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Concurrent and longitudinal neuropsychological contributors to written language expression in first and second grade students

Stephen R. Hooper · Lara-Jeane Costa · Matthew McBee · Kathleen L. Anderson · Donna C. Yerby · Sean B. Knuth · Amy Childress

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Abstract The primary purpose of this study was to examine several key questions related to the neuropsychological contributors to early written language. First, can we develop an empirical measurement model that encompasses many of the neuropsychological components that have been deemed as important to the development of written language? Second, once derived, will the neuropsychological components of this model remain stable over first and second grades or will the model change in its composition? Third, will the strength of the relationships between neuropsychological components and writing outcomes be constant over time, or will the strength of the relationships change over time? Finally, will the derived empirical model show significant concurrent and predictive relationships with written expression? The sample included 205 first grade students recruited from a single school district who were followed into the second grade via two cohorts: Measures were aligned with major neuropsychological components as extracted from theoretical models of written expression and available empirical findings examining the neuropsychological contributors to writing in children.

S. R. Hooper
Departments of Psychiatry and Pediatrics, University of North Carolina School of Medicine, Chapel Hill, NC 27599-7255, USA

S. R. Hooper (✉) · K. L. Anderson · D. C. Yerby
The Center for Development and Learning CB# 7255, Carolina Institute for Developmental Disabilities, University of North Carolina School of Medicine, Chapel Hill, NC 27599-7255, USA
e-mail: Stephen.hooper@cdl.unc.edu

L.-J. Costa · S. B. Knuth · A. Childress
School of Education, University of North Carolina School of Medicine, Chapel Hill, NC 27599-7255, USA

M. McBee
Frank Porter Graham Child Development Institute, University of North Carolina, Chapel Hill, NC 27599, USA

These domains included fine-motor speed, language, short-term memory, long-term memory, and various attention/executive functions including working memory. Confirmatory factor analyses (CFAs) and longitudinal structural equation modeling (SEM) methods documented that three core latent traits were present and stable at both grades 1 and 2: Fine-Motor, Language, and Attention/Executive Functions. The overall model was highly related to written expression and spelling at both grades 1 and 2, with the first grade latent traits accounting for 52 and 55% of the variance in second grade written expression and spelling, respectively. At both grades, the Language and Attention/Executive Functions latent traits were more highly associated with written expression and spelling than the Fine-Motor latent trait.

Keywords Neuropsychological contributors to written language · Written language development · Neuropsychological predictors of early written language · Written expression in early elementary school

The study of written expression has begun to receive the attention of researchers, clinicians, and school personnel in the past two decades (Hooper, Knuth, Yerby, Anderson, & Moore, 2009), but there remains a strong need for evidence-based practices to be consistently implemented in the school setting (Baker, Chard, Ketterlin-Geller, Apichatabutra, & Doabler, 2009). The development of writing skills in students presents a significant challenge for educators, particularly in this day of high-stakes testing and heightened accountability. Although, our knowledge of the underlying neuropsychological components of reading and associated instructional strategies has proliferated over the past 20 years, we have only begun to understand the neuropsychological factors that contribute to the development of written expression (Edwards, 2003; Graham & Harris, 2005). Although there has been a considerable amount of research grounded in the cognitive processes of writing (e.g., planning, translating, reviewing, & revising; Hayes & Flower, 1980), research on the developmental neuropsychological processes contributing to early writing development has received minimal attention (e.g., Berninger et al., 1992), and even less attention from a longitudinal perspective and/or with young children at-risk for writing problems. Such research is needed so that children at risk for writing problems can be identified early in schooling and be given early intervention services in writing to prevent or lessen later writing problems.

Neuropsychological functions related to written expression

Numerous studies have documented the qualities inherent in good or "expert" writers (e.g., Bereiter & Scardamalia, 1987; Berninger, Stage, Smith, & Hildebrand, 2002; Gregg & Mather, 2002; Hayes, 2000; Hayes & Flower, 1980; Houck & Billingsley, 1989), and the influence of neuropsychological functions (e.g., memory, attention) on writing processes has begun to surface. Nearly 20 years ago Levine et al. (1993) suggested the importance of a variety of neuropsychological functions in the writing process. These functions included memory, attention, graphomotor output, sequential processing, higher-order cognition, language, and visual-spatial functions; however, no data were available to support when and to what degree these functions influenced the writing process.

To date, the findings from various empirical efforts, as well as the cognitive constructs underscored by several key theories in written expression (e.g., Hayes & Flower, 1980; Hayes, 1996), implicate a number of potential neuropsychological contributors to the development of early written expression in children. These include fine-motor, language, short-term memory, long-term memory, working memory, and attention/executive functions.

Fine-motor functions

Fine-motor functions facilitate the actual formation of the letters and words, and the speed with which this is accomplished. Despite the need for some type of fine-motor output to produce a written product, most of the cognitive theoretical models addressing written language have not included such a component (e.g., Hayes & Flower, 1980; Kellogg, 1999). Based on evolving empirical literature, however, more contemporary models of written language for children (e.g., Not-So-Simple View of Writing; Berninger & Winn, 2006) do include fine-motor functions as important to transcription skills. Neurodevelopmental finger function skills and timed alphabet writing performance (graphomotor) have been identified as strong predictors of handwriting, spelling, and writing skills for students in elementary school (Berninger & Rutberg, 1992; Berninger et al., 1992). Berninger and Rutberg (1992) also described the importance of fine-motor planning and control to the development of writing in early elementary grade children. Most recently, Richards et al. (2009) documented the neurological correlates of finger sequencing without motor output in a small sample of good and poor writers, and showed the relationship of associated brain activation patterns to handwriting, spelling, and composing. Consequently, it will be important for fine-motor functions to be included in any measurement model for written expression in young elementary school children.

Language-related functions

Nearly all of the theoretical models of written language have included various language and linguistic functions (e.g., the Kellogg model includes reading). Basic language and linguistic functions represent a wide array of neuropsychological abilities critical to the writing process. These include phonological processing, orthographic coding, vocabulary, word finding, sentence syntax, language pragmatics, and reading capabilities. These basic language functions appear necessary for success in the older writer, and critical for the development of early writing skills. Abbott and Berninger (1993) provided one of the first empirical studies examining this issue. They noted that oral language/verbal reasoning, including such functions as word finding, phonological processing, and reading, contributed to composition fluency. Berninger et al. (1992) also found that orthographic coding (i.e., whole word, letter, letter clusters) had a strong positive correlation with handwriting, spelling, and compositional skills.

Another language-related function, rapid naming, also holds promise for its relationship to early written language development. Given that general naming ability tends to precede, and consequently predicts, a child's letter and word reading capabilities (Compton, Olson, DeFries,& Pennington 2002; Neuhaus & Swank, 2002), it stands to reason that letter naming proficiency would be a critical language-related component in any neuropsychological model. Automaticity in both the orthographic coding and phonologic processing is critical to reading (Neuhaus & Swank, 2002), and likely early writing skills. Rapid automatized naming (RAN; Denckla & Rudel, 1974) has been linked closely to reading-related abilities (Schatschneider, Carlson, Francis, Foorman, & Fletcher, 2002; Vukovic & Siegel, 2006; Wolf & Bowers, 1999), but others have begun to show its importance to writing. Berninger et al. (2006) showed that rapid automatized naming had a significant positive correlation with writing. Further, Neuhaus, Foorman, Francis, and Carlson (2001) noted that the process of letter naming functions becoming fully automatic can extend into the fourth grade, thus rapid automatic naming has the potential to be a key predictor of later writing problems in early elementary school students.

Memory functions

Various memory functions appear to be important to the writing process. Long-term memory facilitates the extraction of information to be included in the writing task, such as idea generation, topic knowledge, and understanding of audience. Short-term memory is critical to the reviewing and revising processes of writing, and is important in the spelling process. Unlike working memory, short-term memory does not contain a major executive component. Whereas working memory and short-term memory have been used interchangeably in the literature, it is the executive, regulatory component in working memory that separates the two. In comparison to short-term memory, long-term memory is relatively stable (Kintsch, Patel, & Ericsson, 1999).

The mechanisms of short-term memory are linked to those of long-term memory to facilitate information processing and storage, and they have been included in several key theoretical models of written language (Hayes, 1996). Despite their inclusion in these models, however, there has been precious little empirical work that has examined these functions with respect their contributions to the development of written language in young elementary school children. One study by Hooper, Swartz, Wakely, de Kruif, and Montgomery (2010) using fourth and fifth grade students with and without writing problems documented the presence of broader memory problems across modalities that can undermine the entire writing process; however, the availability of other empirical efforts has been limited to date.

Working memory functions

Another key neuropsychological function on which investigators have focused is working memory (Lea & Levy, 1999; McCutchen, 1996, 2000). Baddeley (2007) described working memory as a neuropsychological system involving temporary storage that uses manipulation of information during complex tasks. This neurocognitive workspace, or working memory, is important to written expression because it is the function that underlies the active maintenance of multiple ideas, the retrieval of grammatical rules from long-term memory, and the recursive self-monitoring that is required during the act of writing (Kellogg, 1999). Working memory contributes to the management of these simultaneous processes, and a breakdown may lead to problems with written output (Levy & Marek, 1999). Indeed, working memory has been included in nearly all of the major models of written language (e.g., Berninger & Winn, 2006; Hayes, 1996; Kellogg, 1999). The efficiency of these processes plays a role in determining the capacity of working memory (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001). McCutchen (1996) found that poor writers typically have reduced working memory capacity when compared to good writers, and Swanson and Berninger (1994, 1996) reported that working memory had both general and domain-specific contributions to the writing process.

The limited capacity of working memory makes writing a challenging task for anyone due to the multiple processes (e.g., planning, revising) used in writing (Gray & McCutchen, 2006). In addition, writing puts more demands upon working memory than oral communication (Bourdin & Fayol, 2000) because transcription skills must be coordinated within the limited confines of working memory (Berninger, 2000; McCutchen, Covill, Hoyne, & Mildes, 1994). Transcription processes that are not fluent place a significant demand on working memory (McCutchen, 1996). On the other hand, fluency in text production can increase the amount of working memory available for higher level writing processes (McCutchen, 2006). Thus, it seems reasonable to suppose that differences in working memory capacity would be related to writing performance in younger students learning to write. For a measurement perspective, it is important to include working memory functions.

Attention/executive functions

Closely related to working memory is the broad domain of executive functions. Indeed, some investigators actually place working memory within the construct of executive functions given its regulatory nature (Barkley, Murphy, & Fischer, 2008; Funahashi, Bruce, & Goldman-Rakic, 1989); however, given its importance to the writing process, it is important to measure working memory and executive functioning separately (Miyake et al., 2001). At one time, planning and executive control were thought to be executed by a single unit, yet this idea has since evolved and can be described as a multi-component model where the central executive has distinguishable functions for manipulating information in working memory (Repov & Baddeley, 2006). These functions include the abilities to focus, divide and switch attention, and relate the contents of working memory to long-term memory (Repov & Baddeley, 2006). Further, executive functions aid in successful performance by regulating attention control and the integration of information (Repov & Baddeley, 2006; Shallice 1982). Specifically in writing, the various executive functions contribute to planning, translating, programming, reading, and editing (Kellogg, 1996), and they have been included in most models of written language. For example, in the Not-So-Simple View of Writing (Berninger & Winn, 2006), various executive functions (e.g., supervisory attention, goal setting, planning, self-monitoring) are critical to text generation. In fact, Vandenberg and Swanson (2007) found the central executive to be the only component of a working memory system to predict planning, translating, revision, higher-order skills, and vocabulary in high school students. Similarly, in populations where executive dysfunction is suspected, such as in children with ADHD, high rates of writing problems have been uncovered (Mayes & Calhoun, 2007).

Even though text generation and the organization of the writing process are influenced by executive functions (Berninger & Amtmann, 2003), there is little empirical research on this relationship in younger students. Graham and colleagues provided some of the initial findings related to the self-regulation components of the writing process (Graham, 1997; Graham & Harris, 2000; Graham & Harris, 2009; Harris & Graham, 2009), with their empirically based findings being manifested in programmatic treatment strategies (i.e., Self-Regulated Strategy Development model). Our group has directly examined the differences of various executive functions across good and poor writers. Hooper, Swartz, Wakely, de Kruif, and Montgomery (2002) showed that fourth and fifth grade students with and without writing problems manifested specific differences in their profile of executive functions, with the poor writers being less proficient at initiation, sustaining, set shifting, and inhibition; however, only small to moderate effect sizes were present.

The current study

Based on the available empirical results and the available theoretical models, there does appear to be a clear role for neuropsychological functions in written expression; however, there are few, if any studies that have tested the various components simultaneously from an empirical perspective, particularly in young elementary school children. In this regard, we have endeavored to examine these underpinnings of early written expression and spelling by proposing a model that includes the components deemed important to the development of written expression including fine-motor, language-related, short-term memory, long-term memory, working memory, and attention/executive functions. As such, this study addresses several key questions related to the neuropsychological contributors to early written language. First, are the measures valid indicators of their corresponding latent constructs? This would include measures of fine-motor control, language-related variables, short-term memory, long-term memory, working memory, and executive functions such as attention regulation, planning, and efficiency. Even though it is unlikely that all of these components will withstand issues of collinearity, the expectation is that the data will support significant contributions by several of the neuropsychological functions that will be represented in an empirically-based model. Second, does the proposed model explain the relationships among the latent constructs equivalently for first and second graders? Given the proximity in time of the measures, we would expect to see relative stability in the components of the model from first to second grade. Third, will the strength of the relationships between specific neuropsychological components and writing outcomes be constant over time, or will the strength of the relationships change over time? Finally, will the derived empirical model of neuropsychological functions show significant concurrent and predictive relationships with two major components of writing: written expression and spelling?

Method

Participants

Participants included 205 first grade students from seven elementary schools in a single, suburban-rural school district in North Carolina. This represented approximately 40% of the entire pool of potential first grade participants in this district. A single school district was selected for recruitment in order to minimize potential problems related to basic core curriculum differences and different instructional philosophies that can exist between systems even with a standard state course of study. For first and second grade writing development, classroom instruction included ongoing development of the alphabetic principle, utilizing vocabulary effectively in written communication, composing written sentences, planning and composing narrative texts that are descriptive and creative in nature, appropriate use of capitalization, punctuation, syntax, and grammar, and emergent revising of text skills. These skills were immersed in daily classroom activities, with little in the way of direct instruction for written expression. All of the students were in a regular classroom setting as the primary school placement and had attended kindergarten. In addition, all of the students had a functional understanding of English as determined by teacher report of their primary language of use within the classroom setting. The total sample was recruited in first grade via two cohorts in successive years: cohort 1 ($n = 104$) and cohort 2 ($n = 101$), and then both cohorts were tracked into second grade.

The sample comprised 42.9% female students and, at the first assessment, ranged in age from 6.0 to 7.33 years; at the second assessment, the ages ranged from 7.0 to 8.25 years. Approximately 75.1% of the students were European American/white, 18.5% were African-American/black, 1% was Native American, 1% was Asian American, and 4.4% were multi-racial. Within the sample, 12.2% were Hispanic. Nearly 32% of the students applied for the free and reduced lunch program in the target school district in the 2007–2008 school year. As for the maternal education status of the participants, 10.1% reported not graduating from high school, 10.1% received their high school diploma or GED, 30.2% had some additional college or technical training, 12.2% received an associate's degree, and 37.4% graduated from college.

Measures

Measures were selected based on their alignment with the neuropsychological components that have been associated with written language via theoretical models and available studies examining the neuropsychological factors in written language. Measures also were selected based on their psychometric properties and availability in the school setting in an effort to facilitate translation into the educational setting. All of the measures were administered and scored according to the standardized procedures in the test manuals. In an effort to control for order effects, the assessment measures were divided between two administration blocks: Block A and Block B. Tasks in Block A included psychoeducational and language measures, and tasks in Block B included fine-motor, language, memory/retrieval, and attention/executive function measures. As well, the order in which the blocks were administered was counterbalanced to minimize order effects, thus half of the participants received Block A first and half received Block B first in first grade, and the order was reversed in second grade. Children were assessed on their anniversary date (±2 weeks), with the average time between the two assessments being about 12 months.

Fine-motor control

Fine-motor control was measured using the Finger Sense Succession task for both the dominant and nondominant hands from the Process Assessment of the Learner-Second Edition (PAL-II, Berninger, 2007). This task was based on the classic finger sequencing procedure proposed by Denckla (1973), and later by Wolf, Gunnoe, and Cohen (1983), and required the student to touch the thumb against each finger in sequences with each hand. This task has been identified as a potential predictor of beginning writing (Berninger & Rutberg, 1992). We also used the PAL-II Alphabet Writing task, which required the student to write the letters of the alphabet, in order, under timed conditions (i.e., the number of letters in 15 s). We are aware of the potential overlap of this task with selected aspects of the WIAT-II Written Expression scale at this age level, we wanted to include a graphomotor measure in this component of the model given the focus on writing output. Reliability coefficients for these tasks ranged from 0.87 to 0.89 (Berninger, 2007).

Language-related

Within the language domain, three PAL-II subtests were administered to assess language development: Rapid Automatic Naming-Letters/Digits, Word Choice, and Syllables and Phonemes. The Rapid Automatic Naming-Letters/Digits subtest is a timed task of rapid automatic naming in which the student demonstrates fluency by quickly naming an array of letters and letter groups. If the student did not accurately read the letters, then a similar task with digits was administered. Reported stability coefficients for this task were strong, ranging from 0.84 to 0.92 (Berninger, 2007). The Word Choice subtest measures the student's orthographic coding abilities. The student circled the correctly spelled word within a set of three words, in which the other two words were spelled incorrectly but would be pronounced similarly. Internal consistency estimates ranged from 0.66 to 0.83 (Berninger, 2007).

Phonological processing was assessed using the Syllables and Phonemes subtests in second grade for all students, and in the first grade for cohort 2. Here, the student identified syllables and sounds in words. The student was asked to repeat a word with a syllable or sound omitted, or to identify the remaining phonemes when one phoneme has been omitted. This task was used to replace our original phonological processing measure, the Comprehensive Test of Phonological Processing (CTOPP, Wagner, Torgesen, & Rashotte, 1999) Elision subtest, at the request of the school system. The CTOPP Elision subtest was administered to cohort 1 in the first grade only, and required students to repeat words with a part omitted. The CTOPP Elision subtest and PAL-II Syllables and Phonemes were combined for this analysis into a single phonological processing variable (i.e., Phonemes). Reliability estimates for the PAL-II Syllables and Phoneme subtests ranged from 0.74 to 0.92 (Berninger, 2007), and from 0.89 to 0.90 for the CTOPP Elision subtest (Wagner et al., 1999).

In a similar vein, we assessed receptive vocabulary using two different tasks. In first grade for cohort 1 we employed the Peabody Picture Vocabulary Test-IV (PPVT-IV, Dunn & Dunn, 2007) whereas in the second grade we used the Comprehensive Receptive and Expressive Vocabulary Test-Second Edition (CREVT-2, Wallace & Hammill, 2002). Both receptive language tasks required students to select a target picture from an array of pictures representing a designated vocabulary word. Reliability estimates were 0.94 and 0.91 for the PPVT-IV and CREVT-2, respectively.

Short-term memory

Short-term memory was measured using the visual and verbal recall and recognition tasks from the Wide Range Assessment of Memory and Learning-2 (WRAML-2; Adams & Sheslow, 2003). Given the theoretical models of written language, along with the available empirical literature, the memory domain was divided into two separate components: working memory and long-term memory/retrieval. Two subtests were administered to assess short-term memory: Picture Memory (i.e., visual recall) and Story Memory (i.e., verbal recall). For Picture Memory, one at a time students examined four stimulus picture cards for 10 s, and then were provided with a similar picture scene in which they had to identify the parts of the picture that had been moved, changed, or added. During the Story Memory subtest, the examiner read two stories to the student. After each story, the student was asked to verbally recall the parts of the story. Internal consistency estimates for these tasks ranged from 0.78 to 0.91 (Adams & Sheslow, 2003).

Long-term memory

For the Long-Term Memory domain, the recognition tasks associated with Picture Memory and Story Memory were employed. For both Picture Memory and Story Memory the recognition subtests were administered approximately 25 min following the immediate recall conditions. Students were given a 4-page booklet with 44 different pictures for the Picture Memory recognition task, and were asked to decide if the picture was seen earlier or not. For Story Memory, the child was asked multiple-choice questions about each story. Internal consistency estimates for these tasks ranged from 0.46 to 0.81 (Adams & Sheslow, 2003).

Working memory

Several tasks were selected that represented working memory, both verbal and nonverbal. Verbal working memory at grade 1 for cohort 1 was assessed using the CTOPP Nonword Repetition subtest and, at the request of the school district, the Wechsler Intelligence Scale for Children-IV-Integrated (WISC-IV-I, Wechsler, 2004) Digit Span subtest was used for the remainder of the students. On the CTOPP Nonword Repetition task, the child listened to a recording of a series of pseudowords and then was asked to repeat the nonwords exactly as heard. Internal consistency for this task was 0.80. For WISC-IV-I Digit Span subtest, students were asked to repeat an increasingly longer sequence of digits, first forward and then backwards. Reliability estimates for this task ranged from 0.69 to 0.83. The CTOPP Nonword Repetition subtest and the WISC-IV-I Digit Span subtest were combined to form a single variable called Verbal Working Memory.

Nonverbal working memory was assessed using the WISC-IV-I Spatial Span subtest. Similar to the Digit Span subtest, the Spatial Span subtest includes forward and backward sequence tasks. During the forward component of the Spatial Span subtest, the student watched as the examiner taps a series of blocks, and then the student repeated the sequence. During the backward sequence component, the student watched the examiner touch a series of blocks and then repeated the sequence in reverse order. For the WISC-IV-I task, reliability estimates ranged from 0.68 to 0.83.

Attention/executive functions

Executive function measures were selected to assess planning, retrieval fluency, and attention regulation. For this domain, we administered two subtests from the Woodcock Johnson Tests of Cognitive Abilities (WJ-III; Woodcock, McGrew, & Mather, 2001): Planning and Retrieval Fluency. The Retrieval Fluency subtest provided an estimate of the student's verbal retrieval and efficiency by asking the student to name as many different items as possible within 1 min related to a specific category (i.e., things you eat and drink, first names of people, animals). The Planning subtest assessed the student's planning and problem solving abilities by asking the student to trace increasingly more difficult drawings without lifting the pencil from the paper. Reliability for these two tasks were 0.80 and 0.75, respectively.

Attention regulation was assessed using the VIGIL Continuous Performance Test (CPT, The Psychological Corporation, 1999). The VIGIL is an 8-min computerized task that requires the students to watch a computer screen as a series of single letters appeared. They are asked to press the space bar when the letter K appeared immediately after a letter A. Both errors of omission and errors of commission are generated as indices of selective attention and impulsivity, respectively. Test–retest reliability was approximately 0.70 for both errors of omission and commission.

Written language outcomes

For this study we will examine two writing outcomes: WIAT-II Spelling and Written Expression (Wechsler, 1999). The WIAT-II Written Expression and Spelling subtests were selected because they represent key components of an empirically-derived functional writing system. Age-based standard scores are generated for each of these subtests. At grades 1 and 2, the Written Expression subtest consisted of three tasks, timed alphabet writing, written word fluency, and sentence combining. The student is given 15 s to write the lower case letters of the alphabet, in order, and 60 s to write words related to a topic. Finally, the student is asked to combine two simple sentences into one well-written sentence with the same meaning. Internal consistency for this subtest was 0.91. The Spelling subtest includes items to demonstrate knowledge of written letters, letter groups, and words. Internal consistency for this subtest was 0.94.

Data analyses

To address the four research questions, we used confirmatory factor analyses (CFAs) and structural equation modeling (SEM). For the first question, we used these strategies to develop the neuropsychological/neurocognitive model for first and second graders separately and, for the second question, to determine the stability of an obtained model over time (Kline, 2005). The aim here was to determine whether the students' scores from the measures of fine-motor, language, long-term memory, working memory, and executive function were valid indicators of their latent constructs at first grade and second grade, and across the two grade levels. For the third question, we introduced the writing and spelling outcomes to the model and investigated the temporal stability of relationships between the components of the neuropsychological model and outcomes. Here, we examined whether the strength of the relationships between the derived neuropsychological components and writing outcomes would be constant over time, or whether the strength of the relationships would change over time. Finally, for the fourth question, the empirically derived neuropsychological underpinnings were examined to determine if they predicted written expression and spelling at each grade level and over time. All analyses were performed using Mplus version 5.2 software and utilized maximum likelihood estimation (MLE). Missing data were handled using full information maximum likelihood estimation (FIML; Enders & Bandalos, 2001), which allowed for the calculation of unbiased parameter estimates without the loss of statistical power that accompanies listwise deletion.

Neuropsychological model construction

For question 1, confirmatory factor analysis was used to analyze how well the data fit the proposed model. The measurement models were tested to verify the relationships between the latent constructs (i.e., fine motor, language, long-term memory, working memory, executive functions) and their corresponding indicators. Separate analyses were conducted for first grade second grade.

Longitudinal measurement invariance

For question 2, multiple group CFAs established the stability of the neuropsychological model across grade levels. This involved testing the longitudinal measurement invariance of the neuropsychological model developed in the first step by fitting a series of successively constrained models to both grade levels simultaneously. In the first step, the factor loadings, residuals, and intercepts were allowed to take on unique values at each grade. Alternatively, in the second step the factor loadings were forced to take on identical values across groups. A likelihood ratio test was conducted to test the equivalence of the factor loadings in the two grades. Additional steps investigated the stability of intercepts, residual variances, error covariances, factor covariances, and indicator residual variances.

Stability of relationships between neuropsychological components and outcomes

For question 3, an analysis was conducted to examine the strength and stability of the relationships between neuropsychological components and writing outcomes at first and second grade. This analysis used successively-constrained SEMs to test whether the relationships between neuropsychological components and outcomes were the same at first and second grade, or whether some components changed in importance. The fit of a SEM allowing the correlations between neuropsychological components and outcomes to take on unique values at first and second grade was compared to the fit of a model where these correlations were constrained to equality. A likelihood-ratio test of the difference in model fit provided a test of the stability of the relationships.

Predictive power of the neuropsychological model

In our final analyses for question 4 we aimed to understand the predictive relationships among the established latent constructs and the two writing outcomes: WIAT-II Written Expression and Spelling. The six models regressed the established latent variables on these outcomes. The six models that were considered are: Model 1—First grade latent traits predicting first grade written expression; Model 2—First grade latent traits predicting first grade spelling; Model 3—Second grade latent traits predicting second grade written expression; Model 4—Second grade latent traits predicting second grade spelling; Model 5—First grade latent traits predicting second grade written expression; and Model 6—First grade latent traits predicting second grade spelling.

Results

Descriptive statistics

An examination of the descriptive statistics in Table 1 reveals that for both grade levels the students' mean scores were largely within the average range for most measures. Further, the standard deviations suggested reasonable variation in responses for this sample. The PAL-II Rapid Automatic Naming-Letters/Digits subtest was below average at both grades, but all of the other measures were within the average range. Given that the bulk of the scores were age-based in their

Table 1 Descriptive statistics on the neuropsychological tasks at grades 1 and 2

Measures	Grade 1			Grade 2		
	N	*M*	SD	*N*	*M*	SD
PAL-II: Finger Sense Succession Dominant Hand Scaled Score	200	8.87	2.65	199	8.89	2.94
PAL-II: Finger Sense Succession Nondominant Hand Scaled Score	196	9.22	2.27	198	9.24	2.43
PAL-II: Alphabet Writing Scaled Score	206	7.98	2.65	200	7.22	2.19
PAL-II: Word Choice Accuracy Scaled Score	203	8.69	3.46	199	10.00	3.51
PAL-II: Letters Scaled Score	197	3.47	2.43	199	4.38	2.67
CTOPP Elision Standard Score	102	9.83	2.50	0		
PAL-II: Phonemes Scaled Score	104	7.94	3.28	200	8.77	3.47
PAL-II: Digits Scaled Score	6	9.55	2.88	6	8.27	3.34
PPVT-4 Standard Score	102	102.42	14.13	0		
CREVT-2: Receptive Vocabulary Standard Score	104	96.34	10.52	200	96.55	11.85
VIGIL Omissions—total raw	203	60.20	30.75	200	45.52	20.76
VIGIL Commissions—total raw	203	83.41	64.02	200	75.26	62.31
WJ-III: Planning Age-based Standard Score	206	106.14	8.81	200	103.09	9.26
WJ-III: Retrieval Fluency Age-based Standard Score	205	95.96	15.39	200	97.00	15.13
WRAML-2: Picture Memory Recognition Standard Score	206	9.71	2.97	200	10.12	2.81
WRAML-2: Story Memory Recognition Standard Score	206	11.12	2.98	200	11.49	2.89
WISC-IV Digit Span Forward Scaled Score	104	9.05	2.71	200	8.79	2.58
WISC-IV Digit Span Backward Scaled Score	104	9.64	3.25	200	9.39	2.69
CTOPP Nonword Repetition Standard Score	102	9.53	2.12	0		
WISC-IV Spatial Span Forward Scaled Score	206	9.88	2.90	200	10.23	2.83
WISC-IV Spatial Span Backward Scaled Score	206	9.32	3.29	200	10.07	3.15
WRAML-2: Picture Memory Standard Score	206	8.40	3.23	200	9.19	2.81
WRAML-2: Story Memory Standard Score	206	10.78	2.58	200	11.03	2.85
WIAT-II: Written Expression Standard Score	206	89.71	12.41	200	89.69	12.44
WIAT-II: Spelling Standard Score	206	100.41	16.03	200	101.27	13.27
WorkingMem *z*-score	206	99.35	12.77	200	96.56	11.85
ReceptiveLang *z*-score	206	0.00	0.92	200	0.00	0.80
Phonemes *z*-score	206	0.00	0.92	200	0.00	0.89

In order to address missing data on some assessments, the following new variables were created: WorkMem = CTOPP Nonword Repetition for cohort 1 in grade 1 or the mean of WISC Digit Span Forward and Backward otherwise. ReceptiveLang = PPVT SS for cohort 1 in grade 1, CREVT RV score otherwise. Phonemes = CTOPP Elision for cohort 1 in grade 1, mean of PAL Syllables and PAL Phonemes otherwise. When PAL Letters was missing, it was replaced by PAL Digits. All scores were converted to *z*-scores before creating ReceptiveLang and Phonemes variables. All scores converted to *z*-scores prior to analysis. All scaled scores had a mean = 10, SD = 3; all standard scores had a mean = 1 ==, SD = 15; and all *z*-scores had a mean = 0, SD = 1 derivation, significant variations between grades was not expected, and any variations observed in Table 1 likely reflect normal variation in performance. Additionally, a correlation matrix of variables is provided in Table 2 to show the relationship among the variables used in this study.

Construction of neuropsychological models

The first goal of the analysis was to investigate the plausibility of the various neuropsychological components that have been theoretically and empirically linked to written expression in children, and to test the degree to which those components fit data collected on first and second graders. The proposed neuropsychological model, displayed in Fig. 1, required substantial modification before acceptable fit statistics were achieved. The following discussion describes the iterations from the initially proposed neuropsychological model to the resultant model that was consistent with the data.

Step 1

The model was hypothesized to include the neuropsychological components of fine-motor, language, long-term memory, working memory, and attention/executive functions. The model was fit separately to the first and second grade datasets. For the first grade data, the model converged with an error message indicating that the estimated correlations between several latent variables were greater than 1, and that the Short-Term Memory latent variable was a problem. The same error message was generated when the model was fit to the grade 2 data. In addition, modification indices suggested that the PAL-II Alphabet Writing variable should load on all of the latent variables.

Step 2

Based on the results of Step 1, the model was modified. The Short-Term Memory latent variable was removed, and its indicator variables were dropped. Additionally, because the PAL-II Alphabet Writing variable was highly correlated with all the latent variables, assigning it to any individual latent variable could induce excessive correlations between latent variables, as we observed in Step 1; therefore, the PAL-II Alphabet Writing indicator was dropped from the Fine-Motor latent variable.

The revised model was fit separately to the grade 1 and grade 2 datasets. Once again, error messages indicated that correlations between latent variables exceeded the value of 1. The problem was focused on the Working Memory latent variable. In the second grade data, in tandem with the same error encountered in the first grade data, an additional error message indicated that the residual covariance matrix for the indicator variables was not positively defined, with the estimated residual variance of the PAL-II Finger Sense Succession non-dominant hand variable being less than 0.

Table 2 Variable intercorrelations at grade 1

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) PAL-II Finger Sense Succession Dominant Hand Scaled Score	1.000						
(2) PAL-II: Finger Sense Succession Nondominant Hand Scaled Score	0.646	1.000					
(3) PAL-II: Alphabet Writing Scaled Score	0.148	0.093	1.000				
(4) PAL-II: Word Choice Accuracy Scaled Score	0.054	−0.003	0.303	1.000			
(5) PAL-II: Letters Scaled Score	0.099	0.092	0.289	0.376	1.000		
(6) PAL-II: Phonemes Scaled Score	−0.080	−0.103	0.367	0.450	0.444	1.000	
(7) PAL-II: Digits *Z* Score	0.224	−0.500	0.409	−0.013		0.716	1.000
(8) PPVT-4: Standard Score	0.048	−0.078	0.243	0.242	0.325		0.988
(9) CREVT-2: Receptive Vocabulary Score	−0.053	−0.130	0.155	0.098	0.112	0.392	−0.017
(10) VIGIL Omissions—total	−0.032	−0.030	0.002	−0.113	−0.178	−0.250	−0.720
(11) VIGIL Commissions—total	−0.039	−0.021	−0.151	−0.119	−0.151	−0.071	0.191
(12) WJ-III: Planning Age-Based Standard Score	0.057	0.024	0.099	0.134	0.254	0.341	0.396
(13) WJ-III: Retrieval Fluency Age-Based Standard Score	0.155	0.054	0.269	0.160	0.239	0.347	0.912
(14) WRAML-2: Picture Memory Standard Score	0.091	−0.063	0.187	0.172	0.188	0.264	−0.195
(15) WRAML-2: Story Memory Standard Score	0.064	−0.023	0.308	0.228	0.292	0.423	0.820
(16) WISC-IV Digit Span Forward Scaled Score	0.081	0.067	0.169	0.145	0.259	0.450	−0.698
(17) WISC-IV Digit Span Forward Backward Scaled Score	0.064	0.152	0.247	0.411	0.318	0.435	−0.698
(18) WISC-IV Spatial Span Forward Scaled Score	0.081	0.075	0.262	0.112	0.194	0.203	−0.134
(19) WISC-IV Spatial Span Forward Backward Scaled Score	0.245	0.184	0.268	0.234	0.286	0.321	0.638
(20) WRAML-2: Picture Memory Standard Score	0.067	0.138	0.060	0.013	0.017	−0.161	0.324
(21) WRAML-2: Story Memory Standard Score	0.063	0.053	0.221	0.104	0.212	0.311	−0.029
(22) WIAT-II: Written Expression Standard Score (Age-based)	0.122	0.062	0.820	0.333	0.338	0.500	0.337
(23) WIAT-II: Spelling Standard Score (Age Based)	0.029	0.000	0.401	0.426	0.436	0.741	0.691
(24) CTOPP Nonword Repetition Standard Score	0.032	−0.082	0.107	0.230	0.225		0.144
(25) CTOPP Elision Standard Score	0.084	−0.031	0.348	0.295	0.232		0.911
(26) WorkingMem	0.058	0.015	0.159	0.274	0.273	0.533	0.090
(27) Receptivelang	0.010	−0.075	0.261	0.201	0.275	0.392	0.561
(28) Phonemes	−0.019	−0.074	0.290	0.330	0.300	0.848	0.448

Table 2 continued

Variable	(8)	(9)	(10)	(11)	(12)	(13)	(14)
(8) PPVT-4: Standard Score	1.000						
(9) CREVT-2: Receptive Vocabulary Score		1.000					
(10) VIGIL omissions—total	−0.089	0.029	1.000				
(11) VIGIL commissions—total	−0.281	−0.068	−0.282	1.000			
(12) WJ-III: Planning Age-Based Standard Score	0.305	0.229	−0.060	−0.073	1.000		
(13) WJ-III: Retrieval Fluency Age-Based Standard Score	0.358	0.293	−0.083	−0.042	0.244	1.000	
(14) WRAML-2: Picture Memory Standard Score	0.362	0.223	−0.098	−0.207	0.134	0.269	1.000
(15) WRAML-2: Story Memory Standard Score	0.525	0.404	−0.005	−0.288	0.320	0.343	0.306
(16) WISC-IV Digit Span Forward Scaled Score		0.206	−0.026	−0.155	0.269	0.292	0.206
(17) WISC-IV Digit Span Forward Backward Scaled Score		0.162	−0.178	−0.247	0.277	0.268	0.278
(18) WISC-IV Spatial Span Forward Scaled Score	0.163	0.175	−0.038	−0.178	0.199	0.213	0.145
(19) WISC-IV Spatial Span Forward Backward Scaled Score	0.358	0.085	−0.097	−0.190	0.399	0.242	0.191
(20) WRAML-2: Picture Memory Standard Score	0.016	0.039	0.014	0.100	0.004	0.022	0.002
(21) WRAML-2: Story Memory Standard Score	0.462	0.334	−0.125	−0.108	0.199	0.385	0.319
(22) WIAT-II: Written Expression Standard Score (Age-based)	0.331	0.289	0.035	−0.228	0.232	0.354	0.271
(23) WIAT-II: Spelling Standard Score (Age Based)	0.388	0.357	−0.046	−0.119	0.318	0.376	0.321
(24) CTOPP Nonword Repetition Standard Score	0.207		0.121	−0.170	0.226	0.365	0.238
(25) CTOPP Elision Standard Score	0.415		−0.042	−0.214	0.349	0.299	0.267
(26) Receptivelang	1.000	1.000	−0.016	−0.180	0.262	0.330	0.274
(27) Phonemes	0.415	0.396	−0.095	−0.148	0.353	0.358	0.282

Variable	(15)	(16)	(17)	(18)	(19)	(20)	(21)
(15) WRAML-2: Story Memory Standard Score	1.000						
(16) WISC-IV Digit Span Forward Scaled Score	0.389	1.000					
(17) WISC-IV Digit Span Forward Backward Scaled Score	0.279	0.377	1.000				
(18) WISC-IV Spatial Span Forward Scaled Score	0.188	0.213	0.396	1.000			
(19) WISC-IV Spatial Span Forward Backward Scaled Score	0.288	0.269	0.445	0.475	1.000		

Table 2 continued

Variable	(8)	(9)	(10)	(11)	(12)	(13)	(14)
(20) WRAML-2: Picture Memory Standard Score	0.075	0.019	−0.110	0.069	0.043	1.000	
(21) WRAML-2: Story Memory Standard Score	0.573	0.328	0.190	0.166	0.176	0.018	1.000
(22) WIAT-II: Written Expression Standard Score (Age-based)	0.436	0.404	0.395	0.372	0.371	0.042	0.349
(23) WIAT-II: Spelling Standard Score (Age Based)	0.408	0.434	0.558	0.353	0.392	−0.075	0.317
(24) CTOPP Nonword Repetition Standard Score	0.264			0.247	0.198	0.058	0.314
(25) CTOPP Elision Standard Score	0.388			0.206	0.358	−0.066	0.360
(26) WorkingMem	0.326	0.830	0.830	0.302	0.302	0.002	0.309
(27) Receptivelang	0.460	0.206	0.162	0.173	0.234	0.084	0.374
(28) Phonemes	0.400	0.541	0.494	0.203	0.346	−0.059	0.364

Variable	(22)	(23)	(24)	(25)	(26)	(27)	(28)
(22) WIAT-II: Written Expression Standard Score (Age-based)	1.000						
(23) WIAT-II: Spelling Standard Score (Age Based)	0.637	1.000					
(24) CTOPP Nonword Repetition Standard Score	0.290	0.403	1.000				
(25) CTOPP Elision Standard Score	0.521	0.625	0.329	1.000			
(26) WorkingMem	0.367	0.491	1.000	0.329	1.00		
(27) Receptivelang	0.341	0.372	0.207	0.415	0.239	1.00	
(28) Phonemes	0.474	0.657	0.329	1.000	0.284	0.238	1.00

Variable	(29)	(30)	(31)
(29) WorkingMem	1.000		
(30) Receptivelang	0.206	1.000	
(31) Phonemes	0.452	0.395	1.00

All scores converted to *z*-scores prior to analysis. In order to address missing data on some assessments, the following new variables were created: WorkMem = CTOPP Nonword Repetition for cohort 1 in grade 1 or the mean of WISC Digit Span Forward and Backward otherwise. ReceptiveLang = PPVT SS for cohort 1 in grade 1, CREVT RV score otherwise. Phonemes = CTOPP Elision for cohort 1 in grade 1, mean of PAL Syllables and PAL Phonemes otherwise. When PAL Letters was missing, it was replaced by PAL Digits. All scores were converted to z-scores before creating ReceptiveLang and Phonemes variables

Step 3

Based on the results of Step 2, the Attention/Executive Functions and Working Memory latent variables were consolidated into a single factor given their purported association via the central executive as defined by Baddeley's (2007) working memory model. The error variance of the PAL-II Finger Succession non-dominant

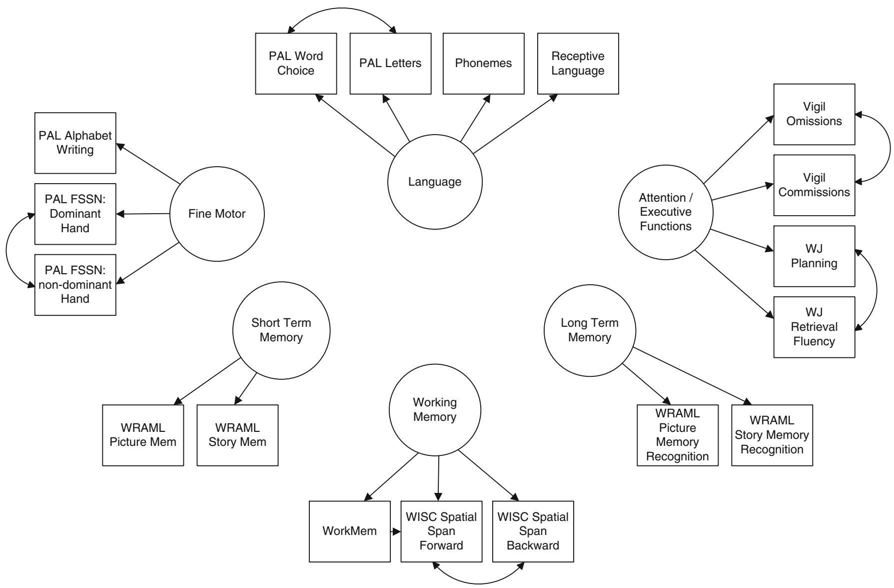

Fig. 1 Initial model for the neuropsychological underpinnings of early writing skills. *Note*: Correlations between latent variables omitted for clarity. All possible latent variable correlations were freely estimated. WorkMem is CTOPP NR at grade 1 (for cohort 1) and mean of WISC Digit Span forward and backward otherwise. Receptive Language is the PPVT-4 at grade 1 and the CREVT receptive vocabulary score at grade 2

hand variable was fixed to 0 to address the estimation error noted in Step 2. The model converged without error in the first and second grade datasets. Model fit for first grade was excellent, χ^2 (82) = 95.38, $p < 0.15$, $CFI = 0.98$, $RMSEA = 0.03$, 90% CI = [0.00, 0.05], $SRMR = 0.05$. Model fit for second grade was moderately poor, χ^2 (82) = 139.07, $p < 0.001$, $CFI = 0.92$, $RMSEA = 0.06$, 90% CI = [0.04, 0.08], $SRMR = 0.05$. Examination of the modification indices for the second grade model indicated that the Language latent variable was highly correlated with the Fine-Motor and Long-Term Memory latent variables. Furthermore, the Attention/Executive Function, Language, and Long-Term Memory latent variables were mutually correlated at $r = 0.90$ or higher for both grades.

Step 4

Based on the results of Step 3, several modifications were made to the model. The receptive language and phonemes indicator variables were dropped from the Language latent construct in order to reduce the correlations between language and the remaining latent variables. Furthermore, the Long-Term Memory latent variable was consolidated into the Attention/Executive Functions latent variable given the regulatory demands on information retrieval. Following these steps, a revised measurement model, displayed in Fig. 2, was identified that fit the first and second grade data quite well. Model fit for first grade was excellent, χ^2 (59) = 67.66, $p < 0.21$, $CFI = 0.98$, $RMSEA = 0.03$, 90% CI = [0.00, 0.05], $SRMR = 0.05$.

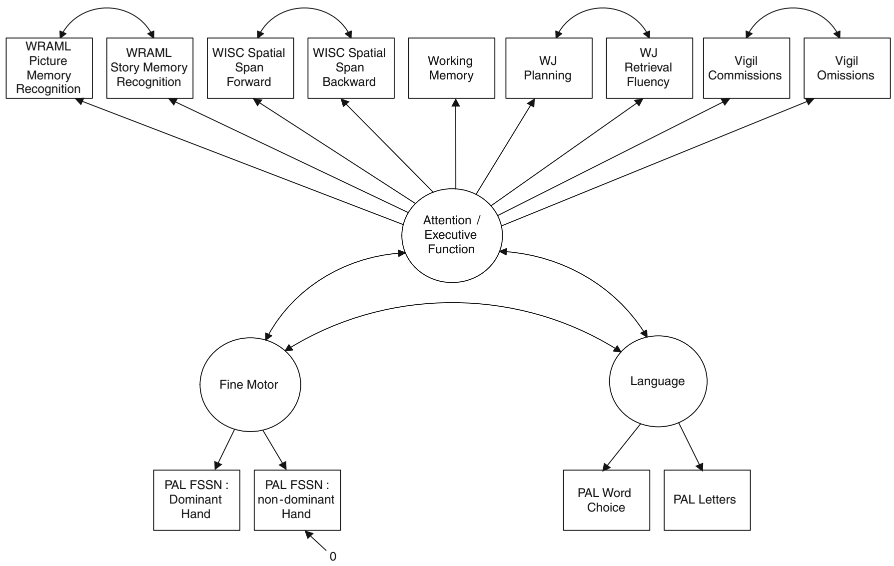

Fig. 2 Derived model for the neuropsychological underpinnings of early writing skills. *Note*: Working Memory is CTOPP NR at grade 1 (for cohort 1) and mean of WISC Digit Span forward and backward otherwise. Receptive Language is the PPVT-4 at grade 1 and the CREVT receptive vocabulary score at grade 2

Model fit for second grade was good, χ^2 (59) = 80.87, $p < 0.03$, $CFI = 0.95$, $RMSEA = 0.04$, 90% CI = [0.01, 0.07], $SRMR = 0.05$.

Analysis of longitudinal measurement invariance

The next set of analyses addressed the second research question and examined the measurement invariance of the derived model (Fig. 2) across grades. Measurement invariance refers to the stability of measurement across groups or over time (Vandenberg & Lance, 2000). Measurement invariance of the neuropsychological model across time points must be established before any meaningful longitudinal comparisons of the model's predictive power can be performed. In this case, because our ultimate goal is to investigate potential differences in predictive power of the model's latent variables on writing outcomes, it must first be established that the measurement model summarizes the relations between variables equivalently for first and second graders. If invariance cannot be established, observed differences in predictive power could be an artifact of measurement instability. For the purposes of the analysis in this study, only invariance of factor loadings was required.

The procedure for assessing measurement invariance relies on the testing of a sequence of progressively more constrained nested measurement models against one another (Vandenberg & Lance, 2000). The fit of subsequent models can be tested via chi square difference tests because the models are nested. This procedure takes advantage of the helpful fact that differences in chi square statistics are also distributed as chi square (Thompson & Green, 2006).

Table 3 Results of measurement invariance analysis

Step	Model	χ^2	*df*	χ^2 Difference	DF difference	*p* Difference
1	Baseline	147.19	117			
2	Loadings	156.78	129	9.60	12	0.65
3	Intercepts	156.81	142	0.03	13	>.999
4	Error covariances	169.85	146	13.05	4	0.01*
5	Factor covariances	172.08	149	2.22	3	0.53
6	Residuals	176.89	162	4.82	13	0.98

* $p < 0.01$

The first step involved fitting a multiple-group confirmatory factor analysis model that is as unconstrained as possible. That is, the factor loadings, intercepts, error covariances, factor covariances, and indicator residual variances were free to take on unique values for each grade. The factor variances and means were fixed to zero in each group. The fit statistics for this step served as a baseline. Each successive constraint applied to the model will cause the fit to worsen, according to the chi square test, but the amount of "worsening" can be tested for statistical significance. If the model fit does not become significantly worse at each stage of additional constraint, there is evidence for measurement invariance.

In the second step, values were constrained consecutively to take on equal values in the two grades, factor loadings, indicator intercepts, error covariances (i.e., the curved arrows in Fig. 2), the covariances between latent variables, and finally the indicator residual variances. Table 3 summarizes the results of the measurement invariance analysis.

Results of these procedures provided strong evidence of measurement invariance for loadings ($p < 0.65$) and intercepts ($p > 0.999$), indicating that the relationships between indicators and factors were the same for first graders and second graders. The equality of intercepts indicated that the latent variable scales were equal across grades. This last step would have been important if tests of latent means were planned; however, those tests were not of interest to this study. There is evidence that invariance was violated in step four, when error covariances among indicators were held to equality, but this type of invariance is not required to address our specific study questions. Furthermore, there was no evidence of a violation of measurement invariance for factor covariances, indicating that the latent variables had equal intercorrelations in first and second grade, nor was invariance violated for residuals, indicating that the quality of measurement of the indicators for their latent variables did not change over time. The standardized loadings from the last step of the invariance analysis are presented in Table 4. The latent variable intercorrelation matrix is provided in Table 5.

Analysis of longitudinal stability of relationships between neuropsychological components and outcomes

Having established adequate measurement invariance for the first and second grade data, the next step of the analysis examined the third research question: the stability

Table 4 Standardized factor loadings for final step of measurement invariance model

Constructs	Indicator	Standardized loading[a]
Fine-motor	Finger sense succession dominant	0.80
	Finger sense succession nondominant	0.84
Language	RAN letters/digits	0.67
	Word choice	0.57
Attention/executive function	Spatial span forward	0.40
	Spatial span backward	0.56
	Retrieval fluency	0.59
	Planning	0.52
	Working memory[b]	0.62
	Commission errors	−.27
	Omission errors	−.25
	Story memory recognition	0.56
	Picture memory recognition	0.38

[a] All loadings statistically significant at $p < 0.001$

[b] Working memory is the summation of the CTOPP Nonword Repetition at time 1 (cohort 1) and mean of WISC-IV PI Digit Span Forward and Backward for all other assessment points

Table 5 Correlations between latent variable for final step of measurement invariance model

Constructs	FM	L	A/EF
Fine-Motor (FM)	1.00		
Language (L)	0.22	1.00	
Attention/executive function (A/EF)	0.18	0.70	1.00

All correlations are statistically significant at $p < 0.01$

WE written expression, *FM* fine motor, *L* Language

of the strength of relationships between the latent variables from the overall derived empirical model, and writing tasks at first and second grade. In particular, would there be differential relationships of the derived latent traits with the designated writing outcomes. Beginning with the measurement model obtained during the last step of the invariance analysis, two new models were created so as to include the writing outcomes of interest: WIAT-II Written Expression and WIAT-II Spelling. Given the high correlations between the latent variables (e.g., $r = 0.70$ for Language with Attention/Executive Function), there was concern about suppressor effects caused by excessive collinearity between the latent variables. Therefore, rather than estimating structural paths from each latent variable to each outcome, as would be customary, covariances between the latent variables and outcomes were estimated. By doing this, the "statistical control" properties of multiple regression were not invoked, where each variable's regression coefficient is interpreted as the residual relation between the variable and the outcome with the influence of other predictors partialed out. Instead, the total independent relation between each variable and the outcome were estimated, as if the other predictors were not included in the model, thereby avoiding potential problems with collinearity.

In order to test the developmental notion, that fine-motor skill would be more highly related to outcomes for first graders than the other latent traits, and perhaps less so for second graders, a procedure similar to the one that was used to investigate measurement invariance in the neuropsychological model was used. First, a model was estimated where the measurement model was held invariant across grades, but the strength of the covariances between the latent variables and the outcomes were free to take on unique values in first grade and second grade. The model fit for this step was excellent, χ^2 (189) = 233.16, $p < 0.02$, $CFI = 0.97$, $RMSEA = 0.03$, 90% CI = [0.02, 0.05], $SRMR = 0.06$. The correlations between WIAT-II Written Expression and Fine-Motor were weak at grades 1 ($r = 0.12$) and 2 ($r = 0.06$); the correlations between WIAT-II Written Expression and Language were moderate at grades 1 ($r = 0.56$) and 2 ($r = 0.67$); and the correlations between WIAT-II Written Expression and Attention/Executive Functions were moderate at grades 1 ($r = 0.65$) and 2 ($r = 0.61$). For the WIAT-II Spelling, the correlations with Fine-Motor at grades 1 and 2, respectively, were 0.03 and 0.003; with language at grades 1 and 2 respectively, were 0.70 and 0.74; and with Attention/Executive Functions at grades 1 and 2, respectively, were 0.72 and 0.58. These differences are subjected to statistical test in the following step.

In Step 2, the covariances between the latent variables and the outcome were held to equality in first and second grade. If the differential theoretical notion is correct, holding the parameters to equality should result in significantly reduced model fit. Because the two models are nested, a chi square difference test can be conducted, statistically testing the difference in fit. This amounts to a joint test of equality for all the covariances between the latent variables and the outcome. The model fit for this step was excellent, χ^2 (195) = 238.77, $p < 0.02$, $CFI = 0.97$, $RMSEA = 0.03$, 90% CI = [0.02, 0.05], $SRMR = 0.06$. The chi square difference test was non-significant, $\chi^2(6) = 5.61, p < 0.47$; therefore, there were no statistically significant differences in the correlations between the latent variables and outcomes over time. Consequently, the theoretical notion pertaining to differential impact of the latent traits on written expression at different time points was not supported; however, these findings only apply to children in first and second grades, with perhaps a different pattern of results being obtained with older students. Specifically, fine-motor did not have a larger influence for first graders than second graders. It is important to note, however, that the relationship between written output and the latent traits of language and attention/executive functions appeared to be much stronger than for the fine-motor domain (e.g., fine-motor & spelling $r = 0.003$ versus language and spelling $r = 0.74$ for 2nd grade).

Analysis of cross-sectional and longitudinal predictive power of the neuropsychological model

In the final phase of the analysis, the cross-sectional and predictive relations between the latent variables and outcomes were examined. For this analysis we conducted a series of three models for each outcome (i.e., WIAT-II Written Expression and WIAT-II Spelling). The first model was cross-sectional for first grade. The second model was cross-sectional for second grade, and the third model allowed first grade neuropsychological components to predict second grade

Table 6 Predictive model results for WIAT-II written expression outcome

Latent variable	Model 1: concurrent grade 1			Model 2: concurrent grade 2			Model 3: longitudinal		
	B (SE)	*p*	R^2	*B* (SE)	*p*	R^2	*B* (SE)	*p*	R^2
Fine motor	0.02 (.06)	0.75		−0.10 (.07)	0.16		−0.03 (.06)	0.69	
Language	0.15 (.26)	0.57		0.50 (0.15)	0.001		0.52 (.35)	0.14	
Attention/executive (model)	0.53 (.24)	0.03	0.44	0.28 (.13)	0.03	0.48	0.23 (.34)	0.51	0.51

Regression coefficients, standard errors, and *p* values are unreliable due to excessive collinearity

Table 7 Predictive model results for WIAT-II Spelling outcome

Latent Variable	Model 1: concurrent grade 1			Model 2: concurrent grade 2			Model 3: longitudinal		
	B (SE)	*p*	R^2	*B* (SE)	*p*	R^2	*B* (SE)	*p*	R^2
Fine motor	−0.06 (.064)	0.06		−0.12 (.07)	0.09		−0.09 (.07)	0.07	
Language	0.60 (.345)	0.08		0.58 (.13)	<.001		0.63 (.35)	0.08	
Attention/executive (model)	0.22 (.340)	0.51	0.63	0.23 (.12)	0.07	0.52	0.13 (.35)	0.71	0.55

Regression coefficients, standard errors, and *p* values are unreliable due to excessive collinearity

outcomes. Although we remained concerned about collinearity, our main interest was to examine the total variance explained jointly by the Fine-Motor, Language, and Attention/Executive Function variables. The regression weights for each latent variable, though reported, should be interpreted with extreme caution due to the collinearity between Language and Attention/Executive Function. Results for the WIAT-II Written Expression and Spelling outcomes are reported in Tables 6 and 7, respectively. For WIAT-II Written Expression, the latent variable model accounted for approximately 44 and 48% of the variance for the concurrent relationships at grades 1 and 2, respectively, and for over 51% of the variance for the prediction of second grade WIAT-II Written Expression from the grade 1 latent trait model. Therefore, nearly half of the difference between students written expression abilities can be explained by fine-motor, language, and executive functioning skills. As well, over half of the difference between second graders written expression abilities can be explained by their first grade fine-motor, language and executive functioning skills. For WIAT-II Spelling, the latent variable model accounted for approximately 63 and 52% of the variance for the concurrent relationships at grades 1 and 2, respectively, and for nearly 55% of the variance for the prediction of second grade WIAT-II Spelling from the grade 1 latent trait model. Therefore, over half of the difference between students spelling abilities can be explained by fine-motor, language, and executive functioning skills. As well, over half of the difference between second graders spelling abilities can be explained by their first grade fine-motor, language and executive functioning skills.

Discussion

This study addressed several key questions related to the neuropsychological contributors to early written language. For the first question, we examined the putative components of a neuropsychological model that would be associated with written language in young elementary school children, with the specific neuropsychological components being ascertained from both the theoretical and empirical literature. The proposed model included measures assessing the key neuropsychological domains of fine-motor control, language-related, short-term memory, long-term memory, working memory, and attention/executive functions. After several iterations of the data where tasks and domains were eliminated or re-positioned, a parsimonious empirical model emerged that included three key latent traits: Fine-Motor, Language-Related, and Attention/Executive Functions.

The composition of the Fine-Motor latent trait included a fine-motor control task that forms foundational skills for the graphomotor component of written expression. The composition of the Language-Related latent trait included a rapid letter naming task and a word orthographic coding task, which relates to writing fluency and spelling skills. The rapid letter naming task has been strongly linked to reading problems (Lervag & Hulme, 2009), but its inclusion with orthographic coding in this model also indicates its importance to written expression. In particular, its loading on the Language-Related latent trait with the orthographic coding task may be related to issues of processing speed at this developmental level (Waber et al., 2001). Finally, the Attention/Executive Function latent trait provided for several key dimensions important for written expression; namely, attention, inhibitory control, planning, verbal fluency, both verbal and visual working memory, and long-term retrieval. Taken together, these three latent traits capture many of the aspects of the available theoretical models, and they support the importance of these functions when studied individually in empirically-based studies (e.g., McCutchen, 2000). We recognize that the labels for these latent traits do not encompass the full range of abilities represented by the functional areas of fine-motor, language, and attention/executive functions (e.g., we only have word indicators in the language latent trait), but there appears to be inherent construct validity to this model when compared to the available literature, particularly with respect to the functions that have been linked to early written language.

However, there was significant collinearity in some of our measures that necessitated the removal of tasks assessing short-term memory, receptive vocabulary, and phonological processing. Although it is recognized that these functions have been deemed important to the development of written language (Abbott & Berninger, 1993), several of the domains selected a priori did not fit into the final model and were not independent of the three latent traits that survived the empirical scrutiny. For example, the variance from the phonological processing task may have been subsumed by rapid naming task at this age level, but may dissociate as children age. In general, the removal of these constructs does not necessarily negate their importance to the development of written language in first and second grade, but their removal does raise questions about how such functions relate to other factors in a developmental model of written expression. Although we anticipated and received significant challenges related to collinearity of our measures, the resulting model represents one of the first attempts to develop an empirical foundation for the measurement of the neuropsychological functions in early writing development. Alternatively, as noted earlier, perhaps these functions will begin to statistically separate with increasing age and concomitant neurological maturity.

These findings do implicate attention/executive functions as more important than previously thought to the early development of written language skills. This observation is consistent with findings by Graham (1997), Hooper et al. (2002), and Altemeier, Jones, Abbott, and Berninger (2006) who all documented significant executive deficits in older children with writing problems. These findings also were consistent with earlier efforts examining working memory (Kellogg, 1999; McCutchen, 2000; Swanson & Berninger, 1996) and attention (Chenault, Thomson, Abbott, & Berninger, 2006) wherein children with writing problems tended to experience difficulties in these neuropsychological domains. More generally, the present results underscore the importance of early regulatory functions, including verbal and nonverbal working memory, attention, planning, and rapid retrieval for success in both writing and spelling.

For our second question, the results also indicated that the model was stable from first to second grade. The fit indices for the measurement invariance estimates were satisfactory, thus requiring no change in the composition of the model across grades. Relative stability in the components of the model from first to second grade was not surprising given the proximity in the time of the measures. To date, we are not aware of any empirical derived models of the neuropsychological components of writing that have been shown to be relatively stable over time. The importance of this finding is that change over time can be studied using the same model, and the impact of model variance in the change in written expression will be significantly lessened; however, it will be critical to see if this model remains stable as students enter the middle elementary school years.

For the third question, we investigated whether the strength of association between the derived latent traits and the writing outcomes would be constant over time, or whether any of the functions (e.g., fine-motor) would fade in importance relative to time as well as the other latent traits. Our findings indicated that the strength of associations from grade 1 to grade 2 did not change over time. Even though these findings were not in line with predictions from the Not-So-Simple View of Writing theoretical model (i.e., fine-motor and language variables would be more predictive of writing than attention/executive functions at this developmental time point), it may be that the relationships of fine-motor functions with later writing skills emerge earlier with respect to their impact on written language, and that functions such as language and written language actually carry more weight in the development of early writing skills.

Though we did not find any significant differences within the three latent traits moving from grade 1 to grade 2, we did find that the Language-Related and Attention/Executive Function traits were more highly associated with written expression and spelling at both grades 1 and 2 than Fine-Motor speed. In fact, the relationships between Language-Related and Attention/Executive Functions with written expression and spelling were moderate to large in magnitude across both first and second grades, accounting for upwards to 45% of the variance in written expression (Language-Related with Written Expression at grade 2) and 55% of the variance in spelling (Language with Spelling at grade 2). In contrast, the relationships between the Fine-Motor latent trait and written expression and spelling were quite small and accounted for negligible amounts of the variance. These findings suggest that language-related functions and attention/executive abilities may have a larger influence on written expression and spelling during the earlier elementary school years than previously imagined, and their inclusion in an empirically-based measurement model may hold significant value for identifying students at-risk for later writing disabilities.

These findings would be consistent with recent work by Dockrell, Lindsay, Connelly, and Mackie (2007), Puranik, Lombardino, and Altmann (2007), and Fey, Catts, Proctor-Williams, Tomblin, and Zhang (2004) who noted that children with specific language impairments and/or dyslexia will have constraints placed on their written output by their language difficulties, and that these functions can be predictive of later writing problems. Indeed, rapid naming has been deemed as placing constraints on early reading fluency (Lervag & Hulme, 2009) and, given its inclusion in our model, it also may place constraints on written output. Similarly, the early involvement of executive functions in written output suggests that young elementary school children may be capable of moving more rapidly from "knowledge-telling" to "knowledge transformation" as described by Bereiter and Scardamalia (1987). Here, the earlier involvement of more complex problem solving capabilities provides a vehicle for this movement and, when the executive processes are weak or impaired, the young writer may be left at the knowledge-telling stage for a longer time period and likely will require intervention.

For the fourth question, we endeavored to examine whether the derived empirical model of neuropsychological functions would show significant concurrent and predictive relationships with written expression. Our findings did indicate that the overall model was highly correlated with both written expression and spelling at grades 1 and 2, with large amounts of variance in these outcomes being explained by the derived neuropsychological model. Of particular interest here was the predictive relationship involving the latent traits in first grade, and later writing and spelling in second grade. Although only one year removed, the first grade latent trait model accounted for approximately 52% of the variance for second grade written expression, and nearly 55% of the variance for second grade spelling. As such, the derived model appears to hold significant promise for predicting later performance in two key components of writing in the early elementary school years. How these predictive relationships will evolve as the children age will continue to be examined as our sample moves into third and fourth grades.

Limitations

There are several limitations that require mentioning. First, one criterion for selection of the measures related to the strength of their psychometric properties;

however, the measures we selected may not have worked as expected with our sample, and other measures may have produced a different empirical model. For example, utilization of different types of working memory tasks, such as an n-back task or a sentence repetition task, may have permitted the existence of a separate working memory latent trait, and this will require ongoing scientific scrutiny.

Second, it is important to note that we did not include any covariates in the model. Variables such as IQ, race, gender, socioeconomic status, and student–teacher relationship could have modified the model such that different predictive patterns would have been uncovered. For example, in conjunction with the evolving literature on the reading-writing connection (Fitzgerald & Shanahan, 2000; Nelson & Calfee, 1998), does being able to read in first grade predict written expression and spelling in the second grade? Cross-sectional, longitudinal, and instructional studies support reading, writing, and spelling as integrated processes (Bear, Invernizzi, Templeton, & Johnston, 2003; Moats, 2000), although their functional systems are deemed to be separate (Berninger & Richards, 2002). Snow, Burns, and Griffin (1998), the National Reading Panel (2000), and others (e.g., Mermelstein, 2006; Vellutino, Fletcher, Snowling, & Scanlon, 2004) support the notion that successful reading requires skills in phonological awareness, phonics, fluency, vocabulary, and comprehension, in conjunction with stimulating authentic and meaningful reading and writing experiences, and these skills and experiences also likely affect the development of written expression. Given these assertions, would our phonological processing and receptive vocabulary variables perform differently if reading was included in the model? Even though the primary purpose of this paper was to examine the neuropsychological contributors to written expression, the inclusion of key covariates in future studies will be important.

Finally, it is important to emphasize that only the first two grades of elementary school were included in this study, but the longitudinal design will enable us to examine the model for possible changes in composition and stability as our sample ages into the middle elementary school years. In this regard, the writing outcomes for this study were the WIAT-II Written Expression and Spelling subtests. Although these tasks were examined separately, neither one provides a sample of narrative expression. The Written Expression subtests does provide for important emergent components of narrative expression (i.e., timed alphabet writing, written word fluency, sentence combining), but a narrative writing sample is not produced on the WIAT-II until grade 3. It will be important to determine if our neuropsychological model continues to be strongly predictive of written outcomes as the writing product shifts to a text composing writing sample in the third grade.

Conclusions and future directions

The results of this study provided some of the first empirical data examining a large array of neuropsychological components that have been theoretically or empirically linked to written expression in children. As such, the derived neuropsychological model provides an initial evidence-based effort to define specific neuropsychological variables for inclusion into a writing assessment for early elementary school children, with key emphasis on language and attention/executive functions as potential early predictors of later writing and spelling functioning. Given the demographic composition of our sample, we do suspect that our findings will generalize to most regular education classrooms, although how issues of race, gender, and socioeconomic status will affect this model remains to be determined. How this model will change as the children move into the upper elementary grades will continue to be examined, particularly with respect to whether this empirically-based model remains stable over time, the shifting of measurement with more mature and refined neuropsychological abilities, how the model will be affected by participants' exposure to varied instructional approaches and materials, and how it predicts more specific elements of narrative writing.

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