 2005).

Daneman and Carpenter's model of working memory. Daneman and Carpenter (1983) introduced a new operational definition of working memory—the Sentence Span task. They studied the reading and listening spans of college students to differentiate the capacity limitations in verbal working memory for storing language representations and for processing them. Storage is assessed by the ability to repeat correctly the last word in each sentence in a set. Processing is assessed by the ability to answer correctly a question about the content of a sentence in the set. Daneman and Carpenter contributed to operationalizing the concept of working memory by (a) expanding the target unit of language beyond the word to the sentence and (b) requiring evidence that items are scored for both storage and processing accuracy, which are independent dimensions of working memory. Swanson and colleagues adapted this Sentence Span task for research and the clinical assessment of school-age children (e.g., Swanson, 1999a, 1999b, 2006; Swanson & Ashbaker, 2000).

Relevance of Working Memory to Written Language Development and Disorders

A large body of research has validated phonological working memory as an important source of individual differences in learning to read (e.g., for an early influential research review, see Wagner & Torgesen, 1987; for more recent influential research reviews, see Ehri, 2004; Ehri, Nunes, Stahl, & Willows, 2001; National Institute of Child Health and Human Development, 2000). Moreover, instructional activities in phonological awareness (e.g., Adams, Foorman, Lundberg, & Beeler, 1997), which have been shown to be effective components of early literacy instruction, require that children hold spoken words in working memory while they analyze the sounds in them.

Behavioral evidence for three word forms and their parts in literacy learning. Research supports the importance of three kinds of processing in learning to read and spell: *phonological* (spoken words and their parts), *orthographic* (written words and their parts; e.g., Apel, Wolter, & Masterson, 2006; Berninger, 1987; Berninger, Raskind, Richards, Abbott, & Stock, 2008; Berninger, Rutberg, et al., 2006; Berninger, Yates, & Lester, 1991; Garcia, 2007; Pacton, Perruchet, Fayol, & Cleeremans, 2001; Richards, Berninger, & Fayol, 2009; Silliman, Bahr, & Peters, 2006), and *morphological* (word parts that signal meaning or grammar; e.g., Carlisle, 2000, 2004; Carlisle & Fleming, 2003; Nagy, Anderson, Schommer, Scott, & Stallman, 1989; Nagy, Berninger, & Abbott, 2006; Nagy, Osborn, Windsor, & O'Flahavan, 1994; Nunes & Bryant, 2006; Silliman et al., 2006).

Working memory units for the three word forms and their parts. Working memory has units for the storage and processing of (a) spoken words (phonological), (b) written words (orthographic), and (c) word structures such as base ± prefixes, inflectional, and/or derivational suffixes, and grammar markers such as possessives and contractions (morphological). Clinical measures of phonological, orthographic, and morphological word forms and their parts given in research studies provided evidence for *triple word form theory*: Coding all three word forms and their parts into memory, analyzing them, and coordinating them contributes to the reading and writing of children and adults with dyslexia (impaired word-level reading and spelling) (e.g., Berninger, Abbott, et al., 2006; Berninger, Raskind, et al. 2008) and typically developing readers and writers (Berninger, Raskind, et al., 2008).

Brain evidence for the three word forms. Studies in which individuals perform phonological, orthographic, and/or morphological tasks while their brain is scanned with functional magnetic resonance imaging (fMRI) have identified which brain regions are activated in common across word forms and their parts and which are activated uniquely for a specific word form and its parts. Crosson et al. (1999) identified unique fMRI activation patterns for phonological and orthographic word units in the working memory of adults. Likewise, Richards and colleagues identified common and unique patterns of fMRI activation for phonological (e.g., Richards, Aylward, Berninger, et al., 2006; Richards et al., 2005, 2007), orthographic (Richards et al., 2005, 2007; Richards, Aylward, Berninger, et al., 2006; Richards, Berninger, & Fayol, 2009), and morphological (e.g., Richards, Aylward, Berninger, et al., 2006; Richards et al., 2005, 2007) word units in the working memory of children and showed that the brain constructs relationships across them (Richards, Aylward, Raskind, et al., 2006). These word units, which store lexical items while they are processed at the word level and/or the subword level (e.g., syllable, phoneme, rime, or morpheme), support the development of linguistic awareness as children reflect on the phonological, orthographic, and morphological properties of the spoken and/or written words that are stored in working memory (Berninger, Raskind, et al., 2008).

Differentiating sensory and higher level processing of word forms and their parts. Phonological word form storage and processing requires a higher level of processing in the brain (association areas of temporal, parietal, and frontal lobes) than does auditory processing (primary auditory area of temporal lobes); children with impairments in phonological word form storage and processing are likely to have reading and spelling problems but usually not because of auditory processing problems (see Berninger & Richards, 2002). *Orthographic word form storage and processing* involves written words and the letters in them. A visual–spatial scratch pad (Baddeley & Hitch, 1974) for storing and processing nonverbal visual information is insufficient for storing and processing written words, which are visible language.[1] Children who have impaired orthographic word form storage and processing are likely to have reading and/or writing problems but probably not because of impaired visual perception (see Vellutino, 1979). *Morphological word form storage and processing* is used for both spoken and written language. As such, it may play an important role in the integration of phonological and orthographic codes across spoken and written words (Berninger, Raskind, et al., 2008) and bridging the levels of the single-word and multiword constructions (syntax) in language. Children with impaired morphological storage and processing are likely to have not only reading and writing problems but also oral language problems with single words and syntactic structures with multiple words.

Working memory architecture. Biological and behavioral evidence is accumulating for a working memory architecture that supports written language acquisition in children with and without learning disabilities. This architecture, which may be the brain's language learning mechanism, includes not only storage and processing units for three word forms (and their parts), which were already discussed, but also a module for syntactic processing as word units accumulate; phonological (phonological to mouth) and orthographic (orthographic to hand) loops that participate in language functions; and a panel of executive functions for self-government of language, which are discussed next (for review of evidence, see Berninger, Abbott, et al., 2006; Berninger, Raskind, et al., 2008).

Syntactic storage and processing of multiword units. Although children may not progress from the one-word to multiword stage of oral language development unless syntactic units in working memory for storing accumulating words have myelinated or become functional, it is also the case that becoming aware of the grammatical function of suffixes in spoken words stimulates the development of syntactic units in working memory, which order accumulating words on the basis of their grammatical functions during oral language acquisition. Weaknesses in morphological word form storage and processing early in language development might not be evident until the child is faced with learning written language during the school years (see Berninger, 2008). During the school years, syntactic structures are important for reading comprehension (e.g., Cain & Oakhill, 2007; Catts & Kamhi, 2005) and written composition (e.g., Scott, 2002; Scott & Windsor, 2000).

Phonological and orthographic loops. The rapid automatic naming (RAN) task assesses the phonological loop function, which is the time-sensitive integration of phonological codes for names and orthographic codes for alphanumeric or pictorial stimuli. Children with and without dyslexia differ in their ability to sustain phonological loop function over time (across rows); children with dyslexia fall into two classes—steady slow and slow and slower (Amtmann, Abbott, & Berninger, 2007). Phonological loop function was found to predict class of response of low-achieving second-grader spellers to explicit spelling instruction in applying spelling knowledge to their independent composing (Amtmann, Abbott, & Berninger, 2008). An orthographic loop from orthographic word forms and their parts in working memory to sequential finger movements guides handwriting, spelling, and composing (e.g., Berninger, 2007b; Berninger, Rutberg, et al., 2006; Richards, Berninger, & Fayol, 2009).

Executive functions. Altemeier, Abbott, and Berninger (2008) discovered in their study that inhibition (i.e., focus on the relevant and ignore the irrelevant) and rapid alternating switching attention (i.e., ignore what was relevant in the past and focus on what is now relevant) contributed unique variance to reading and writing achievement in typically developing readers and writers and in children with dyslexia in the elementary grades. These same executive functions and one for updating working memory were found to contribute unique variance to reading and writing achievement in children and adults with dyslexia (Berninger, Abbott, et al., 2006). In a study by Altemeier, Jones, Abbott, and Berninger (2006), both lower order executive functions (inhibition and rapid automatic switching) and higher order executive functions (planning) contributed to third and fifth graders' integration of reading and writing skills.

Working memory supports normal reading and writing development (Hoskyn & Swanson, 2003; Montgomery, Magimairaj, & O'Malley, in press; Swanson & Berninger, 1995, 1996) but contributes uniquely to writing compared to reading (Swanson & Berninger, 1996) and in different ways across and within the same stage of development (e.g., Swanson, 1999b). In a study by Alloway et al. (2005), teachers' ratings of children's reading at school entry were associated with different aspects of working memory than were the teachers' ratings of the children's writing. Learning disabilities may be related to impaired working memory, but the impaired working memory component may be only phonological storage and processing (e.g., Kirby, Marks, Morgan, & Long, 2004), the phonological loop and executive functions (e.g., Swanson, 1999a, 2006; Swanson & Ashbaker, 2000), or any combination of working memory components described earlier (Berninger, Abbott, et al., 2006).

Relevance of Levels of Language to Specific Learning Disabilities

Longitudinal studies by Catts, Fey, Zhang, and Tomblin (1999) validated the importance of differentiating the phonological, morphological, and syntactic levels of language in defining specific

[1]Initially, both nonverbal and verbal visual stimuli are processed by the same neural pathways in primary visual areas, but subsequently, they are processed by other neural pathways (see Berninger & Richards, 2002).

reading disabilities. Some children with reading disabilities have an oral language disability specific to word- or subword-level phonology (e.g., dyslexia), whereas others have a more pervasive oral language disability including, but not restricted to, phonology, but primarily characterized by severe impairment in morphology and syntax (e.g., language learning disability, LLD, or selective language impairment, SLI; Catts, Adlof, & Weismer, 2006) and/or text-level inferencing (Silliman & Scott, 2009). Phonological problems are often more severe in children with dyslexia than in children with other specific oral language disorders (Catts, Hogan, & Adlof, 2005). Syntax problems are particularly pronounced in the writing of children with specific oral language disorders (Scott, 2002; Scott & Windsor, 2000). Thus, although children with dyslexia, LLD, or SLI may have phonologically based spelling problems, those with LLD or SLI are more likely than those with dyslexia to have significant problems with written composition, particularly in the syntactic structures in their written expression of ideas. Children with LLD or SLI generally have impaired reading comprehension with or without associated word reading problems (e.g., Catts, Adlof, & Weismer, 2006); however, some children have specific reading comprehension problems related to impaired working memory rather than impaired syntax (e.g., Cain & Oakhill, 2007).

Purpose of the Current Research Study

Although some speech and language clinicians may link differential diagnosis of specific reading disabilities to levels of language and working memory, such knowledge is not shared by all multidisciplinary teams making special education eligibility decisions in schools. Also, many schools are overemphasizing phonological skills without sufficient emphasis on other language skills and are not incorporating evidence-based instruction for overcoming working memory inefficiencies. The purpose of this study was to increase evidence-based knowledge about the relationships among levels of language in working memory that could be applied clinically.

We modeled word-level working memory (WL-WM) for two reasons. First, evidence reviewed earlier supports the existence of storage and processing units for separate phonological word form and orthographic word form storage and processing units. Second, evidence is rapidly growing that both phonological *and* orthographic word processing contribute jointly to learning to read and spell written words (e.g., Abbott & Berninger, 1993; Apel et al., 2006; Pacton et al., 2001; Richards, Aylward, Raskind, et al., 2006; Seymour, 1997; Share, 2004; Silliman et al., 2006; Templeton & Bear, 1992; Treiman, 1993, 1998; Treiman, Berch, Tincoff, & Weatherston, 1993; Treiman, Kessler, Knewasser, Tincoff, & Bowman, 2000; Varnhagen, Boechler, & Steffler, 1999). Morphological word form units also contribute to learning to read and spell written words, but they were not examined in the current study.

To study WL-WM, we administered and compared two factors that differed in whether spoken words or written words had to be stored and processed. The phonological tasks required the storage and processing of spoken words or component phonemes in working memory and have been shown to be related to reading real words and pseudowords (e.g., Wagner & Torgesen, 1987). The orthographic tasks required the storage and processing of letters or written words and have been shown to be related to word reading, word decoding, and reading fluency (e.g., Berninger, Abbott, Thomson, & Raskind, 2001), as well as handwriting, spelling, and composing (e.g., Berninger, Cartwright, Yates, Swanson, & Abbott, 1994; Berninger, Yates, Cartwright, Rutberg, Remy, & Abbott, 1992). The current study evaluated the relationship of working memory factors based on phonological and orthographic word form measures to five reading and writing outcomes (i.e., word reading, reading comprehension, handwriting, spelling, and composing).

We modeled sentence-level working memory (SL-WM) for two reasons. First, *sentence listening* has been shown to have a relationship to reading acquisition (e.g. Cain & Oakhill, 2007; Gough & Hillinger, 1980; Oakhill, Hartt, & Samols, 2005). Second, *sentence writing* working memory was found to have contributed more than sentence listening working memory did to children's writing achievement in fourth through sixth grade (ages 9 to 12; Berninger et al., 1994). Based on research available at the time, Berninger and Swanson (1994) proposed that working memory does not begin to contribute uniquely to written composition until fourth grade and above.

To study SL-WM, we administered and compared two tasks that required listening to sentences but varied in whether the response called for an oral or written answer. We tested the hypotheses that WL-WM predictors would be significantly related to word-level (word reading and spelling) and subword-level (handwriting) outcomes and that SL-WM predictors would be significantly related to sentence- or text-level outcomes (reading comprehension and written composition). The rationale was that the level of language in storage and processing units in working memory would be related to the children's written language skills at the same level or closely related level (below for word level and above for sentence level). In contrast to measures that do not use a working memory task for assessing levels of language, both the WL-WM and SL-WM tasks had storage and processing requirements that increased in complexity across items.

METHOD

Participants

Recruitment. Children were recruited from a large urban school system near a research university that serves a diverse student population in terms of socioeconomic status and racial and ethnic groups. Letters were sent to all parents of kindergarten and second-grade children, inviting their children to participate in a 5-year longitudinal study to start at the beginning of the next school year when their child would be in first or third grade, respectively. Interested parents contacted the research coordinator, who answered any questions they had about the study, which was approved by the university's institutional review board. Parents had to commit to bring their child to the university annually for 5 years to complete testing during the second, third, or fourth month of the school year. The children had to meet inclusion criteria of a developmental history without indicators of developmental disability due to brain injury or disease, neurogenetic disorder, diagnosed intellectual deficiency, primary developmental language, motor disorder, or emotional disturbance. Both parental informed consent and child assent were obtained. The investigators complied with ethical and professional principles for research with human participants.

With the exception of a few siblings, most children in the study were from different schools in the large district, and many different elementary schools in the district were included in the sample, which was neither a sample of convenience nor a referred sample with clinical disorders. The sample was representative of the greater Pacific Rim region where the participants lived (see characteristics that follow). This region continues to see increases in its average test scores on high-stakes tests and the National Educational Assessment of Progress as a result of initiatives encouraging the use of research-supported instructional practices and accountability in assessing student learning outcomes to improve students' probability of success in an increasingly global economy.

Characteristics. For the current study, we analyzed test results for Years 2 and 4 once all of the relevant measures for testing the hypotheses had been given. The children who began in first grade were in second grade in Year 2 and fourth grade in Year 4. The children who began in third grade were in fourth grade in Year 2 and sixth grade in Year 4. Overall attrition was low. Of the 124 second graders (69 girls and 55 boys; age in months, $M = 92.8$, $SD = 3.7$) who were assessed in Year 2, 118 (66 girls and 52 boys) also participated when they were in fourth grade in Year 4. Of the 109 fourth graders (57 girls and 52 boys; age in months, $M = 116.0$, $SD = 3.7$) who were assessed in Year 2, 104 (51 girls and 53 boys) also participated when they were in sixth grade in Year 4; 1 boy who did not participate in fourth grade did participate in sixth grade.

The sample reflected diversity in ethnicity and parents' level of education; see the Appendix for the descriptive statistics. Age range was typical for each grade level as the sample did not include children with delayed entrance to school or school retention (with the exception of 1 child who repeated a grade and another who was advanced a grade in the middle of the study). Because of the small amount of missing data, final sample sizes for the structural equation model (SEM) analyses were 122 second graders and 108 fourth graders in Year 2 and 114 fourth graders and 104 sixth graders in Year 4.

Measures

Reliability and scoring of measures. For psychometric tests, reported reliabilities are average test–retest reliabilities across the age or grade range studied. For the experimenter-designed measures of WL-WM, SL-WM, and handwriting (Alphabet 15), extensive scoring studies were conducted until nearly perfect interrater agreement was reached for scoring.[2] For published tests, we used scoring procedures described in the test manual. For the experimenter-designed tests, scoring procedures are available from the first author.

Model underlying measurement, data analyses, and clinical application. In the section that follows, each test administered is grouped by the predictor or outcome measure for which it was an indicator in the factors used in the structural equation modeling described under data analyses and results. Also see Table 1 Section I,

Table 1. Structural equation model (SEM) and SEM results for quantitative values reported in Table 5.

I. Model
- A. Predictor factors
  - 1. Word/Subword-level predictor factors
    - a. Indicators of phonological coding (storage and processing of spoken words)
      - 1) Nonword repetition
      - 2) Numbers reversed
    - b. Indicators of orthographic coding (storage and processing of written words and letters)
      - 1) Letter retrieval before and after in alphabetic order
      - 2) Words and their letters in the mind's eye
  - 2. Sentence-level predictor factors
    - a. Indicators of sentence listening and speaking
      - 1) Sentence listening and oral repetition
      - 2) Sentence listening and answering processing questions
    - b. Indicators of sentence listening and writing
      - 1) Sentence listening
      - 2) Writing sentences according to requested directions
- B. Outcome factors
  - 1. Word-level outcomes
    - a. Word reading
    - b. Spelling
  - 2. Sentence- and text-level outcomes
    - a. Reading comprehension
    - b. Written expression

II. Summary of results
- A. Significant unique paths from word level to literacy outcome (unidirectional arrow in Table 5)
  - 1. Word reading second, fourth, and sixth grades
  - 2. Reading comprehension second grade
  - 3. Handwriting second and fourth grade
  - 4. Spelling second, fourth, and sixth grades
  - 5. Written expression second and fourth grade
- B. Significant unique paths from sentence level to literacy outcome (unidirectional arrows in Table 5)
  - 1. Word reading none
  - 2. Reading comprehension fourth and sixth grade
  - 3. Handwriting none
  - 4. Spelling none
  - 5. Written expression none

which summarizes the model for predictor factors and outcome factors and their respective indicators. The data analyses addressed whether there was a relationship between the predictor and outcome measures, thus validating the use of the clinical subtest measures for assessment related to literacy and written language learning.

WL-WM: Phonological word form storage and processing predictor. For the Woodcock Johnson—Revised (WJ-R; Woodcock & Johnson, 1990)—Numbers Reversed (reliability .75), the child listened to increasingly longer series of numbers and was asked to repeat each sequence in reverse order.

For the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999) Nonword Repetition (reliability .78), the child listened to increasingly complex nonsense words and then repeated each one exactly as heard within a 5-s limit.

WL-WM: Orthographic word form storage and processing predictor. For *Letter Retrieval,*[2] the child was asked to recall the letter before or after a specified letter in the alphabet; the complexity increased by asking for a letter just one letter before or after the designated letter to two or three letters before or after the designated letter. This task required holding the ordered set of alphabet letters

[2]The initial studies, which focused on reaching a consensus on scoring criteria that reflected the theoretical construct, resulted in high agreement across multiple raters, and resulted in few errors (i.e. were scorer friendly). Interrater reliability for the preliminary scoring studies ranged from 100% on *Letter Retrieval Before and After* to 99.7% on *Words in the Mind's Eye.* A final study was conducted in which at least two raters participated and scored a randomly generated sample of 30 protocols to ensure that interrater agreement was nearly perfect. For sentence listening, the percentage of agreement for two independent judges based on 30 protocols was 95.3%. For sentence writing, the percentage of agreement across raters was 90.5%. These measures have since undergone test development and national norming by The Psychological Corporation; see Berninger (2007a) for psychometric properties (scaled scores with $M = 10$ and $SD = 3$) and various kinds of reliabilities.

from long-term memory in working memory while the serial search was performed. The child received 1 point for each correct response within the 5-s-per-item time limit.

For *Words in the Mind's Eye,*[2] on the first eight items, the child was asked to spell written words forward along with the examiner, imagine the words in the mind's eye, and then spell the words backward alone with eyes shut. On the next eight items, the child was asked to keep looking at the word in the mind's eye and recall the letter in specific letter positions designated by the examiner in the normal forward spelling of the word. One point was awarded for each correct backward spelling, and 1 point was awarded for each correctly identified letter in specific word positions (e.g., first, last, third, or fourth).

SL-WM: Aural–oral mode predictor. *For sentence listening,*[2] the examiner signaled the child with "Listen!" and then presented the sentence set orally. The number of sentences presented increased in increments of one across the eight sets of items.[3] Then the examiner signaled the child with "Question!" and asked a question about the content of the sentence(s) that required factual recall or inferential thinking and assessed the child's listening comprehension. Finally, the examiner signaled the child with "Repeat!" and the child repeated the sentence or sentences just presented. In contrast to typical sentence listening span tasks that ask the child to recall the last word in each sentence in the item set (e.g., Berninger et al., 1994), this task required the child to reproduce each sentence in a set orally. No more items were administered after a child could no longer answer the process question correctly and correctly recall any of the sentences in a set. Points were awarded for correct recall of the sentence (verbatim or gist; 0 to 2) and for answering the process question correctly (0 to 1).

SL-WM: Aural–written mode predictor. For *sentence writing,*[2] the examiner signaled the child with "Listen!" and then presented a sentence or set of sentences orally. Then the examiner signaled the child with "Goal!" and gave instructions about what to write; for example, "Write one interesting sentence that could come before the sentence you just heard." In contrast to the Berninger et al. (1994) version of this task, whereby the child always wrote a sentence that came after the set of last heard sentences, instructions varied as to whether the child should write a sentence that came before, in the middle, or after the heard sentences. The child had to store the just-heard, semantically related sentences in working memory while planning a sentence to write. When the examiner signaled the child with "Write!" the child wrote the sentence. One point was awarded if the child produced a sentence that was psychologically relevant to the sentence prompt, that is, the written sentence maintained coherence with the written discourse that followed or preceded it.

Reading and writing outcome factors.

Oral word reading. For *oral reading accuracy of single real words,* the Wechsler Individual Achievement Test—Second Edition (WIAT–II; The Psychological Corporation, 2001) Word Reading (reliability .98) was given. The child pronounced real words on a list without context clues. Although Word Reading has earlier items that assess letter identification and early phonological skills, in the age range studied, most or all items contributing to the final score involved reading single real words.

[3]Typically, sentence span working memory tasks include sets of unrelated sentences. To improve ecological validity, we modified our SL-WM tasks to have sets of related sentences for assessing the storage and processing of sentences that were related in meaning, which is typically the case for real-world text.

Reading comprehension. For *text-level reading comprehension,* the WIAT–II Reading Comprehension subtest (reliability .93) was given. The child read passages silently that had colorful illustrations and answered orally literal or inferential questions about each passage. The child could refer to the passage in answering the questions on this untimed subtest. For *sentence-level reading comprehension,* PAL Sentence Sense (Berninger, 2001; reliability .64) was given. The child circled the one sentence in a set of three sentences that was meaningful. All sentences contained only real words, but two sentences contained a one-word foil that rendered the whole sentence meaningless. Correct answers on this timed test required close attention to sentence-level comprehension of syntax during timed silent reading.

Handwriting. Three handwriting tasks based on programmatic research (Berninger et al., 1992, 1994) were given. For the Automatic Alphabet Writing—15 s task (reliability .97, Berninger et al., 1997), The child was instructed to print letters in manuscript form in alphabetic order as accurately and quickly as possible with a pen on lined paper; 1 point was awarded for each legible letter in alphabetic order within the first 15 s. For the Copy Sentence task, the child was instructed to copy a sentence containing the 26 letters of the alphabet (20-s time limit), and for the Copy Paragraph task, the child was instructed to copy a paragraph (90-s time limit). One point was awarded for each correctly copied legible letter within 20 s on the first copy task (reliability .82) or 90 s on the second copy task (reliability .76; Berninger, 2001). For all handwriting tasks, 1 point was awarded if (a) the letter could be accurately identified outside of word context, (b) relative proportionality of component letter parts was maintained, and (c) the letter was not a reversal or inversion of another letter.

Spelling. For spelling, the WIAT-II Spelling subtest (reliability .94) was given. The child spelled in writing dictated single words of increasing phonological, orthographic, and morphological complexity. Words to be spelled were first pronounced alone, then in sentence context, and then alone again. They were scored for accuracy (number of words correctly spelled).

Written expression. The WIAT–II Written Expression subtest (reliability .96) was given to assess composition—at the word and sentence levels in second grade and the word, sentence, and text levels in fourth and sixth grades. For word fluency, the child was asked to generate in writing as many words as possible for specific categories within 60 s. For sentence combining, the child was given two sentences and was asked to combine them into one well-written sentence. For composition, the child was given a topic prompt for an essay and was asked to write a paragraph about it for 10 min. Compositions were scored for content, organization, and mechanics.

Procedure

All children were tested individually in a private room in either the university's research facility or the local school (in a few cases when the parent was unable to bring the child to the university). Testing was conducted by highly trained and supervised graduate research assistants. Standard order of administration remained constant across the years for the measures in this study.

Data Analyses

Descriptive statistics were computed for each measure that was used as an indicator of a working memory predictor or literacy outcome factor in the overall model. Correlations were computed

Table 2. Descriptive statistics for measures used for the word-level working memory (WL-WM) factor, the sentence-level working memory (SL-WM) factor, and the reading and writing outcome factors.

	Cohort One Grade 2 N = *122*		*Cohort One Grade 4* N = *114*		*Cohort Two Grade 4* N = *108*		*Cohort Two Grade 6* N = *105*	
	M	SD	M	SD	M	SD	M	SD
WL-WM measure								
Numbers Reversed	106.91	19.36	112.52	21.50	108.19	18.90	114.47	20.68
Nonword Repetition	9.48	2.18	9.94	2.40	10.07	2.33	10.54	2.48
Letter Retrieval	2.47	1.48	3.47	1.47	3.47	1.43	4.21	1.38
Words in the Mind's Eye	9.35	2.26	10.99	1.31	10.88	1.49	11.38	0.96
SL-WM measure								
Sentence Listening	16.84	4.40	20.11	3.01	19.90	3.72	21.96	2.93
Sentence Writing	3.13	1.49	3.95	1.16	4.17	1.07	4.35	0.94
Literacy measure								
Word Reading	112.12	14.94	112.34	11.26	111.59	10.66	112.92	10.76
Reading Comprehension (text)	109.04	13.16	112.41	9.34	110.93	9.29	117.46	14.24
Sentence Sense	–0.83	1.05	–0.20	0.78	–.40	0.67	–.00	1.00
Alphabet 15	0.22	0.92	0.74	1.26	.56	1.00	.90	0.93
Copy Sentence	0.28	1.15	n.a.	n.a.	0.69	1.06	n.a.	n.a.
Copy Paragraph	0.38	1.16	0.30	0.99	1.08	1.34	1.13	1.09
Spelling	107.94	13.13	107.07	14.80	108.97	14.68	109.20	13.74
Composition	101.89	13.91	112.33	15.95	110.27	14.90	114.48	11.73

Note. For the Numbers Reversed (Woodcock & Johnson, 1990) subtest, $M = 100$, $SD = 15$; for the Nonword Repetition (Wagner, Torgesen, & Rashotte, 1999) subtest, $M = 10$, $SD = 3$; for the remaining working memory tasks, raw scores are reported in the table to show the range of possible scores of 0 to 28 (listening), 0 to 6 (letters), 0 to 16 (words), and 0 to 5 (writing), but grade-corrected *z* scores were used in the analyses. For the Word Reading, Reading Comprehension, Spelling, and Written Expression subtests of the Wechsler Individual Achievement Test—Second Edition (WIAT–II; The Psychological Corporation, 2001), $M = 100$, $SD = 15$. PAL *z* score for grade ($M = 0$, $SD = 1$) reported in table but range of possible raw scores is provided here—Sentence Sense (0–20), Alphabet Writing (0–26), Copy Sentence (0–26), Copy Paragraph (0–358).

among the indicators of the two working memory predictor factors for the children who were in second or fourth grade in Year 2 of the study and then in fourth or sixth grade in Year 4. Distributions for each measured variable were examined for normality, skewness, and multivariate kurtosis. No violations of assumptions were found. Additionally, robust standard errors were used to evaluate the statistical significance of paths and to control for Type I errors in the SEMs. Relationships between the working memory factors and literacy outcomes were then investigated using SEMs. Even when factors had single indicators (e.g., word reading, spelling, and written expression), they were modeled as latent variables in the SEM.

The model was evaluated for how two levels of language requiring storage and processing in working memory predictors (i.e., the predictor factors) were related to specific reading and writing outcomes (i.e., the outcome factors) at targeted grade levels (second, fourth, and sixth grades) in literacy development.[4] The specific reading and writing skills were analyzed separately for two reasons. First, annual parent reports with individual students' profiles of specific reading and writing skills showed intra-individual differences in the relative level to which each reading or writing skill had developed. Second, to test the hypotheses that WL-WM was related to children's word-level reading or writing skills and SL-WM was related to children's sentence-level reading or writing skills, we needed to evaluate each literacy skill separately.

RESULTS

Descriptive Statistics and the Model

Means and standard deviations for each indicator (clinical measure) of the working memory predictor factors and each indicator of the literacy factors are reported in Table 2 by grade when children were in Years 2 and 4 of the study. All measures used as indicators of predictor or outcome factors in the structural model are summarized in Table 1. Standard scores for age ($M = 100$, $SD = 15$) or *z* scores for grade ($M = 0$, $SD = 1$) were used in these analyses because of interest in the relative development of skills compared to peers.

Correlations among the clinical measures used for each of the predictor factors (indicators of the factors in Table 2) are reported in Table 3 for the second (Year 2) and fourth (Year 4) graders and in Table 4 for the fourth (Year 2) and sixth (Year 4) graders. For the WL-WM factor, the magnitude of the correlation between the phonological and orthographic word forms was low or moderate, as

[4]Preliminary studies had compared other competing theories that contrasted the modality of processing of the predictors separately in terms of auditory language and visual language, but the models could not be fit. One reason might be that on all of the word-level tasks, children recruited both modalities and integrated phonological and orthographic information (e.g., visualizing numerals in the Digits Backward task, visualizing letters in pseudowords in the Nonword Repetition task, naming letters in the Alphabet Retrieval or Words in the Mind's Eye tasks). Forging connections between spoken and written language may occur more easily within than across levels of language within spoken or written language, at least in the grade levels studied. In contrast, models based on separate levels of language in working memory collapsed over modality (spoken or written) within a level of language had acceptable fits. Confirmatory factor analyses were also conducted in which total correlations were estimated and were found to be acceptable.

Table 3. Correlations among WL-WM (1 = Numbers Reversed, 2 = Nonword Repetition, 3 = Letter Retrieval, 4 = Words in the Mind's Eye) and SL-WM (5 = Sentence Listening and Speaking, and 6 = Sentence Listening) measures for children in Grade 2 (Year 2) and Grade 4 (Year 4).

	1	*2*	*3*	*4*	*5*	*6*
1.	–	.27	.28	.31	.37	.35
2.	.20	–	.14	.26	.23	.28
3.	.36	.04	–	.38	.33	.34
4.	.43	.13	.39	–	.43	.38
5.	.34	.06	.17	.38	–	.41
6.	.33	.12	.25	.40	.52	–

Note. Correlations at second grade are below the diagonal; correlations at fourth grade are above the diagonal.

expected, because these are separate storage and processing units at the word level of working memory, but the measurement models showed that each indicator had a loading on its theoretically based factor that was statistically different from zero, as expected, because these storage and processing units are interrelated at the word level. For the SL-WM factor, the correlations ranged from .41 to .52 in second and fourth grade, but because of restriction of range, only .16 in sixth grade; nevertheless, with two indicators, the congeneric one-factor measurement model accounts for these correlations (Bollen, 1989).

SEM Analyses

All SEM analyses were based on maximum likelihood estimates with robust standard errors and on the covariance matrix of the indicators using EQS, Version 6 (Bentler, 2001). The SEMs at each grade level modeled two working memory predictor factors (for word and sentence levels) for each literacy outcome factor; see Table 2 for the indicators (clinical measures). The results of the quantitative SEM results are displayed in Table 5 and are also summarized in words in Table 2. Results are reported for second graders in Year 2 and for fourth and sixth graders in Years 2 and 4, but those for the fourth graders in Year 4, which are available from the second author, are similar to those shown for the fourth graders in Year 2.

Table 4. Correlations among WL-WM (1 = Numbers Reversed, 2 = Nonword Repetition, 3 = Letter Retrieval, 4 = Words in the Mind's Eye) and SL-WM (5 = Sentence Listening and Speaking, and 6 = Sentence Listening and Writing) measures for children in Grade 4 (Year 2) and Grade 6 (Year 4).

	1	*2*	*3*	*4*	*5*	*6*
1	–	.41	.45	.42	.27	.09
2	.19	–	.25	.22	.48	.25
3	.37	.21	–	.42	.40	.24
4	.33	.22	.43	–	.30	.05
5	.24	.42	.30	.28	–	.16
6	.17	.23	.20	.17	.47	–

Note. Correlations at fourth grade are below the diagonal; correlations at sixth grade are above the diagonal.

Evaluating the model fit. The comparative fit index (CFI), root mean squared error of approximation (RMSEA), and overall goodness of fit, χ^2, which are reported in Table 5, show that the departures of the actual covariances from the fitted covariances, based on the estimated parameters, were small and provided an acceptable fit to the observed covariance matrices at second, fourth, and sixth grade. Complete results for evaluation of the measurement models are available from the second author.[5]

Significance of SEM path coefficients. Table 5 shows the magnitude and significance for correlation between the working memory predictor factors (WL-WM ↔ SL-WM), the standardized structural path coefficients from the predictor to outcome factors (WL-WM → Literacy Outcome and SL-WM → Literacy Outcome), and the *Z* statistics based on the robust standard errors and unstandardized coefficients. In each SEM at each grade level, the WL-WM factor was significantly correlated with the SL-WM factor, indicating that the WL-WM factor shared reliable variance with the SL-WM factor (see Table 5); thus, the levels of language are not totally independent of each other, but one level never accounts for all of the variance in the other level. This significant covariance is consistent with functional systems theory, according to which separate processes are functionally related for performing specific tasks (Luria, 1970).

Despite this correlation between the predictor factors, one or both predictor factors contributed uniquely over and beyond its shared covariance to specific reading and writing outcome factors at certain grade levels. For these significant paths, the significant unique variance in the reading or writing skill could not be attributed to the other working memory predictor factor. SEM results that are relevant to the tested hypotheses described in the introduction are as follows.

- For second grade, the WL-WM factor significantly predicted each literacy outcome, indicating that it added unique variance to the prediction of the outcome. The SL-WM predictor factor never made a unique contribution.
- For fourth grade, the WL-WM factor significantly predicted word reading, handwriting, spelling, and written expression. At fourth grade, the SL-WM predictor factor significantly predicted reading comprehension.
- For sixth grade, the WL-WM factor significantly predicted word reading and spelling, and the SL-WM factor significantly predicted reading comprehension. For the handwriting and written expression outcomes in sixth grade, neither WL-WM nor SL-WM predictor factors, which were highly correlated with each other, contributed uniquely.

Thus, the tested hypotheses were supported at the word level. WL-WM factors were unique predictors of all word-level reading and writing outcomes (word reading and word spelling) at all grade levels and of handwriting (based on subword letter writing and word

[5]Fit did vary somewhat with literacy skill and grade level. The fit of the SEM for word reading and spelling was acceptable. The fit for reading comprehension, handwriting, and written expression was also acceptable, but not as high because of the correlation of the nonword repetition indicator with the SL-WM predictor factor, which was higher than when modeled through the correlation of the working memory factors. Note that the negative paths and associated nonsignificant *Z* values are all suppressor effects that can be ignored because they are all nonsignificant. The fits at sixth grade for the reading comprehension, handwriting, and written expression outcomes were acceptable (CFI ≥ .90, RMSEA < .10 before rounding; Bentler, 2001); although analyses of the residual covariances indicated that the departures from better fit could be reduced by the addition of correlated errors, that does not affect interpretation of the SEM pathways. Overall, the absolute, relative, and covariance fits of each SEM model were acceptable.

Table 5. Standardized path coefficient (Path), Z value, comparative fit index (CFI), root mean squared error of approximation (RMSEA), and goodness of fit statistic for structural equation models predicting five literacy outcomes from two working memory predictor factors (WL = word level, SL = sentence level) in second, fourth, and sixth grade.

	Word Reading		*Reading Comprehension*		*Handwriting*		*Spelling*		*Written Expression*	
	Path	Z^a	*Path*	Z^a	*Path*	Z^a	*Path*	Z^a	*Path*	Z^a
Second grade										
WL-WM ↔ SL-WM	.77	8.28	.79	8.64	.77	8.59	.77	8.48	.78	8.00
WL-WM → Outcome	.79	3.47	.68	2.47	.83	2.56	.79	3.32	.63	2.26
SL-WM → Outcome	–.06	–.26	.22	.90	–.29	–.87	–.12	–.50	.22	–.80
CFI	1.00		1.00		.99		1.00		1.00	
RMSEA	.00		.00		.03		.00		.00	
χ^2(df)	7.51(12)		15.53(17)		26.99(24)		6.40(12)		4.74(12)	
Fourth grade										
WL-WM ↔ SL-WM	.70	6.26	.71	6.30	.60	4.42	.66	5.58	.70	5.55
WL-WM → Outcome	.51	2.81	.39	1.78	.51	3.00	.69	3.92	.62	3.13
SL-WM → Outcome	.20	1.12	.59	2.63	–.07	–.44	–.08	–.45	–.04	–.22
CFI	.99		.97		.96		1.00		1.00	
RMSEA	.04		.06		.06		.02		.02	
χ^2(df)	13.76(12)		23.07(17)		32.42(24)		12.53(12)		12.42(12)	
Sixth grade										
WL-WM ↔ SL-WM	.72	6.58	.81	6.85	.93	3.54	.66	5.54	.90	3.52
WL-WM → Outcome	.39	2.00	.11	.34	–.57	–.13	.79	4.23	.88	.70
SL-WM → Outcome	.32	1.67	.91	2.73	1.08	.25	–.17	–.93	–.34	–.26
CFI	1.00		.92		.90		1.00		.90	
RMSEA	.00		.09		.08		.00		.10	
χ^2(df)*	11.96(12)		32.55(17)*		27.59(17)*		11.30(12)		23.45(12)*	

[a]*Z* values = 1.96, $p < .05$; *$\chi^2(df)$ with $p < .05$.

copying) in second and fourth grade. The surprise was that the WL-WM factor was a better predictor of two text outcomes (reading comprehension and written composition) in second grade and one text outcome (written composition) in fourth grade.

As predicted, in fourth and sixth grade, text-level reading comprehension was uniquely predicted by the SL-WM factor. Although the written composition score is based mainly on sentence combining and expository text composing, the SL-WM factor never uniquely predicted the composition outcome factor.

The strongest support for the tested hypotheses was observed in sixth grade, when the WL-WM factor was a unique predictor of word-level reading and spelling and SL-WM was a unique predictor of text-level reading comprehension. However, it is also important to note that the WL-WM factor uniquely predicted both word reading and word spelling at all grade levels, consistent with both reading and writing at the word level drawing on the same language processes (e.g., orthographic and phonological as assessed in the current study, but also morphological, as in other studies discussed earlier).

DISCUSSION

Relationships of Levels of Language in Working Memory to Reading and Writing

Validating levels of language in working memory. Research has already demonstrated that (a) levels of language are related to the nature of the reading or writing problems that a child may experience (e.g., Catts & Kamhi, 2005; Catts et al., 1999, 2005, 2006), and (b) children with learning disabilities have significant working memory problems (e.g., Swanson, 1999a, 1999b, 2006; Swanson & Ashbaker, 2000). This research extends that research by showing that for typically developing students who range from poor readers and writers to excellent readers and writers, levels of language in working memory are differentially related to reading and writing outcomes, and the relationships change across the grade levels.

The finding that WL-WM uniquely predicted word-level decoding and text-level reading comprehension, modeled on sentence and text tasks, in second graders is consistent with past reading research showing the importance of word-level decoding in the beginning stages of reading for all reading skills (e.g., Gough & Hillinger, 1980). The SL-WM factor uniquely explained text-level reading comprehension in fourth and sixth grade, when most children are skilled at decoding, but not second grade, when children are focused on learning to decode.

SL-WM did not contribute uniquely to any writing skill at any grade level in the current study, but WL-WM did contribute to handwriting and composition in second and fourth grade and to spelling in second, fourth, and sixth grade. This pattern of results supports the tested hypothesis for WL-WM being related to word-level writing skills, but not for SL-WM being directly related to sentence- or text-level composition skills. Research has shown that transcription skills (handwriting and spelling) explain variance in the composition of elementary-grade children (Graham, Berninger, Abbott, Abbott, & Whitaker, 1997). Thus, during the elementary grades, WL-WM may contribute to composing directly via transcription, which in turn is related indirectly to SL-WM, which is consistent with research showing transcription constraints on working memory abilities in child writers (e.g., Bourdin & Fayol, 1994).

Comparison of WL-WM and SL-WM. Overall, WL-WM explained more unique variance in both reading and writing skills in second, fourth, and sixth graders than did SL-WM. The WL-WM factor uniquely explained word-level reading and spelling at all grade levels. In addition, WL-WM uniquely predicted handwriting, which was modeled on the basis of letter and word writing, and composition, which was modeled on sentence and text writing, at second and fourth grade. Although the WL-WM factor did not uniquely predict handwriting and composition in sixth grade, WL-WM remained correlated with those skills in sixth grade. Thus, the word level of working memory may play an important role in both reading and writing development during the elementary grades. SL-WM, which was first studied in college students, may not be the initial level at which working memory supports reading and writing development. Sentence-level storage and processing, which did support reading comprehension in fourth and sixth grade, may evolve as children become more skilled in both word-level storage and processing in working memory and in written language.

In addition, the SL-WM factor may not have explained the unique variance in composition because composing written text draws on word, sentence, and text levels of language in working memory, and the current study did not include a text-level working memory (TL-WM) task. Writing instruction that emphasizes only sentence syntax has not been shown to be effective (Graham & Perrin, 2007; Hillocks, 1986), with the exception of training in sentence combining. TL-WM has received less research attention and clinical application than WL-WM and SL-WM, probably because of a lack of standardized, normed measures for doing so. However, Hayes and colleagues (e.g., Hayes, in press) have found that language bursts in between pauses of 2-s duration during composing are important units of composing. Units of language constructed during language bursts may exceed a single sentence unit. These discourse units of production may be constrained by both the capacity of working memory and the temporal coordination of component processes in working memory during translation of ideas and transcription. If so, neither WL-WM nor SL-WM alone captures the full working memory workspace supporting composing. More research, with a focus on clinical application, is needed on the nature of language bursts in children's writing at different grade levels and how these language bursts may be related to working memory capacity, efficiency, and temporal coordination.

Developmental change in working memory. Relative gains in working memory across development in reference to peers on nationally normed tests and experimenter-designed measures were observed. (See the increases in test scores across the grades in Table 1 on indicators of working memory.) Siegel (1994) also showed improvement over time in working memory, which may not be a fixed ability but may be sensitive to changing environmental and instructional experiences as well as children's maturation and innate ability. National norms are based on snapshot assessments at a single point in development rather than longitudinal changes in development.

Revising past research conclusions. Berninger and Swanson's (1994) conclusion, based on research evidence available at the time, that working memory does not begin to contribute uniquely to writing until fourth grade and above needs to be revised based on the current results. Much of that evidence came from research using the Sentence Span working memory task that was described at the beginning of this article. The current study (see Tables 2 and 5) shows unique contributions from WL-WM to all writing as well as reading outcomes as early as second grade. Working memory does contribute to beginning writing before the fourth grade, but at the word rather than the sentence level. Conclusions about working memory and literacy outcomes may depend on the level of language at which the storage and processing components of working memory are assessed.

Limitations and Future Research Directions

Sample size is large for many longitudinal studies and adequate for SEM. Additional research is needed to determine if the results replicate across samples and research studies. Although there is considerable range and individual variation, the sample is on average above average relative to the population mean based on national standardization samples on which tests are normed. However, the school district from which the sample was recruited has seen a rise in average test scores on state *and* national assessments as a result of federal initiatives calling for evidence-based instruction and accountability in student learning outcomes. This issue may affect other research samples because implementation of science-based reading instruction and high-stakes standards is increasing the mean level of performance on standardized tests of reading and writing achievement in some schools. Future research might investigate whether results replicate in samples that may be on average below the population mean based on national norms. Schools should be concerned with the full range of student population, from lowest achieving to highest achieving, and not with only one end or part of the distribution exclusively.

Future research might address whether a third level-of-language working memory mechanism shows significant growth during adolescence and supports discourse analysis: text-level long-term working memory (Ericsson & Kintsch, 1995), which enhances access in working memory to background knowledge in long-term memory and integration of that knowledge within discourse schema during reading comprehension and written composition. In addition, developmental change in other components of working memory, such as the phonological loop, which contributes to adult skilled writing (e.g., Chenoweth & Hayes, 2003), and the orthographic loop, which contributes to developing written composition (Berninger, Nielsen, Abbott, Wijsman, & Raskind, 2008; Berninger, Rutberg, et al., 2006), should be studied in elementary and high school students.

Clinical Application for Written Language Disorders

Differences between eligibility decisions and diagnosis. In school settings, eligibility decisions for special education are based on categories of eligibility, which vary greatly from state to state and are not required to be based on research-supported differential diagnoses (see Berninger & Holdnack, 2008). Children with LLD or SLI often are not eligible for communication disability services under federal special education laws because their receptive and/or expressive oral language problems are not severe enough compared to the population mean to qualify for communication disorder services; nor are they eligible for learning disabilities services under federal special education laws because their IQ-achievement discrepancy is not large enough.

Neither IQ-achievement discrepancy nor response to instruction addresses the fundamental issue of diagnosis or relevant treatment.

More appropriate is the assessment of individual students' language learning profiles, which identify relative weakness or impairment (and strengths) in specific levels of language and working memory components that are instructionally relevant. For example, see Silliman and Scott's (2009) proposal to identify problems in syntactic awareness versus text-level inferencing and Sabatini's (2009) proposal for using profiles that identify instructional needs.

Assessment–intervention links. Children with SLI or LLD (e.g., Butler & Silliman, 2002; Catts & Kamhi, 2005; Wallach & Butler, 1994) have a different written language learning profile than is typical of children with dyslexia. Oral and written language learning disability (OWL LD) is the same as SLI or LLD but has been renamed to educate psychologists, who often refer to language, reading, and writing as if the latter two are not language, that (a) reading disabilities may be related to oral language and not just written language impairments; and (b) like the wise old owl, children with both oral and written language disability may be smart even if they do not show significant IQ-achievement discrepancy on formal testing because they are not language-based thinkers and may think and express their ideas in different ways (Berninger, 2007a, 2007b, 2008).

Children with SLI, LLD, or OWL LD are typically slower in learning oral language during the preschool years, but because they may have received and responded to early intervention for oral language during the preschool years, their linguistic awareness (i.e., syntactic, morphological, phonological, and orthographic) problems during the school years, which interfere with required literacy learning and understanding instructional language across the curriculum, may be missed unless they are identified on formal assessment. These children are likely to respond to phonological awareness and phonics instruction, but unless they receive morphological and syntactic awareness and comprehension strategy instruction, they are likely to have persisting reading comprehension, spelling, and composition difficulties (see Berninger, 2008). In contrast, children with dyslexia had early oral language that was at least in the average range and often better, and their problems with written language first surface in kindergarten when they are expected to learn to name and write alphabet letters and associate sounds with them. The school language learning profile of children with dyslexia is typically characterized by persisting problems in phonological and orthographic coding in working memory, phonological decoding, and spelling (i.e., word- and subword-level working memory skills), but not with reading comprehension or syntax (TL-WM skills; Berninger, 2007a, 2007b, 2008).

Multidisciplinary research has shown that an impaired working memory architecture consisting of coding units for storing and processing the three word forms, two loops, and a panel of executive functions, as described earlier, may result in three written LLDs depending on the specific components affected (Berninger, Raskind, et al., 2008). Although executive functions may be impaired in each of these, the nature of impairment in the word coding units and loops affects whether the individual has *dysgraphia* (handwriting and sometimes spelling disability related to impaired orthographic word coding and/or the orthographic loop); *dyslexia* (word decoding and spelling disability related to impaired orthographic coding, phonological coding, phonological loop, and/or orthographic loop); and/or *SLI, LLD,* or *OWL LD* (real word reading and reading comprehension disability related to impaired phonological, orthographic, and morphological word coding, syntactic coding, phonological loop, and/or orthographic loop). Dysgraphia may or may not co-occur with dyslexia or OWL LD.

These diagnostic categories are not mere labels—they describe learning profiles with treatment implications. Children with dysgraphia need specialized instruction in handwriting and/or spelling and the transfer of transcription to independent composition (e.g., Berninger et al., 1997). Children with dyslexia need specialized instruction that develops their phonological, orthographic, and morphological awareness and their ability to coordinate phonological, orthographic, and morphological knowledge in word decoding and spelling (Berninger, Raskind, et al., 2008; Berninger & Wolf, 2009a, 2009b). Children with SLI, LLD, or OWL LD need specialized instruction in word retrieval (reflecting difficulty in applying executive functions to long-term memory search for and working memory activation of word meaning, pronunciation, and spelling), syntactic awareness, and text inferencing (Cain & Oakhill, 2007; Silliman & Scott, 2009). (See Berninger, 2007a, 2007b, for an assessment–intervention model for these three specific written LLDs that draws on a variety of assessment tools and easily accessible instructional interventions.) Once each of the three working memory components and the relevant levels of working memory are assessed, results inform treatment planning.

Speech and language specialists and other school professionals with whom they consult and collaborate can use the following evidence-based programs to treat written language disabilities:

- *SPELL–2: Spelling Performance Evaluation for Language & Literacy* (Masterson, Apel, & Wasowicz, 2006) and *SPELL—Links to Reading and Writing* (Wasowicz, Apel, Masterson, & Whitney, 2004) provide a comprehensive, user-friendly approach to linking assessment and instructional treatment with a focus on phonology, orthography, and morphology.
- *The Wilson Reading System*[6] incorporates multisensory teaching techniques with explicit instruction in phonology, orthography, and morphology.
- *Retrieval, Automaticity, Vocabulary, and Engagement With Language, and Orthography (RAVE-O),* developed and validated by Maryanne Wolf and colleagues, provides explicit instruction in phonology, orthography, and morphology with a focus on improving word retrieval and building vocabulary as well.
- *Lovett Empower Reading,* developed and validated by Maureen Lovett, provides lessons for teaching strategies for accurate and efficient decoding and application of this knowledge to independent reading for meaning, information, and pleasure. Some spelling and reading comprehension activities are included. Other programs focus on both word and syntactic processing and awareness.
- *The Nelson Writing Lab* (Nelson, Bahr, & Van Meter, 2004) offers many effective treatment strategies for both writing and reading, which integrate use of technology and were validated for students with oral as well as written language disabilities.
- *Linguistic Remedies* (Wise, Rogan, & Sessions, 2009) provides insightful ideas for applying language research to literacy instruction that is individually tailored to a professional's own cases.

[6]Information on the Wilson Reading System is available at www.wilsonlanguage.com. Information on the RAVE-O systematic approach to reading fluency is available at http://ase.tufs.edu/crlr/RAVE-O/Home.html. Information on the Empower Reading program is available at http://www.theibsc.org/uploaded/IBSC/Conference_and_workshops/Toronto_Workshops/LeatchM_EmpowerReadingInfoSheet.pdf.

In addition, instruction should treat executive function impairments contributing to language learning problems. See Singer and Bashir (2004) for practical suggestions for the assessment and treatment for improving executive functions related to language learning. See Berninger and Abbott (2003) and Berninger and Wolf (2009a, 2009b) for designing lessons that (a) teach each working memory component, including coordinating phonological, orthographic, and morphological awareness of word forms and their parts; (b) teach to levels of language close in time to overcome working memory limitations and create functional reading and writing systems in which all of the components function in concert; and (c) integrate oral and written language to develop literacy skills in children with and without oral language disabilities.

Educating other school professionals about language. The field of speech and language therapy could make a major contribution to improving assessment and treatment for written LLDs by launching a federal initiative to develop research-supported diagnostic guidelines for language learning profiles that have diagnostic and treatment significance beyond the eligibility categories for special education and are applied consistently by multidisciplinary teams throughout the United States. Such profiles could also be designed for students whose first language is not English or a mainstream dialect of English (see Washington & Thomas-Tate, 2009), or whose oral and/or written language problems may be related to other biological, developmental, or environmental factors than characterize specific learning disabilities.

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Contact author: Virginia W. Berninger, 322 Miller, Box 353600, University of Washington, Seattle, WA 98195-3600.
E-mail: vwb@u.washington.edu.

APPENDIX. DIVERSITY OF PARTICIPANTS

Characteristics of the children who were in the second grade in Year 2: Asian American (23.4%), African American (6.3%), European American (64.8%), Hispanic (1.6%), Native American (1.6%), and other (2.3%). Approximately 10% of the parents had less than a high school education or graduated from high school (7% mothers and 12.5% fathers). Nearly 10% of the parents had more than a high school education but less than a college education (11.7% mothers and 7.8% fathers). More than 40% of the parents had an undergraduate education (45.3% mothers and 39.8% fathers). Approximately 33% of the parents had completed graduate degrees (33.6% mothers and 32.0% fathers). Information on parental level of education was missing for 2.4% of the mothers and 7.9% of the fathers.

Characteristics of the children who were in the fourth grade in Year 2: Asian American (21.2%), African American (9.7%), European American (65.5%), Hispanic (0.9%), and other (2.7%). Approximately 7% of the parents had less than a high school education or graduated from high school (7.1% mothers and 7.1% fathers). More than 12% of the parents had more than a high school education but less than a college education (11.5% mothers and 14.2% fathers). More than 40% of the parents had an undergraduate education (50.4% mothers and 36.3% fathers). Nearly 33% of the parents had completed graduate degrees (30.1% mothers and 35.4% fathers). Information on parental level of education was missing for 0.9% of the mothers and 7.2% of the fathers.