Developmental skills related to writing and reading acquisition in the intermediate grades

Shared and unique functional systems

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ABSTRACT: Multiple measures of the fine motor system, the orthographic system, the phonological system, the working memory system, the verbal intelligence system, the writing system, and the reading system were administered to 300 students in grades 4, 5, and 6. Results showed that the writing system and the reading system share many of the same orthographic, phonological, and working memory sub-processes but the *patterns* of concurrent relation between these sub-processes and writing and between these subprocesses and reading differ. These results are consistent with the view that writing and reading draw upon the same as well as unique cognitive systems.

KEY WORDS: Orthography, Phonology, Reading acquisition, Reading disabilities, Working memory, Writing acquisition, Writing disabilities

INTRODUCTION

The notion that functional systems of the working brain are constructed from and/or draw upon other functional systems is not a new one; however, this concept is just beginning to influence mainstream thinking about language development. Luria (1973) pointed out that (a) the same brain structure can participate in more than one functional system, (b) that the same functional system can draw upon multiple local structures distributed throughout the brain, and (c) that functional systems can reorganize throughout development. Ellis (1985, 1987) applied a similar notion to writing and reading. He proposed a cognitive neuropsychological model for writing and reading acquisition in which writing and reading modules are not preformed in the infant brain waiting to be elicited by a certain kind of environmental stimulation at a particular point in the maturational table. Rather, the writing and reading systems are constructed from other cognitive capabilities, such as the visual, phonological, and semantic systems. Thus, developmental writing and reading disorders may be the consequence of disorders in these cognitive systems from which writing and reading emerge. Ellis' model has influenced other reading theorists such as Wolf (1991), who traces some reading disorders to deficits in the oral language system related to naming. In a

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similar vein, current theory in oral language acquisition emphasizes that language is constructed from and draws upon non-linguistic systems (e.g., attentional, perceptual, cognitive, etc.; see Bates 1993).

It follows that writing and reading may share some of the same cognitive subsystems, but that writing may also draw upon cognitive subsystems unique to writing, and reading may also draw upon cognitive subsystems unique to reading. Shanahan (1984) demonstrated that in second and fifth graders the variance explained in reading by writing or in writing by reading never exceeded 45%. This finding is consistent with the claim that writing and reading share common as well as unique variance. Shanahan and Lomax (1986) examined three alternative models of the reading-writing relationship. At the second grade level the interactive model, in which reading affects writing and writing affects reading, fit the data better than the 'reading affects writing' model. At both grade levels the interactive model fit the data better than the 'writing affects reading' model. These findings are consistent with the dynamic view that the reading and writing systems interact with one another bidirectionally and are not modular, non-interacting systems or unidirectional, interactive systems. Juel, Griffith and Gough (1986) showed in a longitudinal study of first and second graders that the reading-writing connection was stronger at the word than text level: The relationship between word recognition and spelling was stronger than the relationship between reading comprehension and written composition.

The major goals of the research reported here, which was focused on developmental skills related to functional writing and reading systems in the intermediate grades, were threefold. First, to determine which developmental skills might be contributing to writing and reading acquisition, we evaluated whether specific developmental skills were correlated with component writing and reading skills. Selection of developmental skills to evaluate was based on our prior work with primary grade children and theoretical considerations, as discussed below. In cases where a developmental skill has concurrent validity for predicting achievement in a specific writing or reading skill, inclusion of that developmental skill in an assessment battery for diagnosing writing or reading disabilities is warranted. We refer to these skills as the developmental skills children bring to the task of learning to write and read because they do not cause learning independent of instruction and the constructive processes and strategies of the learner but may constrain the ease of learning (Berninger 1993).

Second, to determine whether these developmental skills may be contributing uniquely to writing or reading over and beyond the shared variance reflected in the zero-order correlations, we entered certain developmental skills into multiple regressions. Decisions as to which skills to enter depended on the strength of the zero-order correlations in the intermediate grade sample, prior work with a primary grade sample, and theoretical considerations, as explained in the results section.

Third, to draw conclusions, based on individual differences in level to which skills are developed, as to whether the functional reading and writing skills draw upon common or unique skills, we compared the correlation and multiple regression results for specific developmental skills with specific reading skills and writing skills. To the extent that the concurrent relationships between developmental skills and reading and writing skills were the same, we concluded that reading and writing draw upon common skills. To the extent that the concurrent relationships were different, we concluded that the reading and writing skills draw upon unique, that is, different skills.

Selection of the developmental skills for the intermediate grade battery was based partly on the results of a similar multivariate cross-sectional study of 300 primary grade children (Berninger, Yates, Cartwright, Rutberg, Remy & Abbott 1992). The following developmental skills were related to writing and/or reading in first, second, and third graders: grapho-motor (finger function), orthographic coding, orthographic-motor integration, phonological coding, and verbal intelligence.

At a developmental stage when children show tremendous variation in neuromotor maturation (Wolff, Gunnoe & Cohen 1983), speed of sequential finger movements and total accuracy on finger lifting, spreading, localization, and recognition tasks had concurrent validity for predicting fluency of handwriting (number of words correctly copied within a constant time interval) and fluency of composition (number of written words generated within a constant time interval) (Berninger & Rutberg 1992). Orthographic coding, defined as rapid representation of printed words in memory and analysis of whole word, letter, or letter cluster units, had concurrent validity for predicting handwriting fluency and compositional fluency (Berninger, Yates et al. 1992), and for predicting achievement in reading real words and nonwords and spelling real words (Berninger & Abbott 1992). Orthographic-motor integration, defined as the rapid automatic production of the ordered series of alphabet symbols, was the best predictor of component writing skills in general in primary grade children (Berninger & Rutberg 1992; Berninger, Yates et al. 1992). Phonological coding, defined as segmenting spoken words into component syllables or phonemes, had concurrent validity for predicting achievement in reading real words and nonwords and spelling real words (Berninger & Abbott 1992). Verbal intelligence was related to spelling, compositional quality based on mean ratings of content and organization (Berninger, Yates et al. 1992), reading real words and nonwords, and passage comprehension (although it is well known that the relationship between Verbal IQ and reading is greater in the intermediate than primary grades, see Stanovich, Cunningham & Feeman 1984). We do not believe that these are the only skills related to writing and reading acquisition, but decided to include them in the intermediate battery because their concurrent validity had been established for the primary grade battery.

Selection of the developmental skills for the intermediate grade battery was also based on theoretical considerations. Although working memory, in which information is *both stored and processed*, has been investigated in reading comprehension (e.g., Just & Daneman 1992), it is also related to written composition (Swanson & Berninger, 1993). In keeping with Swanson's (1993a, b) work, we examined the relationship between writing or reading and both *verbal* and *nonverbal* working memory. In addition, we examined the relationship between different *levels of language* in verbal working memory and component reading and writing skills. The notion of levels of language is consistent with neuropsychological evidence that different brain structures subserve subword-level (phonological), word-level (naming), and sentence-level (reading) tasks (see, for review, Ojemann 1991) and behavioral evidence for intraindividual differences in levels of language at the word, sentence, and text levels in developing writers in the intermediate grades (Berninger, Mizokawa & Bragg 1991; Berninger, Mizokawa, Bragg, Cartwright & Yates 1993; Whitaker, Berninger, Johnston & Swanson 1993) and at the word and sentence levels in developing readers in the primary and intermediate grades (Berninger 1992).

In research with the primary grade sample we focused on receptive orthographic coding of printed words that we conceptualized as procedures for *creating* representations of written words in memory during beginning reading and writing. In research with the intermediate grade samples, however, we focused on different aspects of the developing orthographic system, which we hypothesized were particularly important during the intermediate grades: speeded receptive orthographic coding; expressive orthographic coding; and the orthographic images created in memory by orthographic and phonological coding for word-specific representations. We reasoned that speed of orthographic coding is an index of the automaticity of a low level process contributing to word recognition and spelling; to operationalize the construct, we selected a measure developed by DeFries and colleagues (e.g., DeFries 1985) to study reading disabilities across the life span. We reasoned that expressive orthographic coding is needed to reproduce whole words and/or their constituent parts. We developed an analogue of our receptive task (Berninger, Yates & Lester 1991) for this purpose. In contrast to the receptive orthographic coding tasks which were based on real words, the expressive orthographic coding tasks (Berninger 1994b) were based on nonwords so that the student could not rely on word-specific representations with semantic codes in performing the task. We also reasoned that orthographic images (Ehri 1980) are related not only to reading (Stanovich, West & Cunningham 1991) but also to writing as an increasing number of word-specific representations accumulate in memory in developing readers and writers. To operationalize orthographic images for real words we selected measures developed by Stanovich and West (1989) and by Olson, Kliegl, Davidson and Foltz (1985).

Selecting measures of phonological skills posed greater challenges based on the large number of measures developed over the past two decades. Two considerations played a role in our adopting Vellutino's phonemic invariance and phonemic articulation tasks (Vellutino & Scanlon 1987). One was that these two tasks have been the best predictors of reading disabilities in large scale psychometric studies conducted by Vellutino (personal communication, September 1990). Another was Byrne and Fielding-Barnsley's (1990) proposal that phonemic awareness of spoken language has two sub-components: *segmentation*, which involves the phonological structures within a word, and *identity*, which involves perceiving that phonemes are the same across different word contexts. Vellutino's phoneme localization and articulation tasks require the student not only to segment words into phonemes but also to process which phonemes are the same and which phonemes are different across two word contexts. To operationalize phonological segmentation we created an analogue of the Modified Rosner Auditory Analysis Test (Berninger, Thalberg, DeBruyn & Smith 1987), on which many children approach ceiling by the end of third grade. Called syllable/rime/phoneme deletion, this test (Berninger 1994b) like the expressive orthographic coding test, uses nonwords so that children cannot access word-specific representation with semantic codes in performing the phonological segmentation at various subword units of sound. In addition to phonological segmentation of subword units, phonological segmentation of whole word units was also assessed using Vellutino's phonetic memory task (Vellutino, Scanlon, Small & Tanzman 1991) which requires learning lists of whole word names for nonwords, which cannot be learned using word-specific representations with semantic codes.

METHOD

Subject

The sample consisted of 100 fourth graders, 100 fifth graders, and 100 sixth graders drawn from five urban and suburban schools. Fifty girls and fifty boys were included at each grade level. Ten percent of the sample were left handed as is found in the normal population. The sample was ethnically diverse: 14% Asian-American, 10% Black-American, 70% White, 4% Hispanic, 1% Native American, and 1% Other. Mother's level of education was used as an index of socioeconomic status and included a range: 49% college or college plus, 24% high school plus, 20% high school, 4% less than high school, and 3% not available.

Procedures

Measures of the fine motor, orthographic coding, orthographic-motor, phonological, working memory systems, writing skills (handwriting, spelling, and composition), and reading skills (reading real words, reading nonwords, and passage comprehension) were administered in *group sessions* (averaging about 20 children) in the fourth or fifth month of the school year or in *individual sessions* in the sixth or seventh month of the school year as indicated below. Given the large number of measures, fatigue effects were avoided by administering measures in three separate sessions. Each student participated in two group sessions of approximately 45—60 minutes duration and one individual session of 45—60 minutes.

Within a session, order of task was held constant: *Session 1* (group), Alphabet Task, Copying, Spelling Subtest of Wide Range Achievement Test-Revised, Compositions, Phoneme Localization, Phonemes in Nonwords and Nonword Spelling, Colorado Perceptual Speed Test, Homophone Choice Task, and Homophone/Pseudohomophone Choice Task; *Session 2* (group), Listening-Recall, Listening-Generation, Dots, and Maps, followed by one of two experiments reported elsewhere (Berninger, Mizokawa et al. 1993; Whitaker et al. 1993); *Session 3* (individual), Verbal IQ, Finger Succession, Syllable/Rime/Phoneme Deletion, Verbal Working Memory (Rhyme, Semantic Association, Phrase, Narrative Text, Expository Text), Expressive Orthographic Coding, Phoneme Articulation, Phonetic Memory, Reading (Word Identification, Word Attack, Passage Comprehension of the Woodcock Reading Mastery Test-Revised). Given the large number of measures, counterbalancing was not possible. Because order of administration was held constant, resulting norms are most valid if measures are administered in the same order as in this study.

DEVELOPMENTAL SKILLS

Measures of the fine motor system

The finger succession task was administered in the individual session using procedures described in Berninger and Rutberg (1992). Children were asked to imitate the examiner touching the thumb to each of the four fingers in succession from the little finger to the index finger — first with the right hand and then with the left hand. The time (in seconds) to complete the cycle five times was recorded for each hand and the presence or absence of overflow — movement of fingers in the opposite hand — was noted. Only the time and overflow for finger succession on the *dominant hand for writing* were used in the analyses. The finger succession task is thought to tap motor planning for sequential finger movements which is needed for manipulating a pencil to produce sequences of alphabet symbols (see, for further discussion of this theoretical construct, Berninger & Rutberg 1992).

Measures of the orthographic system

Orthographic coding. The Colorado Perceptual Speed Test (Decker & DeFries 1981; DeFries 1985)[1] was administered in a group session. Children were asked to match a target stimulus of alphanumeric symbols on the left (e.g., acsr) with one of four alternatives on the same line to the right (e.g., rcas, acsr, sacr, rsca) by circling it. They completed as many matches as they could within a one-minute time limit for each of three parts. The score was the sum of the total correct responses for Parts I, II, and III divided by the total items on all three parts (90). This measure is thought to tap speeded receptive orthographic coding for stimuli that do not correspond to a lexical representation for a real word.

Orthographic images. The Homophone Choice Task (adapted from a computer-based test developed by Cunningham & Stanovich 1990; Stanovich & West 1989)[2] was administered in a group session. Children answered a question (e.g., Which is a flower?) by circling one of two words that are pronounced identically (same phonological code) but spelled differently (different orthographic code) (e.g., rose, rows). The score was the number of correct responses divided by the number of items (25). This measure is thought to tap retrieval of the orthographic image (Ehri 1980) of a word when the initial address code is semantic, that is, answering the question activates semantic categories that determine the correct spelling.

The Homophone/Pseudohomophone Choice Task (adapted from a computer-based test developed by Olson et al 1985; Olson, Wise, Conners, Rack & Fulker 1989)[3] was administered in a group session. Children were instructed to circle the word that was a real word in a pair of words that are pronounced the same (same phonological code) but spelled differently (different orthographic code) (e.g., sammon, salmon), only one of which was a real word. There was a time limit of 3 minutes. The score was the number of correct responses divided by the total number of items (78). This measure is thought to tap retrieval of the orthographic image (Ehri 1980) of a word when the initial address code is orthographic (i.e., processing the stimuli activates orthographic representations which must be matched with entries in the mental lexicon).

Speeded orthographic-motor integration. The Alphabet Task (Berninger & Rutberg 1992; Berninger, Yates et al 1992) was administered in a group session. Children were asked to print the alphabet in lower case letters in sequence as quickly as possible without making mistakes. Capital letters, omissions, additions, transpositions, and reversals counted as errors. One point was awarded for every letter correctly reproduced in the first 15 seconds. Thus the score took into account both accuracy and speed. This measure is thought to tap speeded retrieval and motor output of an ordered set of alphabet symbols (see, for further discussion of the construct of speeded orthographic-motor integration in writing acquisition, Berninger & Rutberg 1992; Berninger & Fuller 1992).

The Expressive Orthographic Coding Task[4] was administered in an individual session. A single whole *nonword* was presented on a 3 × 5 card for 1 second and then removed; see Berninger (1994b) for the stimuli.

Children were then given verbal instructions to reproduce in writing the entire word (whole word coding), a single letter is a designated position (letter coding), or a letter sequence in designated positions (letter cluster coding). This measure was developed to tap ability to reproduce written words or their constituent parts without recourse to word-specific representations with semantic codes.

Measure of the phonological system

Whole-word phonetic coding. Phonetic Memory (modified version of task reported in Vellutino, Scanlon, Small & Tanzman 1991; Vellutino, Scanlon & Tanzman 1991)[5] was administered in an individual session. A list of nonsense words (each one syllable long) was presented one at a time with the child repeating each after the examiner to make sure the syllable was perceived correctly. Then after the examiner repeated the entire sequence (e.g., DES SEEG SEG GEEZ DEEZ DEZ), the child was asked to count backwards from 20 by 2's until the examiner said 'stop' after 6 seconds. Following this interference task, the child was asked to repeat the entire list of nonsense words. This procedure continued with new lists of nonsense words until the child could not recall any of the nonsense words in two consecutive lists. One point was awarded for each word correctly recalled regardless of order. This task is thought to tap phonetic coding of whole word units without any access to semantic codes.

Phoneme segmentation. Syllable/Rime/Phoneme Deletion[4] was administered in an individual session. It uses nonwords only and is an upward extension of a syllable and phoneme deletion task, which uses real words only (Modified Rosner Test, Berninger et al. 1987, on which children begin to approach ceiling by third grade). Children were asked to repeat a whole word (e.g., bafmotbem) without a designated syllable (e.g., mot) or rime (e.g., ot), or to repeat a whole word (e.g., twem) without a designated phoneme (e.g.,/w/). The score was the number of correct responses divided by the total number of items (24). This task is thought to tap phonemic segmentation when only phonological (not semantic) codes are available.

Phonemes in Nonwords[4] was administered in a group session. Children were asked to write the number of sounds in a nonword (e.g., vunhip) before spelling it in writing (e.g., 6). Instructions stressed that children count the number of sounds smaller than the syllable and not the syllables and provided practice items to illustrate this point. The score was the number of correct responses divided by the total number of items (22). This task is thought to tap phonemic segmentation when only phonological (not semantic) codes are available.

Phonemic invariance. Phoneme Localization (Vellutino & Scanlon 1987; Vellutino, Scanlon & Tanzman 1991)[5] was administered in a group session.

Children were read *pairs of words* (half real words, half nonsense words that differed only in one sound segment, e.g., tip, dip or zock, zuck, respectively) and were instructed to indicate whether the sound difference occurred at the beginning, middle, or end of the word by circling one of those words on a response sheet. The score was the number of correct responses divided by the total number of items (10). This task is thought to tap phonemic segmentation and phonemic invariance across word contexts (see Byrne & Fielding-Barnsley 1990).

Phoneme Articulation (Vellutino & Scanlon 1987; Vellutino, Scanlon & Tanzman 1991)[5] was administered in an individual session. Children were read a different set of word pairs (half real words, half nonsense words that differed only in one sound segment, e.g., cup/cop and thope/fope, respectively) and were instructed to produce the sound that was different in each word in the pair. The score was the number of correct responses divided by the total number of items (10). This task is thought to tap receptive phonemic invariance (across word exemplars) and approximate expressions of phonemic contrasts (phonemes are abstractions of sound classes and cannot be produced in pure form in isolation, Liberman, Shankweiler, Liberman, Fowler & Fischer 1977).

Measures of working memory system

All these measures were administered in an individual session, except Listening-Recall and Listening-Generation (Sentence Spans), and Dot Matrix and Maps, which were administered in a group session. Except for the Expository Task and Listening-Generation, these tasks were taken from Swanson's Battery for Assessment of Working Memory (MPPT, Swanson 1992, 1993a, b; Swanson, Cochran & Ewars 1990).[6] The first seven tasks tap verbal working memory and the last two tasks tap nonverbal working memory. All tasks require the simultaneous storage and processing of information. A critical feature of all tasks is that they require the maintenance of some information during the processing of other information. The processing of information is assessed by asking children a comprehension question about the to be remembered material, whereas storage is assessed by item retrieval. Thus, all working memory tasks conform with Baddeley's definition that they 'require simultaneous processing and storage of information' (1986: 34).

Rhyme (Subtest 1, MPPT). Children were asked to *listen* to a list of rhyming words (e.g., run/fun/gun), *answer* a process question (e.g., Did I say sun or fun?), and then *recall* the list. Testing stopped when the process question was failed. One point was awarded for *each word* correctly recalled, as long as the process question was answered correctly. This task is thought to tap storage of sound information in verbal working memory.

Semantic association (Subtest 9, MPPT). Children were asked to *listen* to a list of semantically related words (e.g., coat, carrots, glove, tomatoes), *answer* a process question (e.g., Did I say "carrots" or "banana"?), and then recall the list. One point was awarded *for each list* correctly recalled for which the process question was correctly answered. Testing stopped when the process question was failed. This task is thought to tap storage and processing of word meaning in verbal working memory.

Phrase (Subtest 7, MPPT). Children were asked to *listen* to a list of phrases (e.g., a falling egg, a slow car), *answer* a process question (e.g., Were the items about an "egg" or "truck"?), and then recall the list. One point was awarded *for each list* correctly recalled for which the process question was correctly answered. Testing stopped when the process question was failed. This task is thought to tap storage and processing of multi-word representations smaller than a sentence in verbal working memory.

Narrative text (Subtest 5, MPPT). Children were asked to *listen* to a story about a soldier who survives an emergency escape from a burning plane, to *answer* a process question, and then to *recall* the story. One point was awarded for each proposition correctly recalled or paraphrased, but one point was subtracted for each proposition out of order. This task is thought to tap storage and recall of discourse (narrative structure) in verbal working memory.

Expository test (Adapted from a passage in the Barnell-Loft *Specific Skills* series, Boning 1973). Children were asked to *listen* to an expository text about the letter 'C', to *answer* a process question, and then to *recall* the text. One point was awarded for each proposition correctly recalled or paraphrased, but one point was subtracted for each proposition out of order. This task is thought to tap storage and recall of discourse (expository structure) in verbal working memory.

Listening-recall span (Group-administered version of Daneman & Carpenter's 1980, Sentence Span, adopted by Swanson, Cochran & Ewars 1989). Children were asked to *listen* to a set of sentences (e.g., Many people live on a farm. People have used masks since early times), to *answer* a process question about those sentences (e.g., What have people used since early times?), and then to *recall* the last word of each sentence. One point was awarded for each process question answered correctly (until the process question was missed) and for each word correctly recalled regardless of order (but only if the process question was answered correctly). This task is thought to tap storage and processing of receptive text in verbal working memory and thus to be related to *reading comprehension.*

Listening-generation span. Children were asked to *listen* to a set of sentences, to *answer* a process question about those sentences, and then to *generate* written sentences using each of the last words in those sentences the examiner read (anywhere in the generated sentence). One point was awarded for each process question answered correctly (until the process question was missed) and for each word correctly remembered regardless of order and used in a complete written sentence (but only if the process question was answered correctly). This task is thought to tap storage and processing involved in generating written text in verbal working memory and thus to be related to *written composition.*

Dot matrix (Subtext 2, MPPT). Children were asked to *look* at a configuration of dots in a matrix, *answer* a process question about those dots, and then *reproduce* that configuration of dots. One point was awarded for each instance where the process question was answered correctly *and* the configuration was reproduced correctly. This task is thought to tap storage and processing in nonverbal working memory.

Maps (Subtest 4, MPPT). Children were asked to *look* at a map of streets with street lights at intersections and directional lines connecting street lights, to *answer* a process question about the map, and then to *reproduce* the directional lines and street lights. One point was awarded for each instance where the process question was answered correctly *and* the map was reproduced correctly. This task, which is thought to tap storage and processing in nonverbal working memory, was administered so that there were at least two indicators of nonverbal working memory.

Measure of verbal intelligence

Four subtests of the Wechsler Intelligence Scale-Revised (Wechsler 1974) — information, similarities, vocabulary, and comprehension — were administered and scored according to procedures in the test manual. A prorated Verbal IQ was derived from a table in the test manual.

WRITING SKILLS

All measures of writing were group-administered and used stimuli and procedures described in Berninger, Yates et al. (1992), and Berninger & Rutberg (1992).

Measures of handwriting

Children were asked to copy a short story as quickly as possible without mistakes. One point was awarded for each word copied legibly within the 90 second time limit. Unlike assessment of handwriting based on relative quality of handwriting (e.g., Test of Written Language, Hammill & Larsen 1983, *or* Woodcock Johnson Psychoeducational Battery-Revised, Woodcock & Johnson 1989, 1990), this measure took into account the speed of producing minimally legible writing (see Berninger, Yates et al. 1992, Berninger & Rutberg 1992, and Berninger & Fuller 1992, for discussion of the importance of assessing fluency of handwriting production under time constraints).

Measures of spelling

Dictated spelling of real words. The Wide Range Achievement Test-Revised Spelling subtest (Jastak & Wilkinson, 1984) was administered using procedures in the test manual. Raw scores were converted to standard scores for age, using norms in the test manual.

Dictated spelling of nonwords. Children were asked to spell nonwords.[4] The score was the number of correctly spelled nonwords divided by the total number of items (22).

Spontaneous spelling of real words. The percentage of correctly spelled words was computed for the narrative composition and the expository composition.

Measures of composition

For the *Narrative task* children were asked to complete the choices in the following frame and then continue writing the story for five minutes: One day (*choose person*) had the (choose best or worst) day at school. Compositions were scored for (a) *number of words* (a measure of fluency, see Berninger, Yates et al. 1992, for rationale), (b) *number of clauses* (a measure of micro-organization, see Berninger, Yates et al. 1992, for rationale, and (c) *quality* (mean of two coders whose interrater reliability was 0.75 on a scale of 1 = considerably below grade level, 2 = somewhat below grade level, 3 = grade appropriate, 4 = somewhat above grade level, and 5 = considerably above grade level).

For the *Expository task* children were asked to complete the choice in the following frame and then continue writing the essay for five minutes to explain why: I like (*choose person, place or thing* ___________) because ___________. Expository compositions were scored for the same three dependent measures as for the narrative compositions above. Interrater reliability was 0.60 on the same scale as above.

These composition tasks were designed to tap ability to produce compositions under time constraints. Our working hypothesis was that children who can produce compositions fluently have automatized the low level processes and have more working memory capacity for the high-level processes involved in composing. Furthermore, the developmental origins of composing problems are often related to failure to automatize the low-level processes (see Berninger, Yates et al. 1992). At the intermediate grade levels children rarely protested when they were asked to stop writing after 5 minutes; children rarely needed to be prompted to keep writing for 5 minutes.

READING SKILLS

Reading real words. The Word Identification subtest of the Woodcock Reading Mastery Test-Revised (Woodcock 1987) was administered according to procedures in the test manual. Raw scores were converted to standard scores using age norms in the test manual.

Reading nonwords. The Word Attack Subtest of the Woodcock Reading Mastery Test-Revised (Woodcock 1987) was administered according to procedures in the test manual. Raw scores were converted to standard scores using age norms in the test manual.

Comprehension. The Passage Comprehension Subtest of the Woodcock Reading Mastery Test-Revised (Woodcock 1987) was administered according to procedures in the test manual. Raw scores were converted to standard scores using age norms in the test manual.

RESULTS

Descriptive statistics

Means and standard deviations (see Table 1) were inspected to evaluate possible floor or ceiling effects on any of the measures in the fourth, fifth, or sixth grades. Mean time for finger succession decreased with increasing grade level because the faster the performance, the better the performance. Floor effects were found on overflow which is to be expected in 9—12 year-old children when overflow is less likely to occur than in younger children. Although possible ceiling effects occurred in the accuracy on the group-administered Homophone Choice Task, this task, which had originally been designed by Stanovich and colleagues to yield RTs on an individually administered computerized task, was correlated significantly with criterion measures and contributed to unique increments of variance in multiple regressions in a manner predicted by theory. That is, it contributed unique variance to reading and spelling *real words* (semantic address) but not to reading and spelling *nonwords* (lacking semantic address) as reported below and so was included.

Neither floor nor ceiling effects were found on the Syllable/Rime/Phoneme Deletion Task for nonwords nor was the expected developmental improve-

Table 1. Means and standard deviations for developmental skills, writing skills, and reading skills by grade level

	Grade 4		Grade 5		Grade 6	
	M	SD	M	SD	M	SD
DEVELOPMENTAL SKILLS						
Fine Motor System						
Finger Succession-dominant (s)[a]	9.44	3.02	8.26	2.35	7.97	2.16
Overflow-dominant[a]	0.54	0.50	0.50	0.50	0.41	0.49
Orthographic and Orthographic-Motor System						
Colorado Perceptual Speed[b]	41.15%	11.32	51.12%	10.59	55.50%	11.48
Homophone choice[b]	92.16%	10.51	95.20%	6.80	97.20%	4.94
Homophone/Pseudohomophone Choice[b]	82.09%	12.01	89.36%	8.70	92.07%	7.77
Alphabet Task[b]	13.68	5.79	14.84	5.78	18.54	5.87
Expressive Orthographic Coding[a]	73.34%	13.93	80.79%	11.76	83.76%	11.19
Phonological System						
Phonetic Memory[a]	6.28	4.24	7.84	4.35	9.53	5.03
Phoneme Localization[b]	79.20%	19.58	85.10%	18.72	88.90%	11.71
Phoneme Articulation[a]	63.70%	23.98	78.90%	21.83	81.10%	19.01
Syllable/Rime/Phoneme Deletion[a]	62.16%	16.27	71.54%	14.37	63.80%	16.91
Phonemes in Nonwords[b]	42.24%	18.22	45.28%	20.70	54.51%	17.98
Working Memory System						
Rhyme (alt)[a]	1.31	1.05	1.78	0.95	1.74	1.03
Semantic Association[a]	0.43	0.70	0.59	0.71	0.63	0.76
Phrase[a]	0.44	0.59	0.70	0.61	0.81	0.60
Text						
Narrative[a]	5.27	2.99	5.78	2.59	6.51	2.24
Expository[a]	2.08	1.70	2.61	1.86	3.47	1.92
Listening-Generation Span (alt)[b]	6.98	3.84	8.12	4.20	8.45	4.34
Listening-Recall Span (alt)[b]	6.89	3.81	7.67	3.80	8.01	3.51
Dots[b]	3.56	1.00	3.55	1.29	3.88	1.05
Maps[b]	1.98	1.11	2.07	1.18	2.48	1.06

Table 1. Continued

	Grade 4		Grade 5		Grade 6	
	M	SD	M	SD	M	SD
ACADEMIC SKILLS						
Handwriting[b]	25.09	7.58	28.30	5.46	33.01	7.21
Dictated Spelling						
Real Words[b, c]	100.85	13.28	104.23	17.26	109.67	14.70
Nonwords[b]	48.85%	20.31	62.16%	17.35	60.44%	17.77
Spontaneous Spelling[b]						
Narrative	93.42%	6.36	95.39%	7.54	97.07%	3.61
Expository	92.27%	9.09	95.42%	6.13	96.90%	3.26
Compositions[b]						
Narrative-Words	57.47	20.90	65.60	23.09	78.24	23.67
Narrative-Clauses	7.94	3.21	8.75	3.46	10.38	3.77
Narrative-Quality	3.27	0.94	3.27	0.75	3.46	0.74
Expository-Words	55.61	21.05	62.14	23.99	75.07	25.30
Expository-Clauses	8.37	3.11	9.25	3.89	10.68	4.45
Expository-Quality	3.22	0.94	3.18	0.79	3.43	0.76
Word Recognition						
Reading Real Words[c]	99.90	11.16	104.04	11.43	105.44	11.45
Reading Nonwords[c]	102.58	12.94	105.91	12.46	107.18	11.67
Reading Comprehension[c]	96.37	12.51	101.66	14.57	102.37	13.21

[a] Individually administered.
[b] Group administered.
[c] Age-corrected standard score used from norms in test manual.

ment with grade found; apparently phonological segmentation of nonwords is relatively stable in the age range studied, or individual differnces exceed developmental changes. It was clear that floor effects would probably occur on three subtests of working memory if administered below grade 4 — rhyme, semantic association, and phrase. Far fewer items contributed to each of the working memory measures than contributed to any of the other measures; nevertheless these tasks were analyzed separately for sentence span measures (listening-recall and listening-generate) and for levels of language in verbal working memory (subword, word, multi-word) and for types of nonverbal working memory in order to determine whether specific aspects of working memory may contribute to different component writing and reading skills.

Intercorrelations within functional systems

Pearson product moment correlations (see Table 2) were examined to determine whether the various measures of the same construct tapped the same or different processes. Considering the number of measures involved, we set our criterion of statistical significance conservatively at $p < 0.001$ to avoid Type 1 errors. For the *fine motor system*, time for repeating five cycles of finger succession with the dominant hand *and* amount of overflow of the dominant hand were uncorrelated, as had been the case for primary grade children, which probably reflects the high degree of specificity of the motor system (see Berninger & Rutberg 1992). For both the *orthographic system* and *phonological system*, on the other hand, most of the measures within the same functional system were significantly correlated, but only at low or moderate magnitudes at best, consistent with the hypothesis that they are tapping the same functional system but not redundant processes. For the *working memory system*, some, but not all of the measures were significantly correlated; the nonsignificant correlations may have been due to floor effects on some measures, as discussed above. Working memory does not appear to be redundant with Verbal IQ as Verbal IQ never shared more than 19% of its variance with any working memory measure.

The various measures of spelling were correlated only at a low or moderate magnitude; the various measures of composition were for the most part correlated, but generally at a moderate magnitude (see Table 3). Thus, the correlations are consistent with the theoretical position that the spelling measures tap the same working system, but not completely redundant processes, and the composition measures tap the same working system, but not completely redundant processes.

Validity of predictor measures of developmental skills for assessing criterion measures of writing

Pearson product moment correlations are reported in Table 4 for each pre-

Table 2. Intercorrelations among developmental skills after first standardizing scores within grade[a]

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
Fine Motor System										
V1 Finger Succession-dominant										
V2 Overflow-dominant	0.12									
Orthographic and Orthographic-Motor System										
V1 Colorado Perceptual Speed										
V2 Homophone choice	0.28*									
V3 Homophone/Pseudohomophone Choice	0.56*	0.62*								
V4 Alphabet Task	0.30*	0.27*	0.34*							
V5 Expressive Orthographic Coding	0.37*	0.27*	0.48*	0.28*						
Phonological System										
V1 Phonetic Memory										
V2 Phonemic Localization	0.17									
V3 Phoneme Articulation	0.25*	0.38*								
V4 Syllable/Rime/Phoneme Deletion	0.23*	0.24*	0.52*							
V5 Phonemes in Nonwords	0.17	0.25*	0.33*	0.23*						
Verbal Working Memory										
V1 Rhyme (alt)										
V2 Semantic Association	0.18									
V3 Phrase	0.22*	0.17								
V4 Narrative Text	0.13	0.09	0.19*							
V5 Expository Text	0.13	0.04	0.06	0.48*						
V6 Listening-Recall Span	0.15	0.08	0.17	0.21*	0.27*					
V7 Listening-Generating Span	0.17	0.18	0.15	0.17	0.22*	0.48*				
Nonverbal Working Memory										
V8 Dots	0.07	0.09	0.10	0.13	0.12	0.12	0.12			
V9 Maps	0.14	0.12	0.11	0.12	0.06	0.19*	0.21*	0.25*		
V10 Verbal IQ	0.20*	0.14	0.27*	0.42*	0.44*	0.30*	0.31*	0.10	0.20*	

* $p \leqslant 0.001$ based on correlations to the thousandths place.

[a] Please note that variables in column headings refer to different variables for the fine motor system, the orthographic and orthographic-motor system, the phonological system, and the working memory system (verbal and nonverbal).

Table 3. Intercorrelations among writing and reading skills after first standardizing scores within grade

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14
V1 Handwriting														
Dictated Spelling														
V2 Real Words	0.20*													
V3 Nonwords	0.19*	0.28*												
Spontaneous Spelling														
V4 Narrative	0.21*	0.40*	0.22*											
V5 Expository	0.22*	0.39*	0.24*	0.62*										
Compositions-words														
V6 Narrative	0.43*	0.07*	0.21*	0.12	0.14									
V7 Expository	0.36*	0.12	0.22*	0.14	0.13	0.73*								
Composition-clauses														
V8 Narrative	0.36*	0.10	0.15	0.08	0.11	0.84*	0.60*							
V9 Expository	0.32*	0.14	0.19*	0.11	0.12	0.61*	0.85*	0.54*						
Composition-quality														
V10 Narrative	0.26*	0.30*	0.35*	0.21*	0.25*	0.55*	0.40*	0.52*	0.32*					
V11 Expository	0.25*	0.33*	0.30*	0.23*	0.29*	0.45*	0.45*	0.55*	0.41*	0.46*	0.69*			
Word Recognition														
V12 Reading Real Words	0.21*	0.67*	0.40*	0.42*	0.37*	0.03	0.05	0.05	0.06	0.30*	0.33*			
V13 Reading Nonwords	0.21*	0.63*	0.36*	0.44*	0.34*	0.04	0.07	0.04	0.08	0.23*	0.24*	0.75*		
V14 Passage Comprehension	0.12	0.53*	0.32*	0.28*	0.33*	0.13	0.11	0.13	0.11	0.38*	0.43*	0.68*	0.54*	

* $p \leqslant 0.001$ based on correlations to the thousandths place.

dictor measure, organized by functional system, and each criterion measure of writing. Again, considering the large number of measures involved, we adopted a conservative criterion of 0.001 for statistical significance to control for Type 1 errors. The measures of the fine motor system, when considered alone, did not appear to be related to criterion measures of writing in the intermediate grade sample. In contrast, almost all the orthographic measures, when considered alone, were correlated significantly with all the criterion measures of spelling, handwriting, and composition. The phonological measures, on the other hand, when considered alone, were not correlated with handwriting or most composition measures, but were correlated with most spelling measures. Of the verbal working memory measures in Table 4, when considered alone, only Listening-Generation was related to writing skills — and only to composition, consistently, and not to handwriting or spelling. (Listening-Recall was also correlated significantly with composition, but multiple regression showed that Listening-Generation, but not Listening-Recall, added significant unique increments of variance beyond the zero-order correlations to explaining quality of narrative and expository compositions; so only Listening-Generation was used as an index of verbal working memory for predicting compositional skills.) Verbal IQ was related only to spelling and quality of composition.

Multiple prediction of handwriting

We entered into the multiple regression[7] these predictors of handwriting for the intermediate grades: (a) finger succession-dominant, which had been a good predictor of handwriting in the primary grade sample (see Berninger & Rutberg 1992); and (b) all orthographic tasks except Homophone Choice (see Table 4). The Colorado Perceptual Speed Test, the Alphabet Task, and the Expressive Orthographic Coding Task accounted for significant increments of variance (see Table 5). Thus, speeded orthographic coding (Colorado Test) and speeded orthographic-motor integration (alphabet Task and Expressive Orthographic Coding) contribute unique variance to handwriting and provide the best combination of predictors. Orthographic imaging (homophone/pseudohomophone choice) and fine motor function (finger succession) did not contribute uniquely to handwriting.

Multiple prediction of spelling

We entered the following measures as predictors of spelling for the intermediate grades into the multiple regression:[7] Homophone Choice Task, Homophone/Pseudohomophone Choice Task, and Expressive Orthographic Coding Task (which were consistently correlated with all four spelling criterion measures), Phonetic Memory, Phoneme Articulation, and Phonological Deletion (which were consistently correlated with all four spelling measures), and Verbal IQ (which was correlated with three spelling measures).

Table 4. Zero-order correlations between measures of developmental skills and measures of writing skills (based on standardized scores for grade)

	Handwriting	Dictated Spelling		Spontaneous Spelling		Composition-Words		Composition-Clauses		Composition-Quality	
		R	NW	N	E	N	E	N	E	N	E
Fine Motor System											
Finger Succession-dominant (s)	−0.10	−0.06	−0.17	−0.02	0.03	−0.16	0.19*	−0.12	0.17	−0.10	−0.14
Overflow-dominant	−0.09	−0.11	−0.10	−0.03	−0.04	−0.06	−0.11	−0.03	−0.10	−0.05	−0.07
Orthographic System											
Colorado-Perceptual Speed	0.36*	0.36*	0.18	0.26*	0.30*	0.28*	0.25*	0.24*	0.21*	0.34*	0.34*
Homophone choice	0.16	0.46*	0.18*	0.45*	0.39*	0.11	0.14	0.08	0.11	0.27*	0.28*
Homophone/Pseudohomophone Choice	0.33*	0.58*	0.33*	0.53*	0.44*	0.18*	0.21*	0.15	0.16	0.32*	0.38*
Alphabet Task	0.36*	0.31*	0.17	0.21*	0.24*	0.22*	0.22*	0.22*	0.17	0.29*	0.26*
Expressive Orthographic coding	0.30*	0.47*	0.21*	0.34*	0.41*	0.07	0.09	0.05	0.11	0.24*	0.29*
Phonological System											
Phonetic Memory	0.13	0.26*	0.18*	0.27*	0.24*	0.01	0.06	−0.02	0.04	0.25*	0.24*
Phoneme Localization	0.04	0.27*	0.33*	0.15	0.12	−0.06	−0.11	−0.03	−0.10	−0.05	−0.07
Phoneme Articulation	0.15	0.40*	0.39*	0.26*	0.24*	−0.02	0.07	0.04	−0.01	0.24*	0.24*
Syllable/Rime/Phoneme Deletion	−0.01	0.33*	0.26*	0.21*	0.20*	−0.02	0.05	−0.02	0.03	0.14	0.23*
Phonemes in Nonwords	−0.12	0.16	0.39*	0.13	0.09	0.12	0.15	0.11	0.09	0.21*	0.17
Working Verbal Memory system											
Rhyme (alt)	−0.02	0.16	0.10	0.14	0.14	0.04	0.03	−0.001	0.02	0.11	0.18
Semantic Association	−0.08	0.06	0.16	0.09	0.13	−0.01	0.02	−0.03	0.04	0.04	0.10
Phrase	−0.06	0.13	0.07	−0.01	0.06	0.06	0.01	0.06	−0.04	0.13	0.11
Narrative Text	−0.02	0.09	0.17	−0.02	0.08	0.04	0.06	0.09	0.05	0.15	0.21*
Expository Text	0.07	0.17	0.13	0.10	0.08	0.06	0.08	0.08	0.01	0.24*	0.24*
Listening-Generation Span (Alt)	0.08	0.15	0.18	0.09	0.11	0.23*	0.22*	0.22*	0.23*	0.27*	0.24*
Verbal IQ	0.03	0.36*	0.26*	0.14	0.23*	0.06	0.05	0.12	0.03	0.35*	0.42*

$p \leqslant 0.001$ based on correlations to the thousandths place.
Used abbreviations: R = Real words; NW = Nonwords; N = Narrative text; E = Expository text.

Table 5. Multiple regression of handwriting criterion skills on predictor developmental skills

Independent measures	Standardized coefficient	t	*p*	R^2	F(5, 294)	*p*
				0.22	16.78	0.001
Colorado Perceptual Speed	0.19	3.06	0.002*			
Homophone/Pseudohomophone Choice	0.08	1.12	0.265			
Finger Succession-dominant	−0.04	−0.078	0.436			
Alphabet Task	0.24	4.29	0.001*			
Expressive Orthographic Coding	0.12	2.06	0.040*			

* Accounts for a significant increment of variance at $p < 0.05$.

For spelling *real words that are dictated*, the Homophone Choice Task, the Homophone/Pseudohomophone Choice Task, the Expressive Orthographic Coding Task, the Phoneme Articulation Task, and Verbal IQ accounted for significant increments of variance (see Table 6). Thus, orthographic imaging (with either semantic address on the Homophone Choice Task or orthographic address on the Homophone/Pseudohomophone Choice Task), orthographic-motor integration (Expressive Orthographic Coding), abstraction of phonological invariance (Phoneme Articulation), and verbal intelligence provide the best combination of predictors of this spelling skill. For *spelling nonwords that are dictated*, the Homophone/Pseudohomophone Choice Task and Phoneme Articulation accounted for significant increments of variance (see Table 6). Thus, orthographic imaging (orthographic address) and abstraction of phonemic invariance provide the best combination of these predictors for this spelling skill.

For *spontaneous spelling in narrative compositions*, the Homophone Choice Task, the Homophone/Pseudohomophone Choice Task, and the Phonetic Memory Task accounted for significant increments of variance (see Table 6). Thus, orthographic imaging (semantic or orthographic address) and memory for sound patterns (independent of meaning) provide the best combination of these predictors for this spelling skill. For *spontaneous spelling in expository compositions*, the Homophone Choice Task, the Homophone/Pseudohomophone Choice Task, Expressive Orthographic Coding, and Phonetic Memory accounted for significant increments of variance (see Table 6). Thus, there is converging evidence in both narrative and expository compositions that orthographic imaging (semantic or orthographic address) and memory for sound patterns at the phonetic level (independent of meaning) provide the best combination of predictor measures for spontaneous spelling in written compositions. Orthographic-motor integration contributed to the best combination for spontaneous spelling only on the expository compositions.

Table 6. Multiple regression of spelling criterion skills on predictor developmental skills

Dependent measures	Independent measures	Standardized coefficient	t	*p*	R^2	F(7,292)	*p*
Dictated spelling — Real words					0.44	33.07	0.001
	Homophone Choice	0.13	2.32	0.021*			
	Homophone/Pseudohomophone Choice	0.32	5.18	0.001*			
	Expressive Orthographic Coding	0.17	3.24	0.001*			
	Phonetic Memory	0.06	1.32	0.187			
	Syllable/Rime/Phoneme Deletion	0.06	1.03	0.302			
	Phoneme Articulation	0.11	1.96	0.051*			
	Verbal IQ	0.11	2.14	0.033*			
Dictated spelling — Nonwords					0.22	11.59	0.001
	Homophone Choice	−0.08	−1.23	0.219			
	Homophone/Pseudohomophone Choice	0.27	3.62	0.001*			
	Expressive Orthographic Coding	−0.06	−0.96	0.337			
	Phonetic Memory	0.06	1.07	0.286			
	Syllable/Rime/Phoneme Deletion	0.03	0.51	0.610			
	Phoneme Articulation	0.28	4.37	0.001*			
	Verbal IQ	0.10	1.68	0.094			

Table 6. Continued

Dependent measures	Independent measures	Standardized coefficient	t	*p*	R^2	F(7,292)	*p*
Spontaneous Spelling — Narrative					0.35	22.21	0.001
	Homophone Choice	0.20	3.29	0.001*			
	Homophone/Pseudohomophone Choice	0.34	5.11	0.001*			
	Expressive Orthographic Coding	0.09	1.58	0.114			
	Phonetic Memory	0.14	2.88	0.004*			
	Syllable/Rime/Phoneme Deletion	0.07	1.23	0.220			
	Phoneme Articulation	0.02	0.27	0.785			
	Verbal IQ	−0.12	−2.10	0.036*			
Spontaneous Spelling — Expository					0.28	15.95	0.001
	Homophone Choice	0.17	2.67	0.008*			
	Homophone/Pseudohomophone Choice	0.18	2.56	0.011*			
	Expressive Orthographic Coding	0.24	3.93	0.001*			
	Phonetic Memory	0.11	2.07	0.040*			
	Syllable/Rime/Phoneme Deletion	0.01	0.12	0.906			
	Phoneme Articulation	0.00	0.05	0.959			
	Verbal IQ	0.03	0.54	0.592			

* Accounts for a significant increment of variance at $p < 0.05$.

Multiple prediction of composition

We entered the following measures as predictors of composition in the intermediate grades into the multiple regressions:[7] Colorado Perceptual Test (consistently across all 6 composition measures), Alphabet Task (across 5 of the composition measures), the Listening-Generation Span of Working Memory (consistently across all 6 composition measures), and Verbal IQ (both measures of quality of composition) (see Table 7). In addition, we entered the measure of finger succession, which contributed significant increments of predictive variance for composition in the primary grades (see Berninger, Yates et al. 1992).

For both *narrative-words and expository-words*, the Colorado Perceptual Speed Test, the Finger Succession Task, the alphabet Task, and the Listening-Generation Span of Working Memory contributed significant increments of variance (see Table 7). Thus, speeded orthographic coding, fine motor skills, speeded orthographic-motor integration, and the listening-generation span of working memory, respectively, provide the best combination of predictors of compositional fluency. For *narrative-clauses*, the Colorado Perceptual Test and the Alphabet Task contributed significant increments of variance; for *expository-clauses*, the Colorado Perceptual Test, Finger Succession, and the Listening-Generation Span of Working Memory contributed significant increments of variance (see Table 7). Thus, only the speeded orthographic coding task was included in the best combination for predicting micro-organization on both the narrative and expository compositions. For both *narrative-quality* and *expository-quality*, the Colorado Perceptual Speed Test, the Alphabet Task, the Listening-Generation Span of Working Memory, and Verbal IQ contributed significant increments of variance (see Table 7). Thus, there was converging evidence that across compositions speeded orthographic coding, speeded orthographic-motor integration, the listening-generation span of working verbal memory, and verbal intelligence provided the best combination of predictors of the quality of composition.

Validity of predictor measures for assessing criterion measures of reading skills

Given the large number of measures involved, we again set our statistical criterion of significance conservatively at 0.001 to control type 1 errors. All the orthographic measures and all the phonological measures were correlated with each of the reading measures (see Table 8). The verbal working memory system, on the other hand, showed more differentiation. The rhyme and semantic association tasks were correlated with all three component reading skills — reading real words, reading nonwords, and passage comprehension. The phrase task was correlated with reading real words and passage comprehension. Three verbal working memory tasks involving multi-words units were correlated with passage comprehension — narrative-text, expository-text, and listening-generation span. Expository text may have been correlated with reading real words because ability to process instructional language may affect acquisition of word recognition skills. Only one nonverbal working memory task — maps — correlated with a reading task — passage comprehension. Verbal IQ correlated with all three component reading skills: highest, with passage comprehension, next highest, with reading real words, and lowest, with reading nonwords (see Table 8).

Multiple prediction of reading components

We entered, based on current theory, as predictors of reading all the orthographic skills and phonological skills in Table 8 and Verbal IQ in the multiple regressions for word recognition skills.[7] Connectionist models predict that both orthography and phonology are related to word recognition (see Berninger & Abbott 1993); however, Siegel (1989, 1992) has questioned whether Verbal IQ is related to word recognition. For both *reading real words* and *reading nonwords*, the Homophone/Pseudohomophone Choice Test, the Expressive Orthographic Coding Test, Phoneme Localization, Phoneme Articulation, and Phonological Deletion accounted for a significant increment of variance (see Table 9). In addition, for reading real words only (not nonwords), the Homophone Choice Task and Verbal IQ also accounted for a significant increment of variance. Thus, orthographic imaging (semantic access) and verbal intelligence (tapping knowledge of real words) are included in the best combination for real words, but not for nonwords (which lack semantic access but not orthographic or phonological access), as would be expected. Orthographic imaging (orthographic access), orthographic-motor integration, abstraction of phonological invariance, and phonological segmentation provide the best combination of predictors for both real words and nonwords.

Multiple prediction of reading comprehension

We entered, based on current theory, as predictors of reading comprehension[7] the orthographic skill, the phonological skill and the working memory skills which were most highly correlated with reading comprehension. Given that reading comprehension depends to a large extent on word recognition (Perfetti & Hogaboam 1975), it follows that orthographic and phonological skills will contribute to reading comprehension. Also, it has been shown that working memory is related to both skilled reading (Daneman & Carpenter 1980; Just & Daneman 1992) and developing reading (Swanson & Berninger 1993). The Phoneme Localization task, the Homophone/Pseudohomophone Choice Task, two working memory tasks (semantic association and phrase), and Verbal IQ added significant increments of variance; see Table 9. Thus, orthographic images (orthographic access), abstraction of phonemic invariance, and two levels of language in verbal working memory — single word and multi-word — contribute to reading comprehension.

Table 7. Multiple regression of composition criterion skills on predictor development skills

Dependent measures	Independent measures	Standardized coefficient	t	p	R^2	F(5,294)	p
Narrative-words					0.14	9.17	0.001
	Colorado Perceptual Speed	0.23	3.99	0.001*			
	Finger Succession-dominant[a]	−0.13	−2.43	0.016*			
	Alphabet Task	0.14	2.37	0.018*			
	Listening-Generation Span	0.12	2.11	0.036*			
	Verbal IQ	−0.07	−1.17	0.245			
Narrative-clauses					0.10	6.32	0.001
	Colorado Perceptual Speed	0.17	2.80	0.005*			
	Finger succession-dominant[a]	−0.09	−1.59	0.113			
	Alphabet Task	0.15	2.49	0.013*			
	Listening-Generation Span	0.09	1.51	0.133			
	Verbal IQ	0.02	0.28	0.780			
Narrative-quality					0.28	22.55	0.001
	Colorado Perceptual Speed	0.19	3.61	0.001*			
	Finger Succession-dominant[a]	−0.06	−1.16	0.249			
	Alphabet Task	0.17	3.23	0.001*			
	Listening-Generation Span	0.24	4.60	0.001*			
	Verbal IQ	0.20	3.67	0.001*			

Table 7. Continued

Dependent measures	Independent measures	Standardized coefficient	t	*p*	R^2	F(5,294)	*p*
Expository-words					0.12	8.31	0.001
	Colorado Perceptual Speed	0.19	3.18	0.002*			
	Finger Succession-dominant[a]	−0.17	−3.00	0.003*			
	Alphabet Task	0.14	2.49	0.013*			
	Listening-Generation Span	0.12	2.01	0.045*			
	Verbal IQ	−0.07	−1.09	0.279			
Expository-clauses					0.10	6.68	0.001
	Colorado Perceptual Speed	0.16	2.68	0.008*			
	Finger succession-dominant[a]	−0.16	2.81	0.005*			
	Alphabet Task	0.10	1.75	0.081			
	Listening-Generation Span	0.16	2.64	0.009*			
	Verbal IQ	−0.09	−1.40	0.162			
Expository-quality					0.28	22.72	0.001
	Colorado Perceptual Speed	0.19	3.53	0.001*			
	Finger Succession-dominant[a]	−0.09	−1.80	0.073			
	Alphabet Task	0.13	2.52	0.012*			
	Listening-Generation Span	0.14	2.56	0.011*			
	Verbal IQ	0.31	5.75	0.001*			

[a] The negative sign indicates the inverse relationship between the score on this measure (time in seconds) and accuracy on the criterion measures.
* Accounts for a significant increment of variance at $p < 0.05$.

Table 8. Zero-order correlations (rounded to nearest hundredth) between measures of developmental skills and measures of reading skills (based on standardized score within grade)

	Reading Real words	Reading Nonwords	Passage Comprehension
Orthographic System			
Colorado Perceptual Speed	0.40*	0.33*	0.31*
Homophone Choice[a]	0.46*	0.40*	0.38*
Homophone/Pseudohomophone Choice[a, b]	0.58*	0.54*	0.41*
Expressive Orthographic Coding[b]	0.48*	0.55*	0.37*
Phonological System			
Phonetic Memory[a]	0.28*	0.26*	0.36*
Phonemic Localization[a, b]	0.34*	0.37*	0.31*
Phoneme Articulation[a, b]	0.48*	0.50*	0.41*
Syllable/Rime/Phoneme Deletion[a]	0.45*	0.41*	0.44*
Phonemes in Nonwords[a]	0.20*	0.20*	0.24*
Verbal Working Memory			
Rhyme	0.25*	0.23*	0.27*
Semantic Association	0.21*	0.23*	0.23*
Phrase	0.20*	0.18	0.29*
Narrative Text	0.12	0.00	0.32*
Expository Text	0.20*	0.04	0.32*
Listening-Generation Span	0.16	0.06	0.25*
Nonverbal working Memory			
Dots	0.04	0.06	0.14
Maps	0.10	0.08	0.22*
Verbal IQ	0.51*	0.31*	0.70*

[a] Nonwords; [b] Real words.
* $p \leqslant 0.001$ based on correlations to the hundredths place.

DISCUSSION

Convergent and discriminant validity of predictor developmental skills

Our results support Ellis' (1985, 1987) contention that writing and reading draw upon cognitive skills related to writing and reading but not specific to writing or reading. Multiple orthographic skills were significantly correlated with all component writing skills – handwriting, spelling, and composition (see Table 4) – providing *convergent validity* for the construct of an *orthographic system underlying all writing components.* Multiple phonological skills were significantly correlated with spelling (see Table 4) providing convergent validity for the construct of a *phonological system underlying spelling.* Multiple working memory measures were significantly correlated with quality of composition (see Table 4) providing convergent validity for

Table 9. Multiple regression of predictor developmental skills for reading criterion skills

Dependent measures	Independent measures	Standardized coefficient	t	p	R^2	F(7,292)	p
Word recognition — Real words					0.55	51.31	0.001
	Homophone Choice	0.12	2.33	0.020*			
	Homophone/Pseudohomophone Choice	0.27	4.75	0.001*			
	Expressive Orthographic Coding	0.14	3.03	0.003*			
	Phonemic Localization	0.10	2.29	0.023*			
	Phoneme Articulation	0.12	2.46	0.015*			
	Syllable/Rime/Phoneme Deletion	0.12	2.51	0.013*			
	Verbal IQ	0.25	5.50	0.001*			
Word recognition — Nonwords					0.50	41.54	0.001
	Homophone Choice	0.10	1.91	0.057			
	Homophone/Pseudohomophone Choice	0.22	3.67	0.001*			
	Expressive Orthographic Coding	0.28	5.56	0.001*			
	Phonemic Localization	0.15	3.35	0.001*			
	Phoneme Articulation	0.17	3.11	0.002*			
	Syllable/Rime/Phoneme Deletion	0.13	2.46	0.015*			
	Verbal IQ	−0.00	−0.03	0.973			
Passage Comprehension					0.57	55.02	0.001
	Phoneme Localization	0.12	2.85	0.005*			
	Homophone/Pseudohomophone Choice	0.20	4.77	0.001*			
	Semantic Association	0.10	2.51	0.13*			
	Phrase	0.09	2.11	0.035*			
	Narrative Text	0.02	0.50	0.620			
	Expository Text	−0.00	−0.09	0.932			
	Verbal IQ	0.57	12.08	0.001*			

* Adds significant increment of variance at $p < 0.05$ or better.

the construct of a *working memory system underlying the generation of content and organization of written text.* Likewise, multiple measures of orthographic skills and of phonological skills were correlated with reading real words, reading nonwords, and passage comprehension (see Table 8) providing convergent validity for the constructs of an *orthographic system and phonological system underlying all reading components.*

Within the orthographic system, *discriminant validity* was demonstrated in that speeded receptive, non-lexical orthographic coding (Colorado Test) explained unique variance in handwriting, but not in spelling; and orthographic imaging-orthographic address (Homophone/Pseudohomophone Choice Task) explained unique variance in spelling, but not handwriting.

Orthographic imaging-semantic address in response to questions tapping semantic categories (Homophone Choice Test) and Verbal IQ (correlating highly with vocabulary knowledge for real words) explained unique variance in spelling real words and reading real words, but not in spelling nonwords from dictation or reading nonwords, as would be expected because nonwords lack a semantic code. Orthographic imaging (both semantic address in response to questions tapping semantic categories and orthographic address in detecting the real word when phonology is kept constant) also contributed unique increments of variance to spontaneous spelling of real words in functional contexts (narrative and expository compositions). Phoneme articulation (phonemic invariance across word contexts) contributed unique variance to spelling single words in isolation where all attentional resources are directed toward spelling, but phonetic memory (attending to sound information independent of meaning) contributed unique variance to spontaneous spelling in functional contexts (narrative and expository compositions where attentional resources are spread among all components of the writing process and not just focused on spelling). Both the moderate intercorrelations among the four spelling skills (see Table 3) and the varying pattern of concurrent correlations between different orthographic and phonological skills and different spelling tasks suggest that the spelling tasks are tapping somewhat different processes.

Although speeded fine motor coordination, when considered alone, was not correlated with any of the component writing skills, it contributed a unique increment of variance to composition (narrative-words, expository-words, and expository-clauses, see Table 7) when considered in combination with speeded orthographic coding, speeded orthographic-motor integration, verbal working memory, and Verbal IQ. Thus, in intermediate grade writers the contribution of speeded fine motor coordination may become apparent only in the context of the multiple, complex processes involved in composition.

Listening-generation, but not listening-recall, added unique variance to composition, which is a generative not a passive recall process. Verbal IQ contributed unique variance to spelling, quality of composition, reading real words, and passage comprehension but not to reading nonwords.

Shared sub-processes in reading and writing functional systems

Taken together the results show that writing and reading skills at the same level of language — reading and spelling *words* or comprehending and composing *text* — drew upon common and unique developmental skills. The orthographic system is related not only to writing skills (see Table 4) but also to reading skills (see Table 8), and the phonological system is related not only to spelling skills (see Table 4) but also to reading skills (see Table 8). However, different orthographic and phonological skills contributed to word recognition skills than to spelling skills and to the pronunciation of real words than to pronounceable nonwords. All three orthographic skills and all three phonological skills contributed unique variance to naming real words (see Table 9) but the same three orthographic skills and only one phonological skill (tapping phonemic invariance not segmentation) contributed unique variance to spelling dictated real words (see Table 6). Orthographic images (semantic address) did not contribute unique variance to spelling or reading nonwords, but did to spelling or reading real words.

Speeded receptive orthographic coding, speeded orthographic-motor integration, the listening-generation span of working memory and Verbal IQ contributed to predicting the quality of written composition, but phonemic invariance, orthographic imaging (orthographic address), semantic association in verbal working memory (processing meaning of single words), phrase repetition in verbal working memory (processing meaning of word combinations), and Verbal IQ contributed to passage comprehension, measured by a cloze procedure that taps mainly sentence processing (see Table 9). This result shows that sub-word, word-level, and trans-word level processes contribute to passage comprehension. Presumably, verbal working memory measures for narrative and expository texts would have contributed if the measure of reading comprehension required processing of larger discourse structures.

Orthographic coding and images

In the intermediate grades expressive orthographic coding of words represented in short term memory contributed unique variance to handwriting fluency (see Table 5), spelling of real words (see Table 6), compositional fluency and quality (see Table 7), reading real words and nonwords and passage comprehension (see Table 9). Orthographic images of specific words represented in long term memory contributed unique variance to spelling real and nonwords (see Table 6), reading real and nonwords and passage comprehension (see Table 9). The fact that these orthographic skills have similar and different concurrent relations with component reading and writing skills indicates that they tap common and unique processes in the orthographic system.

Phonological segmentation and invariance

In the intermediate grades phonemic invariance, but not phonemic segmentation, contributed unique variance to spelling real words and nonwords from dictation (see Table 6), but both phonemic segmentation and phonemic invariance contributed unique variance to reading real words (see Table 9). Neither of the phonemic skills contributed to spontaneous spelling in composition, but phonetic coding did, probably because phonetically-coded working memory supports the process of text generation and transcription during composing.

Levels of language in verbal working memory

Only text-level working memory measures, and not subword or word level working memory measures, were related to component writing skills (see Tables 4 and 7). In contrast, subword (rhyme) and word level (semantic association), as well as text-level working memory measures were related to component reading skills (see Table 8). This latter result supports the view that reading instruction should be aimed at teaching to all levels of language, ranging from subword, to word, to text levels (Berninger, 1994a).

Implications for writing disabilities and reading disabilities

All the orthographic, phonological, and verbal working memory measures showed concurrent validity (based on zero-order correlations and regressions) for assessing at least one writing or reading skill and thus may be used to assess writing and reading disorders. One of the motor measures showed concurrent validity based on the multiple regression. The means and standard deviations reported in this article can thus be used to identify for either research or clinical purposes those children '*at risk*' in the developmental skills studied (i.e., at or below-1 standard deviation for grade) or '*disabled*' in these developmental skills studied (i.e., in lowest 5% of the normal distribution or 1.65 standard deviations below the mean for grade). (See Berninger & Rutberg 1992, and Berninger & Whitaker 1993, for discussion of criteria for 'at risk' and 'disabled.')

Deficiencies in the developmental skills studied may exert constraints (limit degrees of freedom) on acquisition of both writing and reading. Further research is needed to (a) identify the most effective approaches to remediating deficiencies in these developmental skills and whether remediating these deficiencies concurrent with quality writing and reading instruction is effective in eliminating writing and reading disabilities, (b) determine whether effective remediation of a particular developmental skill transfers to all functional systems drawing upon that skill, and (c) investigate whether concurrent remediation of a deficient developmental skill plus academic instruction results in faster skill acquisition than academic instruction alone.

Such research needs to be theoretically grounded in a model of writing and reading acquisition that acknowledges not only the neurodevelopmental constraints on writing and reading acquisition but also the importance of (a) the social interactive and cultural context in which literacy is acquired, (b) the nature and quality of the instructional program in writing and reading, and (c) the child's opportunity to practice writing and reading in meaningful, communicative contexts (Berninger 1994a).

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NOTES

1. Stimuli are available upon request from John DeFries, Institute for Behavioral Genetics, University of Colorado, Boulder, CO 80309-0345, USA.
2. Stimuli are available upon request from Keith Stanovich, Ontario Institute for the Study of Education, 252 Bloor Street W., Toronto, Ontario, Canada M5S 1V6.
3. Stimuli are available upon request from Richard Olson, Department of Psychology, University of Colorado, Boulder, CO 80309-0345, USA.
4. Stimuli and procedures are available upon request from Virginia Berninger, 322 Miller DQ-12, University of Washington, Seattle, WA 98195, USA.
5. Stimuli and procedures are available upon request from Frank Vellutino, Child Research and Study Center, State University of New York, Albany, NY 12222, USA.
6. Stimuli and procedures are available upon request from H. Lee Swanson, School of Education, University of California, Riverside, CA 92521, USA or from Virginia Berninger (see note 4).
7. In this study, order of entry was not considered in the multiple regressions because our goal was to validate the set of developmental skills that might contribute to functional writing and reading systems and thus might be useful in explaining writing or reading disorders. We had no *a priori* reason for predicting that one skill might be relatively more important than another.

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