COMPARISON OF PEN AND KEYBOARD TRANSCRIPTION MODES IN CHILDREN WITH AND WITHOUT LEARNING DISABILITIES

Virginia W. Berninger, Robert D. Abbott, Amy Augsburger, and Noelia Garcia

Abstract. Fourth graders with learning disabilities in transcription (handwriting and spelling), LD-TD, and without LD-TD (non-LD), were compared on three writing tasks (letters, sentences, and essays), which differed by level of language, when writing by pen and by keyboard. The two groups did not differ significantly in Verbal IQ but did in handwriting, spelling, and composing achievement. Although LD-TD and non-LD groups did not differ in total time for producing letters by pen or keyboard, both groups took longer to compose sentences and essays by keyboard than by pen. Students in both groups tended to show the same pattern of results for amount written as a larger sample of typically developing fourth graders who composed longer essays by pen. Results for that sample, which also included typically developing second and sixth graders, showed that effects of transcription mode vary with level of language and within level of language by grade level for letters and sentences. However, consistently from second to fourth to sixth grade, children wrote longer essays with faster word production rate by pen than by keyboard. In addition, fourth and sixth graders wrote more complete sentences when writing by pen than by keyboard, and this relative advantage for sentence composing in text was not affected by spelling ability. Implications of the results for using computers for accommodations or specialized instruction for students with LD-TD are discussed.

In a seminal, influential paper, Hayes and Flower (1980) proposed that three cognitive processes guide skilled writing: Planning (generating ideas and setting goals), translating (turning ideas into written text), and revising (recreating the text to improve clarity of idea expression). Further, based on cross-sectional studies with children in first through sixth grades, Berninger and Swanson (1994) claimed that children's translating involves two component processes: text generation, which occurs at different levels of language; and transcription, which includes handwriting (letter production) and spelling (word production).
Berninger and Swanson (1994) concluded that transcription may be especially important in beginning and developing writing in the elementary school years. However, researchers who study adult writers have subsequently documented that transcription is also an important cognitive process in skilled writing (e.g., Alagamarot & Chanquoy, 2001; Alamargot, Dansac, Chesnet, & Fayol, 2007; Hayes & Chenoweth, 2006).

Transcription is a basic cognitive process in writing that enables the writer to translate internal language into external written symbols to express ideas in written language (Berninger et al., 2009; Hayes & Berninger, in press; Richards, Berninger, & Fayol, 2009). Transcription ability, which draws on handwriting and spelling, has been found to uniquely predict composing length and quality in developing writers (Berninger, Cartwright, Yates, Swanson, & Abbott, 1994; Berninger et al., 1992; Graham, Berninger, Abbott, Abbott, & Whitaker, 1997), and is thus not a mere mechanical skill (Richards, Berninger, & Fayol, 2009).

Subsequent instructional studies have shown that early handwriting and spelling problems can be treated effectively in first, second, and third graders and that such early specialized instruction in transcription transferred to improved composition; for a review of this research and the related conclusion that treating transcription problems early in schooling prevents more severe writing problems later, see Berninger and Amtmann (2003). More recently, assessment studies (Berninger, Nielsen, Abbott, Wijsman, & Raskind, 2008a, 2008b; Berninger, Raskind, Richards, Abbott, & Stock, 2008) and instructional studies (Berninger, Rutberg et al., 2006; Berninger, Winn et al., 2008) have supported the conclusion that specific learning disabilities exist in transcription skills – handwriting and/or spelling (Berninger, 2006, 2007a, 2007b, 2008c) – that interfere with typical writing development but are treatable with specialized instruction.

Now that computers are widely available both at home and at school, letter production is not achieved solely through handwriting, and typing on a keyboard has become a widely used mode of transcription. Thus, researchers are beginning to study the development of the ability of children with and without specific learning disability in transcription (LD-TD) to write by two transcription modes – by pen (or pencil) and by keyboard.

Two meta-analyses found moderate positive effects of word processing on length and quality of compositions (Bangert-Drowns, 1993; Goldberg, Russell, & Cook, 2003). Bangert-Drowns (1993) reported that these effects were even larger for poor than for good writers. Other researchers have focused not on length and quality but on time-related factors in text production. For example, Connelly, Gee, and Walsh (2007) found that transcription by pen resulted in faster word production than did transcription by keyboard in elementary-school students. The authors attributed this finding to children having more experience writing with pens and pencils than with typing with keyboards; although computers are available, they are not used as often in the elementary-grade classroom for writing assignments or during writing instruction as pens and pencils, even in an era when children may have considerable experience using computers at home.

Other investigators have focused on processes related to handwriting and keyboarding. Christensen (2004) investigated automaticity of integrating orthographic (letter) codes with motor output functions and discovered that automatic orthographic-motor integration on an alphabetic writing task explained significant variance in fluency of composing by both handwriting and keyboarding, but especially for keyboarding. The measure used is the one found by Berninger et al. (1992, 1994) to be the best unique predictor of compositional fluency in elementary students. Berninger, Abbott et al. (2006) documented intra-individual differences in relative skill on this automatic orthographic-motor integration task for writing manuscript or cursive letters by pen or selecting alphabet letters by keyboard.

Yet other researchers have focused on how transcription, if not automatized, drains resources in capacity-limited working memory (e.g., see Bourdin & Fayol, 1994; Fayol, 1999, 2008; Hayes & Chenoweth, 2006; Olive, Favart, Beauvais, & Beauvais, in press; Olive, Kellogg, & Piolat, 2008). Dauite (1986) proposed that writing by keyboard frees up working memory for higher-level writing processes by removing the burden of the mechanical production of writing by hand. A testable hypothesis deriving from this line of research and Dauite’s proposal is that children may write more and faster by keyboard than by pen.

Finally, considerable research has focused on the development and validation of computer tools for students with learning disabilities affecting writing, ranging from software for teaching or practicing specific writing skills and checking spelling to web-based resources to oral language production alternatives that replace or supplement written language production (for review, see Berninger & Amtmann, 2003).

Research that focuses specifically on the use of computer tools in teaching writing to students with learning disabilities has shown that computers have modest beneficial effects on students’ writing, mostly for editing purposes (MacArthur, 2006). Computers may be most beneficial for writing development when combined with evidence-based, explicit, teacher-guided instruc-

Relationship of Transcription Mode to Levels of Language

The current study was not an instructional study. Instead, the goal was to examine the effect of two transcription modes for producing letters (letter formation by pen or letter selection by keyboard) on children's composing at different levels of language at different grade levels: reproducing alphabet letters in alphabetic order (same task used by Christensen, 2004, to study transcription modes), constructing a single sentence, or composing an essay.

The alphabet writing task was included so we could compare our results to those of Christensen (2004), who used this task to show that the problem in automatic orthographic (letter)-motor integration also underlies compositional fluency by keyboard and by pen. The sentence writing task was included because we are conducting a larger study of when sentence awareness and writing of complete sentences emerge and are mastered. Finally, the essay writing task was included as part of a broader study of development of genre-specific composing.

The rationale of the study was that if the relative advantage of pen as a transcription mode is found only at certain levels of language in writing production, the effect may not be due entirely to more writing experience with one transcription mode than the other. Although faster writing may be related, in part, to more experience with writing by pen (Connolley et al., 2007) and relative lack of explicit instruction in keyboarding compared to writing by pen (Christensen, 2004; Connolley et al., 2007), we wondered if amount and rate of writing on each transcription mode might also vary with level of language.

We focused on essay writing because written assignments at school require that children produce more expository writing (e.g., informational texts) than narrative writing, especially after third grade, as teachers pointed out to our research team when we shared with them the results of an instructional study showing gains in narrative writing. We also considered whether the nature of the learning disabilities (e.g., impaired spelling) might influence whether writing by pen or by keyboard was more advantageous.

The first research aim was to study two modes of transcription – handwriting and keyboarding – at three levels of text generation – letters, sentences, and text – in the same children in second and fourth grade (first cohort that enrolled in first grade) and fourth grade and sixth grade (second cohort that enrolled in third grade). A related goal was to evaluate the same variables for individuals in smaller groups in the larger sample who participated in the brain imaging study. One group had handwriting and spelling disabilities, that is, transcription disabilities, and is referred to as LD-TD; the other group did not. Keeping in mind that the longitudinal sample was not a clinic-referred or school-identified sample of students with learning disabilities in writing and that all children in a large, diverse school system were invited to participate, we were not surprised that a small number in the sample would have specific learning disabilities affecting their writing, despite otherwise typical development.

Children with LD-TD met research criteria for specific learning disabilities in written language, defined on the basis of prototypical profiles and associated phenotypes (behavioral markers) for specific writing disabilities (Berninger, 2007a, 2007b, 2008c) that have been validated in 25 years of programmatic research on writing (Berninger, 2009). However, not all of the children with LD-TD had exactly the same profile of specific writing disabilities and would not necessarily be eligible for special education services.

Diagnosis and eligibility for special education services are not the same: Eligibility for services varies widely from state to state (Berninger & Holdnack, 2008), and children who meet diagnostic criteria often do not meet state eligibility criteria (Berninger, 2006). It is hoped that an evidence-based diagnostic scheme for specific learning disabilities in writing will be developed in the future that is consistent from state to state and ensures that affected individuals are identified and given free and appropriate education for writing beginning in kindergarten and continuing throughout formal schooling whenever necessary, in either general or special education (Berninger, 2006, 2009; Berninger & Holdnack, 2008; Berninger & Wolf, 2008).

The second research aim was to study how spelling ability might interact with constructing complete sentences in single sentences or essays when transcribing by pen or by keyboard at the second-, fourth-, or sixth-grade level. For this second aim, we used three spelling ability groups, who were identified in the larger sample during the first year of the study and reliably remained members of the same three spelling ability groups for four years (Garcia, 2007). We evaluated main effects and possible interactions among these independent variables – spelling ability group (low, average, or superior), transcription mode (pen or keyboard), level of language in text generation (sentences alone or in text), and grade level (second, fourth, or sixth) for number of complete sentences as a dependent measure.
METHOD

Participants

Sample recruitment. To announce the opportunity to participate in a research study, a letter, approved by the Institutional Review Board for Human Subjects, was sent to all parents of children who would be entering first or third grade in the fall in a large urban school district near a research university in the Pacific Northwest in the United States. Interested parents were invited to contact the research coordinator, who explained the study. Informed consent was obtained if children met research inclusion criteria and parents agreed to participate and bring their child to the university annually for five years to complete writing and related tasks.

The research inclusion criteria specified that, based on parental interview and questionnaire, the child showed no indication in developmental or medical history of brain injury or disease, intellectual deficiency, primary language or motor disorders, autism spectrum or other pervasive developmental disorder, diagnosis of severe social emotional disturbance, or neurogenetic disorder associated with abnormal development. Thus, the sample was neither a referred sample nor a sample of convenience already identified by a school system (e.g., enrolled in special education).

Characteristics of sample. The study used an accelerated cohort design, such that the first cohort began the study when they were in first grade and ended when they were in fifth grade; the second cohort began the study when they were in third grade and ended when they were in seventh grade. Attrition was low for the total sample, which included 241 children in the first year. It is reported here for the years that contributed data for the analyses in the current study. For the first cohort, of the original 128 first-grade participants, 124 returned in second grade (second year) and 119 in fourth grade (fourth year). For the second cohort, of the original 113 third graders, 110 returned in fourth grade (second year) and 106 in sixth grade (fourth grade).

Both cohorts were diverse in ethnicity and parental level of education and were representative of the community from which they were recruited. Self-reported ethnicities included European-American (64.8%; 65.5%), Asian-American (23.4%; 21.2%), African-American (6.3%; 9.7%), Hispanic (1.6%; 0.9%), Native American (1.6%, first cohort only), and other (2.3%; 2.7%). Parent level of education varied from < a high school education (7% mothers; 12.5% fathers) to high school (7.1% mothers; 7.1% fathers) to > high school education (11.7% mothers; 7.8% fathers; 11.5% mothers, 14.2% fathers) to undergraduate (45.3% mothers, 39.8% fathers; 50.4% mothers, 36.3% fathers) or graduate degree (33.6% mothers, 32.0% fathers; 30.1% mothers, 35.4% fathers). Level of education was missing for the other parents.

Students with Learning Disabilities in Writing

Children with LD-TD affecting handwriting and/or spelling (first research aim). Data were available at fourth grade for the group who had specific learning disability in transcription skills \((n=8)\), hereafter referred to as LD-TD, and children without LD-TD \((n=12)\), who were matched in verbal ability but differed significantly in handwriting and spelling skills.

The children with LD-TD had transcription skills that were below the mean for age and at least one standard deviation below their Wechsler Intelligence Scale for Children, Third Edition (WISC-3; Wechsler, 1991) Verbal IQ, based on definitions used in other programmatic research on specific writing disabilities (e.g., Berninger, Nielsen et al., 2008a, 2008b; Berninger, Raskind et al., 2008); they did not have to meet research criteria for reading disability.

The non-LD writers were near, at, or above age or grade level for handwriting, spelling, and composing. The non-LD writers \((M = 119.25, SD = 17.00)\) and LD-TD writers \((M = 116.63; SD = 8.23)\) did not differ significantly in Verbal IQ, \(F(1,18) = 0.16, p = .69\). But they differed significantly on a standardized measure of PAL Alphabet 15\(^{1}\) (Berninger, 2007) (non-LD writers, \(M = .45 z; SD = .74\); LD-TD, \(M = -.44 z; SD = .93\)), \(F(1,18) = 5.66, p = .029\), Wechsler Individual Achievement Test, Second Edition (WIAT-II) (Wechsler, 2002) Spelling (non-LD writers, \(M = 114.00; SD = 9.59\); LD-TD, \(M = 93; SD = 6.46\)), \(F(1,18) = 29.22, p = .001\), and WIAT II Written Expression (non-LD writers, \(M = 113.25; SD = 8.78\); LD-TD, \(M = 107.25; SD = 10.74\)), \(F(1,18) = 6.45, p = .029\). The differences in composition are not unexpected given prior research showing a unique relationship between transcription skills and composition quality and fluency (amount written within a time limit) in elementary- and middle-school students (Berninger et al., 1992, 1994; Christensen, 2004; Graham et al., 1997).

These same groups of LD-TD writers and good writers, all of whom were right-handed, have been shown to have brain activation differences on writing tasks, lending additional support to the theory that the group with lower writing skills had biologically based LD-TD. The groups differed significantly in functional magnetic spectroscopic imaging (fMRI) blood oxygen level-dependent (BOLD) activation on a variety of fMRI writing tasks in the summer following fifth grade: idea generation (Berninger et al., 2009), handwriting (Berninger & Richards, 2007, 2008a, 2008b, 2008c;
Measures

WIAT-II spelling subtest, which has a mean of 100 and of the average spellers and the upper limit of average fell at or below 95 for poor spellers, between 105 and group membership in this study. WIAT-II spelling scores words from dictation.

spellers based on the WIAT-II (Wechsler, 2007). 2008a, 2008b; Berninger, Raskind et al., 2008; Garcia, 2007) spelling subtest, a test of spelling single written words from dictation.

Effect of spelling ability on writing complete sentences (second research aim). Garcia (2007) identified children who consistently across the longitudinal study were poor (5 girls, 5 boys, cohort 1; 5 girls, 5 boys, cohort 2), average (5 girls, 5 boys, cohort 1; 5 girls, 5 boys, cohort 2), or superior (5 girls, 5 boys, cohort 1; 5 girls, 5 boys, cohort 2) spellers based on the WIAT-II (Wechsler, 2002) spelling subtest, a test of spelling single written words from dictation.

Handwriting or reading skill was not a criterion for group membership in this study. WIAT-II spelling scores fell at or below 95 for poor spellers, between 105 and 112 for average spellers, and above 122 for superior spellers. The upper limit of poor spellers and lower limit of the average spellers and the upper limit of average spellers and lower limit of superior spellers were separated by two thirds of a standard deviation on the WIAT-II spelling subtest, which has a mean of 100 and standard deviation of 15 (Garcia, 2007). The poor spellers met criteria for LD-TD subtype spelling disability, hereafter referred to as LD-SP; they were not only underachieving in spelling compared to their Verbal IQ but were also spelling below the population mean and had associated deficits in phonology, orthography, and/or morphology (e.g., see Berninger, Nielsen et al., 2008a, 2008b; Berninger, Raskind et al., 2008; Garcia, 2007).

Measures

Order of administration of the writing tasks at three levels of language was kept constant across each year of the study so that comparisons could be made across development not related to effects due to variations in order of administration. First, all children completed an alphabet writing task in which they were instructed to form (by pen) and then select (by keyboard) each of the letters in the alphabet in alphabetic order as accurately and quickly as possible. The examiner recorded the last letter written at 15 seconds and the total time, measured by hand-held stop watch, for writing all 26 letters. For this alphabetic writing task, children were asked to form lowercase, manuscript letters by pen, as used in prior research, because lowercase letters are more frequent than capital letters in the text they read and write; standard keyboards have capital letters rather than lowercase, however.

Next, children were asked to write a sentence and then an essay about specified topics, first by pen, and then by keyboard. For these sentence-level and text-level writing tasks, we did not specify whether children had to use manuscript or cursive letters. That is because past research (Graham, Berninger, & Weintraub, 1998; Jones, 2004) has shown that both typically developing and poor writers use manuscript, cursive, or a mix of manuscript and cursive, and we did not want to disrupt the practiced handwriting format of individual writers during the translation process.

The sentence composing and essay composing writing tasks were the same across transcription mode except that the topics children wrote about were varied in order to maintain interest. However, topics were similar across transcription modes at the sentence (writing or reading) and text (computers and robots) levels. Instructions for each combination of writing task and mode of writing by pen or by keyboard follow.

Children were instructed to use a pen to “Write a good sentence that begins with the word writing.” The child indicated when he or she had completed the sentence by typing a double slash to indicate where he or she thought the sentence ended. Children were allowed to write more if they wished about the topic, but only what they had written before the double slash was entered into subsequent analyses of word count. The amount of time the child wrote up to the double slash was recorded and used in data analyses. Thus, unit of production reflected what the child thought a sentence was. For this research aim, the written production was not scored for sentence fragment, run-on sentence, or complete sentence, as was the case for the second research aim.

After the sentence writing task by pen, children were given the following instructions for essay writing by pen: “Explain what a computer is and what it does to someone who has never seen one or used one.” The time limit was 10 minutes, which we have found is ample for obtaining independently generated composition samples from children in the grade range studied. If the child ceased writing before the time limit, despite two prompts to write more (“What else can you think of?”), the actual time spent writing was recorded. Examiners asked children to identify any word they could not decipher because of illegible handwriting or unconventional spelling; this information was recorded so at the time of data analyses we could discern which letters and words were intended when analyzing data.

Finally, children performed sentence and essay composing tasks by keyboard. Children were first instructed to “Write a good sentence that begins with the word reading.” As with sentence composing by pen, the child indicated that the sentence was completed by typing a
double slash to indicate where he or she thought the sentence ended. Children were allowed to write more if they wished about the topic, but, as for writing by pen, only the number of words they had written before the double slash and the time they had spent writing up to the double slash were used in data analyses.

Then children were given the following prompt for essay writing by keyboard: “Explain what a robot is and what it does to someone who has never seen one or used one.” The time limit was 10 minutes. Again, if, despite two prompts to continue, the child ceased writing before the 10-minute time limit, the actual time spent writing was recorded; examiners asked children to identify any word they could not decipher and recorded the intended word for purposes of later data analyses.

Procedures
Children completed the following tasks at the university, where trained and highly supervised graduate students administered the testing. Children completed a series of writing tasks at different levels of language, first by pen and then by keyboard, which were then scored for each level of language across the transcription modes.

Automatic letter production. The number of legible letters in alphabetic order in the first 15 seconds was counted to assess amount written during this initial time segment for the alphabet writing task by pen and by keyboard. Letters were considered legible if they could be identified if they appeared out of the context of the alphabet writing task. This score, which was used in Berninger et al. (1992, 1994), Graham et al. (1997), and Christensen (2004), is an index of automaticity in retrieving alphabet letters from memory and producing them legibly and quickly in the correct order. We also entered the total time for writing all 26 alphabet letters for both transcription modes into analyses.

Number of words and rate of word production. For the first research aim, the number of words was counted for the sentence writing and essay composing tasks on both transcription modes and converted, based on total time for the task, to a seconds-per-word score. For sentence writing on either transcription mode, the prompt word “Writing” or “Reading” was counted in the word count and analysis, as were any other words before the double slash.

Coding complete sentences. Much of the research on oral language production (oral register of language) (Halliday, 1987) has used the T-unit, or “minimal terminable unit,” which is “one main clause plus any subordinate clause or nonclausal structure that is attached to or embedded in it” (Hunt, 1970, p. 4). However, for three reasons, we did not use T-units in analyzing children’s production of complete written sentences on the sentence writing and essay writing tasks for the second research aim.

First, oral utterances (the oral register) do not necessarily correspond to written language productions. We do not talk in sentences. Second, linguistic analysis of written language productions has been relatively neglected compared to oral language production (Jaffré & Fayol, 2006), and our goal is to remedy that. Third, writing instruction and expectations at school, based on the academic register for written language, emphasize writing in complete sentences rather than sentence fragments or run-on sentences.

Thus, for the sentence writing and essay writing tasks for the second research aim, number of complete sentences, rather than number of words as for the first research aim, was analyzed at two levels of language—single sentences and essays. Complete sentences were defined as (a) one main clause with no other independent or dependent clauses or conjunctions, (b) a main clause plus an embedded or non-embedded subordinate clause and subordinate conjunction (e.g., which or because), (c) two main clauses combined with a coordinating conjunction (and), or (d) two main clauses with a correlative conjunction (or). Punctuation, which marks idea units, was also used to determine sentence boundaries (Fayol, 1999).

To calculate interrater reliability for the coding scheme, two members of the research team were trained to code. After practice, they coded the sentence and the essay writing samples by both pen and keyboard independently for 20 randomly selected participants in second and fourth grade for the first cohort and in fourth and sixth grade for the second cohort. Average interrater reliability was 94.2%.

RESULTS
First Research Aim
Results of the analyses for all the children (234 in year 2; 225 in year 4) are reported because learning disabilities are best understood in reference to the typical variation that occurs in children without learning disabilities (Berninger, 2009). Results for second grade are from cohort 1; results for fourth grade are combined across cohorts 1 and 2; results for sixth grade are from cohort 2.

Descriptive statistics (means and standard deviations) and inferential statistics (repeated analyses of variance, ANOVAs) for each condition (two transcription modes by three levels of language) are reported for amount written (see Table 1) and the letter writing times or word production rates (see Table 2) at each of the three grade levels (second, fourth, and sixth). The findings are explained separately by level of language and grade level.
Table 1

<table>
<thead>
<tr>
<th>Levels of Language</th>
<th>By Pen</th>
<th>By Keys</th>
<th>Partial eta²</th>
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<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Mean</td>
<td>df</td>
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<tr>
<td>Automatic Letter Writinga,b (15 sec)</td>
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<td></td>
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<tr>
<td>Grade 2</td>
<td>4.45</td>
<td>2.20</td>
<td>6.20</td>
</tr>
<tr>
<td>Grade 4</td>
<td>7.18</td>
<td>3.41</td>
<td>11.73</td>
</tr>
<tr>
<td>Grade 6</td>
<td>10.12</td>
<td>3.44</td>
<td>18.31</td>
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<tr>
<td>Words in Sentences</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade 2</td>
<td>6.02</td>
<td>4.39</td>
<td>5.17</td>
</tr>
<tr>
<td>Grade 4</td>
<td>7.62</td>
<td>4.77</td>
<td>9.87</td>
</tr>
<tr>
<td>Grade 6</td>
<td>8.82</td>
<td>5.12</td>
<td>11.52</td>
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<tr>
<td>Words in Essaya</td>
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<tr>
<td>Grade 2</td>
<td>21.67</td>
<td>14.76</td>
<td>13.23</td>
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<tr>
<td>Grade 4</td>
<td>58.34</td>
<td>34.60</td>
<td>36.73</td>
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<tr>
<td>Grade 6</td>
<td>73.87</td>
<td>30.65</td>
<td>59.42</td>
</tr>
</tbody>
</table>

aWithin time limit. bAlphabet 15 seconds; 2001 version of Berninger (2007a), which now has scaled scores.

*Alphabet writing.* Second graders produced more correct alphabet letters in alphabetic order in the first 15 seconds by keyboard (see Table 1), but required more time to produce all 26 letters by keyboard (see Table 2). Likewise, fourth and sixth graders also produced more correct letters in alphabetic order in the first 15 seconds by keyboard (see Table 1), but unlike the second graders, they required less time to produce all 26 letters by keyboard (see Table 2). This pattern of results not only reflects an advantage of the keyboard for *automatic letter writing* (how many items are produced legibly and in order within a time limit early in retrieval of an ordered item set) in grades 2, 4, and 6, but also a developmental change in *handwriting speed* (total time required for producing all items in an ordered set legibly and in order), with fourth and sixth graders becoming faster on the alphabetic writing task by keyboard.

*Sentence composing.* When producing what they thought was a sentence, second graders wrote more words, but fourth and sixth graders wrote fewer words by pen than by keyboard (see Table 1). Consistently, the second, fourth, and sixth graders composed a single sentence unit at a faster rate by pen (see Table 2).

*Essay composing.* Consistently, second, fourth, and sixth graders composed longer essays by pen than by keyboard (see Table 1). Number of words or length of a composition within a constant time interval is considered a measure of compositional fluency, which has been shown to have moderately high correlations with composing quality (e.g., Berninger et al., 1992). When outcome was number of seconds required per word, consistently second, fourth, and sixth graders produced words in essays at a faster word production rate by pen than by keyboard (see Table 2).

*Summary.* Second, fourth, and sixth graders wrote more letters automatically by keyboard than by pen, and fourth and sixth graders wrote the whole alphabet faster by keyboard than by pen. Second graders wrote
longer sentences (number of words in what was perceived as complete sentence unit), but fourth and sixth graders wrote shorter sentences by pen than by keyboard. The second, fourth, and sixth graders wrote sentences faster (seconds per word) by pen than by keyboard. Second, fourth, and sixth graders wrote longer essays (number of words) and wrote essays faster (seconds per word) by pen than by keyboard. Thus, transcription mode effects depended on level of language and grade. Only at the text level did pens have a consistent advantage over keyboards across grade levels for both amount written (number of words) and rate (seconds per word).

**Individual subject analyses.** First, because of the well-documented compositional fluency problems of students with LD-TD (e.g., Berninger & Amtmann, 2003; Christensen, 2004; Connelly, Campbell, MacLean, & Barnes, 2006), we compared the LD-TD (handwriting and/or spelling disability) and non-LD groups who participated in the brain imaging studies on the time they engaged in sustained writing on each level of language task and transcription mode in fourth grade.

The two-way ANOVAs showed that time effects varied with level of language. Transcription mode did not affect letter production time, but it did affect sentence and essay composing time. Whether LD-TD or non-LD groups wrote by pen (LD-TD, $M = 53.25$, $SD = 9.57$; Non-LD, $M = 43.42$, $SD = 19.21$) or keyboard (LD-TD, $M = 50.88$, $SD = 25.69$; Non-LD, $M = 44.25$, $SD = 22.26$), they did not differ significantly in total time for letter production, $F(1,18) = .027, p = .872$. However, both groups took longer to compose sentences and essays by keyboard than by pen.

For sentence composing, in contrast to the findings for the larger sample of typically developing fourth graders who wrote words faster (seconds per word) in sentences by keyboard than by pen, both students with...
Table 3
Individual Analyses of Amount Written by Mode (Pen or Keyboard) and Level of Written Language (Alphabet Writing, Sentence Composing, and Essay Composing) in LD-TD Writers (with Learning Disability in Transcription) and Non-LD Writers in Fourth Grade

<table>
<thead>
<tr>
<th>Alphabet</th>
<th>Sentence</th>
<th>Essay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>By Pen</td>
<td>By Keys</td>
</tr>
<tr>
<td></td>
<td># Letters</td>
<td># Letters</td>
</tr>
<tr>
<td>LD-TD Writers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>9</td>
<td>3</td>
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<tr>
<td>S2</td>
<td>7</td>
<td>4</td>
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<td>S3</td>
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<tr>
<td>S4</td>
<td>7</td>
<td>0</td>
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<tr>
<td>S5</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>S6</td>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td>S7</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>S8</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>Non-LD Writers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S9</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>S10</td>
<td>2</td>
<td>n.a.</td>
</tr>
<tr>
<td>S11</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>S12</td>
<td>7</td>
<td>25</td>
</tr>
<tr>
<td>S13</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>S14</td>
<td>11</td>
<td>11</td>
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<tr>
<td>S15</td>
<td>6</td>
<td>8</td>
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<td>S16</td>
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<td>17</td>
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<td>S17</td>
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<td>15</td>
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<td>S18</td>
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<td>18</td>
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<td>S19</td>
<td>6</td>
<td>15</td>
</tr>
<tr>
<td>S20</td>
<td>15</td>
<td>5</td>
</tr>
</tbody>
</table>

and without LD-TD composed sentences more slowly by keyboard (total seconds) \(M = 57.90, SD = 42.03\) than by pen \(M = 38.50, SD = 16.60\), \(F(1, 18) = 4.53, p < .047\). For essay composing, in keeping with the findings for the larger sample of typically developing fourth graders, both students with and without LD-TD spent more time composing essays by keyboard (seconds) \(M = 415.10, SD = 188.16\) than by pen \(M = 325.05, SD = 157.85\), \(F(1, 18) = 9.92, p = .006\).

For analyses of amount written, we examined individual differences of children with and without LD-TD in the brain imaging study in reference to the results for the larger longitudinal sample displayed in Tables 1 and 2. We did so because results at the group level of analysis do not always generalize to individuals (e.g., Cronbach, 1957), and we have observed individ-

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ual differences among groups of students with writing disabilities in many of our studies (e.g., Berninger, Abbott, Whitaker, Sylvester, & Nolen, 1995). Some data are missing because of technical difficulties with administration or scoring.

As shown in Table 3, for amount written, the majority of individuals within the LD-TD group and the non-LD group showed the same patterns as the sample as a whole in fourth grade. Altogether, five of the eight LD-TD writers wrote more alphabet letters by keyboard than by pen. Of the 11 non-LD writers for whom data were available on this task (matched to the LD-TD sample on verbal ability), 9 wrote more alphabet letters by keyboard than by pen. Children in both groups showed a mixed pattern for sentence composing: 3 of 8 LD-TD writers and 3 of 12 non-LD writers wrote longer sentences with more words by pen; 4 of 8 LD-TD writers and 6 of 12 non-LD writers wrote sentences with more words by keyboard; and 1 of 8 LD-TD writers and 3 of 12 non-LD writers wrote the same number of words by pen and by keyboard. However, as the sample as a whole, individual children in both groups tended to write longer essays with more words by pen than by keyboard: 6 of 8 LD-TD writers and 10 of the eleven non-LD writers with complete data. Thus, the group findings generalized well to individual cases for amount written, especially at the letter and text levels, but some individuals departed from the group findings, as is often found in generalizing group research results to individual cases.

Second Research Aim

Tables 4 and 5 summarize the results pertinent to the second specific research aim. When second and fourth graders in the first cohort were compared on writing complete sentences in essays (see Table 4), the only significant effect was for grade level. Fourth graders wrote more complete sentences in essays (M = 3.56) than second graders (M = 1.96). When the fourth and sixth graders in the second cohort were compared on writing complete sentences in essays (see Table 4), significant main effects were observed for mode (more by pen, M = 5.24, than by keyboard, M = 3.84), and grade (sixth graders wrote more, M = 5.32, than fourth graders, M = 3.77). Further, the mode by grade interaction was significant (the relative difference between modes was larger for the sixth grade, pen, M = 5.33, versus keyboard, M = 4.30, than for fourth grade, pen M = 4.16, versus keyboard, M = 3.39).

No differences related to transcription mode were observed in either cohort for composing single complete sentences (see Table 5). None of the main effects or interactions involving spelling ability was significant for either complete sentences in essays (see Table 4) or complete sentences alone (see Table 5). Thus, LD-SP or average or superior spelling was not related to ability to compose complete sentences in or out of text.

DISCUSSION

First Research Aim

Tested hypotheses. We did not find support for Dauite's (1986) prediction that children with learning disabilities would write more using keyboards because keyboards relieve writers of the mechanical burden of writing letters and thus free up working memory space. Rather, the relative advantage of keyboarding was found mostly, but not always, at the letter level and sometimes at the sentence level, but not at all at the text level, which places greater demands on working memory capacity.

However, the current results do not speak directly to the role of working memory in writing (e.g., Alamargot & Chanquoy, 2001; Alamargot et al., 1997; Bourdin & Fayol, 1994; Chenoweth & Hayes, 2003; Olive et al., 2008, in press) or writing disabilities (e.g., Berninger, 2008; Hooper, Knuth, Yerby, Anderson, & Moore, 2009; Swanson & Berninger, 1996), but indirectly to the role of the keyboard in overcoming working memory problems due to transcription processes not being automatized.

The most important finding relevant to the purpose of the research was that any advantage for transcription mode depended on level of language in the written production, as hypothesized: Writing by pen had a consistent advantage for amount written and rate of composing essays in second, fourth, and sixth graders (first specific aim), and for fourth and sixth graders in composing complete sentences in essays (second specific aim). Thus, prior findings of faster handwriting speed by pen than by keyboard are related, no doubt in large part, to practice and explicit instruction with each transcription mode (Connolley, 2006; Christensen, 2004). However, other factors such as level of language in the writing task may also contribute to writing longer essays and writing them faster by pen. The relative advantage in the current study for composing essays by pen replicated prior findings for narrative composing in third, fifth, and seventh graders (Berninger, 2008a; Berninger & Richards, 2007). Later in the Discussion we consider how on-line processing may account for these findings.

Second Research Aim

When the outcome was writing complete sentences, the results depended on the grade levels that were compared. For the second and fourth graders in the first cohort, neither of the transcription modes had a relative advantage for producing complete sentences in sen-
Table 4
ANOVA Summary for Mode (2), Spelling (3), and Cohort Grade (Cohort 1, Second and Fourth Grade; Cohort 2, Fourth and Sixth Grade) for Complete Sentence in Essay Composing

<table>
<thead>
<tr>
<th></th>
<th>MS</th>
<th>F</th>
<th>df</th>
<th>p</th>
<th>Partial etα²</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cohort 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mode</td>
<td>.01</td>
<td>.01</td>
<td>1</td>
<td>.95</td>
<td>.00</td>
</tr>
<tr>
<td>Mode by spelling</td>
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<td>1.69</td>
<td>2</td>
<td>.32</td>
<td>.53</td>
</tr>
<tr>
<td>Error (mode)</td>
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<td>3</td>
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<tr>
<td>Grade</td>
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<td>11.79</td>
<td>1</td>
<td>.04*</td>
<td>.80</td>
</tr>
<tr>
<td>Spelling by grade</td>
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<td>6.59</td>
<td>2</td>
<td>.08</td>
<td>.82</td>
</tr>
<tr>
<td>Error (grade)</td>
<td>.90</td>
<td></td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mode by grade</td>
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<td>.12</td>
<td>1</td>
<td>.75</td>
<td>.04</td>
</tr>
<tr>
<td>Mode x spell x grade</td>
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<td>.05</td>
<td>2</td>
<td>.95</td>
<td>.03</td>
</tr>
<tr>
<td>Error (mode x grade)</td>
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<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spelling</td>
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<td>5.37</td>
<td>2</td>
<td>.10</td>
<td>.78</td>
</tr>
<tr>
<td>Error (spelling)</td>
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<td></td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cohort 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mode</td>
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<td>23.04</td>
<td>1</td>
<td>.00*</td>
<td>.48</td>
</tr>
<tr>
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<td>.74</td>
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</tr>
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<td>Error (mode)</td>
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<td></td>
<td>25</td>
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<td></td>
</tr>
<tr>
<td>Grade</td>
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<td>10.08</td>
<td>1</td>
<td>.00*</td>
<td>.29</td>
</tr>
<tr>
<td>Spelling by grade</td>
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<td>2</td>
<td>.91</td>
<td>.01</td>
</tr>
<tr>
<td>Error (grade)</td>
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<td>Mode by grade</td>
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<td>4.65</td>
<td>1</td>
<td>.04*</td>
<td>.16</td>
</tr>
<tr>
<td>Mode x spell x grade</td>
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<td>.19</td>
</tr>
<tr>
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<td>25</td>
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<td></td>
</tr>
<tr>
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<td>2.36</td>
<td>.19</td>
<td>2</td>
<td>.83</td>
<td>.02</td>
</tr>
<tr>
<td>Error (spelling)</td>
<td>12.40</td>
<td></td>
<td>25</td>
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<td></td>
</tr>
</tbody>
</table>

Note. Asterisks denote statistically significant differences.
### Table 5

ANOVA Summary for Mode (2), Spelling (3), and Cohort Grade (Cohort 1, Second and Fourth Grade; Cohort 2, Fourth and Sixth Grade) for Complete Sentence in Sentence Composing

<table>
<thead>
<tr>
<th></th>
<th>MS</th>
<th>F</th>
<th>df</th>
<th>p</th>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>.01</td>
<td>.16</td>
<td>1</td>
<td>.70</td>
<td>.01</td>
</tr>
<tr>
<td>Mode by spelling</td>
<td>.09</td>
<td>2.10</td>
<td>2</td>
<td>.16</td>
<td>.23</td>
</tr>
<tr>
<td>Error (mode)</td>
<td>.04</td>
<td></td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade</td>
<td>.01</td>
<td>.16</td>
<td>1</td>
<td>.70</td>
<td>.01</td>
</tr>
<tr>
<td>Spelling by grade</td>
<td>.09</td>
<td>2.10</td>
<td>2</td>
<td>.16</td>
<td>.23</td>
</tr>
<tr>
<td>Error (grade)</td>
<td>.04</td>
<td></td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mode by grade</td>
<td>.01</td>
<td>.25</td>
<td>1</td>
<td>.63</td>
<td>.02</td>
</tr>
<tr>
<td>Mode x spell x grade</td>
<td>.01</td>
<td>.27</td>
<td>2</td>
<td>.77</td>
<td>.04</td>
</tr>
<tr>
<td>Error (mode x grade)</td>
<td>.05</td>
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<td>Error (spelling)</td>
<td>.05</td>
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<tr>
<td><strong>Cohort 2</strong></td>
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<td>Mode</td>
<td>.01</td>
<td>.08</td>
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<td>.78</td>
<td>.00</td>
</tr>
<tr>
<td>Mode by spelling</td>
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<td>.08</td>
<td>2</td>
<td>.92</td>
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</tr>
<tr>
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<td>Mode by grade</td>
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<td></td>
<td>27</td>
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</tbody>
</table>
tence writing or essay writing. Both fourth and sixth graders in the second cohort wrote more complete sentences in essays by pen than by keyboard, but the children in that cohort wrote more complete sentences and wrote relatively more of them when they were in sixth grade than when they were in fourth grade.

Of relevance for children with LD-SP, spelling ability was never related to number of complete sentences. Word-level spelling and sentence-level composing are separate levels of language: Ability at one level does not predict ability at the other levels, as shown previously in developing writers (e.g., Whitaker, Berninger, Johnston, & Swanson, 1994).

**Relationship of Transcription Mode to LD**

Across both the first and second research aims, transcription mode effects did not differ for children with or without LD-TD. This finding held whether children had LD-TD (first aim) or LD-SP (second aim). Thus, whether children do or do not have TD problems, they will not necessarily produce more written language or produce it faster by using a keyboard. That does not mean that they should not use keyboards or be given explicit instruction in using keyboards as part of the instructional program in writing, however. This finding simply suggests that use of computer keyboard alone, without explicit writing instruction, may not be an evidence-based bypass strategy for TD problems.

In the following, we consider, from an on-line processing perspective, why the advantages for writing with pens were found, and then we discuss the educational implications of the findings.

**Relationship of Transcription and Text Generation in Translating Ideas**

The relative advantage of the pen over the keyboard has been found for three different outcomes at the text level of production in elementary-school children: (a) essay writing for amount written and rate of word production in second, fourth, and sixth grade (first research aim of current study); (b) number of complete sentences in essays (second research aim of current study); and (c) number of ideas expressed in essays (second research aim of current study); and (c) number of ideas expressed in essays (second research aim of current study); and (c) number of ideas expressed in essays (second research aim of current study). Also, children wrote sentences at a faster word rate by pen (first specific aim) in second, fourth, and sixth grades.

To begin with, letter production (handwriting) enhances letter identification (James & Gauthier, 2006). Although letter writing may be more automatic by keyboard in second, fourth, and sixth grade and faster in letter writing speed in fourth and sixth grade, the time advantage does not appear to result in longer essays or faster rate of essay writing when composing by keyboard. Forming a written word letter-by-letter by pen may leave a stronger memory trace for written words than does producing a word letter-by-letter by keyboard in beginning and developing writers (current study), just as adults learn novel characters better by writing them by pen than by keyboard (Longcamp et al., 2008).

Pacton, Fayol, and Perruchet (2005) introduced the important concept of implicit graphotactic learning – learning to abstract the statistical regularities underlying identification of written words (composed of graphemes) by writing and spelling words. The motor act of producing a word results in tactile sensations in the brain; such sensations may create an envelope that links letters into a single written word unit, much as oral intonation creates a contour for linking phonemes into a spoken word unit (Richards, Berninger, & Fayol, 2009), and thus facilitates the abstraction of orthographic regularities.

In support of the concept of graphotactic learning through writing the letters in a word, Richards, Berninger, and Fayol (2009) found that children with and without LD-TD differed on an fMRI receptive spelling task with no motor output requirements: The non-LD spellers showed significant activation in primary somatosensory and primary motor regions of the brain, but the LD-TD spellers showed activation only in primary motor regions of the brain. As a result of forming words by pen, good writers may construct, based on tactile feedback from the motor act of forming letters by hand, graphotactic word envelopes for familiar word-specific spellings. However, children with LD-TD, lacking the tactile feedback, may not abstract these graphotactic word envelopes for word-specific spellings (Richards, Berninger, & Fayol, 2009).

Graphotactic word envelopes may develop more quickly and become automatic sooner for handwriting by pen than by keyboard because the writer receives different kinds of tactile feedback when forming letters (putting letters on the page) than by selecting letters (touching a key with an already formed letter) (cf. James & Gauthier, 2006) or viewing letters on paper or monitor (e.g., Longcamp, Anton, Roth, & Velay, 2003).

For example, Longcamp et al. (2003) reported evidence that letter perception engages motor regions of the brain whereas writing engages letter-specific visual regions. Adults learned to discriminate new characters from their mirror images better when taught to produce the characters by pen than by keyboard (Longcamp et al., 2008), indicating that the act of formation may have an advantage over selection of a character (Longcamp et al., 2008). The finding that producing letter forms was faster by keyboard (alphabet writing in first 15 sec) in second, fourth, and sixth grades and alphabet writing total time in fourth and sixth grade) but rate of word production (forming letters in sequence for word
spellings) was faster by pen suggests that the graphotactic envelope for words may reduce time costs over those incurred by the single constituent letters alone. The reduced time costs may be related to how the graphotactic envelope is involved in storage of and access to written spellings.

Research is needed on how writing by pen versus by keyboard may differentially influence the construction of and access to graphotactic word envelopes, which unify letter sequences into word units in memory, where they are coded in terms of single-letter identity, letter sequences, and also the word-specific spelling linked to morphology, semantics, and pronunciation. The current results suggest that although children with and without LD-TD differ in their construction of graphotactic envelopes for specific words (Richards, Berninger, & Fayol, 2009), using the keyboard alone is unlikely to compensate for this problem in children with LD-TD. Specialized instruction in writing, which includes explicit instruction in transcription, may be necessary as discussed later.

Pacton et al. (2005) also found that the abstracted statistical regularities include both morphological and orthographic properties. In both French (Pacton et al., 2005) and English (e.g., Nunes & Bryant, 2006), word pronunciation and spelling are often regular for written morpheme units that appear to be irregular at the alphabet level (grapheme-phoneme correspondence). Garcia's (2007) discriminant-function analyses found that the same set of phonological, orthographic, and morphological awareness abilities discriminated poor, average, and superior spellers from first to sixth grade, showing that spelling does not involve only phonological processes. The act of producing a graphotactic word envelope may activate silent orthotactic and morphotactic regularities even when alphabetic principle is not transparent (see Jaffré & Fayol, 1999; Nunes & Bryant, 2006; Pacton et al., 2005).

Abstracting and activating morphological and orthographic regularities by writing words by pen may benefit composing through the strong connections between morphology and vocabulary meaning and between morphology and text-level comprehension (e.g., Carlisle, 2003; Stahl & Nagy, 2005). As a result of these connections, word writing by pen results in essays that are longer, produced at a faster rate, and in fourth grade and above may contain more complete sentences (current study) and more ideas (Hayes, 2008; Hayes & Berninger, 2009). Future research might address possible differences between handwriting and keyboarding in abstracting or activating morphological and orthographic regularities at the word-level during composing.

A complicating factor in comparing writing by pen and by keyboard is the fact that we use only one hand when writing by pen but two hands when writing by keyboard. Only the contralateral cerebral hemisphere regulates one writing hand, but two contralateral cerebral hemispheres are involved when writing by two hands; coordinating the two hemispheres requires a white fiber tract commissure (corpus callosum), which may not be fully myelinated until the middle school years or later (age 11 and above) (see Berninger & Richards, 2002).

Future research might investigate the degree to which differences between handwriting and typing might be related to differences in using one hand by pen or two hands by keyboard; for example, unimanual hand function may facilitate development of graphotactic envelopes for word production more than does bimanual hand function. In our clinical and research experience, children with LD-TD often self-report preference for the mouse, which requires only one hand to operate, as a mode of computer interface. Perhaps keyboarding methods for using only one hand for selecting keys could be developed and evaluated for children with and without LD-TD in the formative stages of writing development. Alternatively, using a pen-like tool to form letters on a computerized writing tablet may have an advantage over a keyboard. In addition, whether keyboards with lowercase letters might result in better text-level composing might be investigated. However, relative advantages were observed at the letter-level for the keyboard, suggesting that the capital letter labels may not be a problem.

Finally, in an fMRI study, producing serial finger movements, controlled for non-serial finger movement alone, activated brain regions associated robustly with cognitive, metacognitive, and language processes in non-LD writers (Berninger & Richards, 2007, 2008a, 2008b, 2008c; Richards, Berninger, Stock et al., 2009). Such activation may contribute to idea expression, sentence construction to express complete thoughts, and composition of longer essays.

Future research might assess whether writing words by pen is associated with more activation related to higher level cognitive processes than is writing words by keyboard, at least in beginning and developing preadolescent writers, because of how forming letters through sequential pen strokes engages serial finger movements more than does selecting and pressing letters on a keyboard— at least until graphotactic envelopes are created for word-specific sequential keystrokes as well as word-specific sequential penstrokes within and across letters.

**Implications for Practice**

**Use of computers in accommodations for students with LD-TD.** Parents often report that schools offer their children with writing-related learning disabilities
accommodations in the form of using a computer to complete writing assignments rather than specialized instruction in writing (Berninger, 2006, 2008b). Although some educational professionals believe that computer keyboards alone will bypass writing problems and enable students with LD-TD to express their ideas in written language, many parents observed that their children's writing problems persisted even when they had computer accommodations (Berninger, 2006, 2008b). An educationally relevant finding of the current study is that across different outcomes for the first and second research aims, students with and without learning disabilities showed the same pattern of relationships between transcription modes and levels of language. That is, they tended to compose longer essays and compose at a faster rate by pen than by keyboard. Thus, although accommodations in the form of using a computer keyboard to bypass transcription problems may be necessary and appropriate in some cases, they may not be sufficient.

**Specialized instruction in writing for students with LD-TD.** The results of the current study suggest that relying only on accommodations with a keyboard may not be appropriate. Other research has shown that in the early grades children need explicit instruction and practice in forming letters legibly and automatically by sequential component strokes and in multiple strategies for connecting units of spoken and written language in sequential spelling units for specific words (for review, see Berninger & Amtmann, 2003). Recent meta-analyses for students in fourth grade and above have shown that explicit, systematic instruction in writing that teaches strategies for a variety of writing tasks and that incorporates computers in the instructional program is effective (Graham & Perrin, 2007a, 2007b). Research has also shown that in addition to incorporating computers into the instructional program in writing, developing writers benefit from interactions between the teacher and student writers and among student writers in setting and evaluating goals for planning, translating, and revising in composing text of many genres (Wong, 2001; Wong, Butler, Ficzere, & Kuperis, 1996, 1997; Wong, Butler, Ficzere, Kuperis, & Corden, 1994; Wong, Wong, Darlington, & Jones, 1991). Thus, evidence supports the use of computers, not in isolation, but in the social context of evidence-based writing instruction.

For recent reviews of evidence-based writing instruction for students with LD-TD, see Graham, MacArthur, and Fitzgerald (2007), Hooper et al. (2009), and Troia (2009). For evidence-based teaching strategies for writing, see Graham and Harris (2005) and Harris, Graham, Mason, and Friedlander (2008). For lesson plans validated in instructional research with older students with persisting, diagnosed LD-TD that show that is never too late to respond to explicit writing instruction, see Berninger and Wolf (2009, in press). Appropriate writing instruction for students with LD-TD can be provided in the general education as well as special education classroom if teachers are adequately trained in evidence-based writing instruction, have access to evidence-based writing curriculum and instructional tools, and implement them with fidelity; but recent surveys indicate that much work remains to make that a reality (e.g., Graham, Harris, Mason, Fink-Chorzempa, Moran, & Saddler, 2008; Graham, Morphy, Harris et al., 2008).

**Diagnosis of specific learning disabilities.** Although the primary goal of this research was to evaluate the relationship between level of language and transcription mode, the current research, which is part of a larger programmatic line of research on typical writing and specific writing disabilities, also calls attention to the instructional needs of students with LD-TD. Nationally, in the United States, the reading problems of students with LD have been emphasized rather than their writing problems. Federal legislation specifies written expression as one area in which a student may have an educationally handicapping condition that entitles the affected individual to a free and appropriate education (FAPE), but how that gets translated into practice in each state varies greatly. Existing federal legislation is not sufficiently explicit to identify educationally handicapping conditions in transcription skills in writing (but not necessarily the content of their idea generation) (e.g., see Berninger, 2006, 2008b, 2008c).

Many schools use the Written Expression Composite on the Woodcock Johnson, Third Edition (Woodcock, McGrew, & Mathers, 2001), based on writing samples (untimed measure of sentence-level composing that is scored for content and quality of composing rather than transcription processes) and writing fluency (timed sentence-level composing). However, higher scores on writing samples may mask LD-TD. In contrast, use of writing fluency alone, which is more likely to be impaired in LD-TD (Berninger & Amtmann, 2003; Christensen, 2004, Connelly et al., 2006), is more likely to identify students who need specialized instruction in writing related to TD. WJ III Spell Sounds (Woodcock et al., 2001), a measure of pseudoword spelling, and measures of real-word spelling and handwriting are also likely to identify LD-TD (Berninger, 2006, 2008c).

Research has shown that some children have only LD-TD, which is also dysgraphia (impaired letter form production) – handwriting disability only (Berninger, Raskind et al., 2008c), spelling disability only (Fayol, Zorman, & Lét, 2009), or handwriting and spelling disability (Berninger, 2008c; Berninger, Raskind et al., 2008). Other children have co-occurring problems in
reading and oral language problems (see Berninger, 2007a, 2007b, 2008c; Berninger, Raskind et al., 2008). Students with dyslexia have both reading and writing disability (Berninger, Nielsen et al., 2008a), and gender differences are associated with the writing disability, particularly the TD component (Berninger, Nielsen et al., 2008b). Individual differences exist in the processes related to writing by pen and by keyboard, and these should be assessed to generate recommendations about most appropriate accommodations and explicit writing instruction for individual students with LD-TD.

See Berninger, Abbott et al. (2006b) for evidence-based processes that explain unique variance in writing manuscript and cursive letters by pen and by keyboarding and can be used in assessment for instructional planning. For example, using the keyboard is not necessarily a good bypass strategy if assessment shows that a student with LD-TD has deficits in rapid automatic naming or planning sequential finger movements (see Berninger, Abbott et al., 2006b).

Moreover, many students with LD are twice exceptional and may be both intellectually gifted and have LD-TD. But because they are so bright, sometimes it is assumed that they are lazy or unmotivated because their LD related to handwriting or spelling or both has not been diagnosed or treated (Yates, Berninger, & Abbott, 1994).

SUMMARY AND CONCLUSION
The results of the current study show that some individuals with writing disabilities, just as typically developing writers, may write text better by pen than by keyboard. Accommodations in the form of using keyboards are not a substitute for explicit instruction in transcription for students with LD-TD. These students need instruction in using both the pen and the keyboard within a systematic instructional program that also teaches the other cognitive processes in writing. Appropriate accommodations may or may not include keyboards, depending on what assessment shows are relevant strengths and weaknesses in an individual’s learning profile and whether relevant instruction in keyboarding is provided. In the information era, students with and without LD-TD may benefit from explicit instruction in writing by both pen and keyboard across levels of written language (letters, words, sentences, and text) so that their writing is legible, conventional, and fluent by both transcription modes.

REFERENCES
Berninger, V. (2008a, February). Relationship between levels of language and transcription mode. Presentation at the Santa Barbara Conference on Writing Research: Writing Research Across Borders, Santa Barbara, CA.


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NOTES

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1 This nationally normed test based on a measure validated in cross-sectional writing studies (Berninger et al., 1992, 1994) and revised in 2007 (Berninger, 2007a, 2007b) assesses number of legible letters in alphabetic order produced and revised in 2007 (Berninger, 2007a, 2007b) within the first 15 seconds of writing the alphabet from memory in lowercase, manuscript letters.

2 Except for proper nouns, only the first word of a sentence is capitalized; thus, overall, more lowercase letters are used in written sentences produced by either pen or keyboard.

3 The authors thank Thomas Halverson, senior lecturer and researcher, University of Washington (personal communication, May 2, 2008) for suggesting this explanation of our findings.

4 Legible = recognizable letter forms out of context; conventional = dictionary spellings and acceptable syntax (grammar); fluent = coordinated, effortless, and fast coordination of multiple processes.

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