Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing*.

Modes of Alphabet Letter Production during Middle Childhood and Adolescence: Interrelationships with Each Other and Other Writing Skills

Zachary Alstad[a], Elizabeth Sanders[a], Robert D. Abbott[a], Anna L. Barnett,[b] Sheila E. Henderson,[c] Vincent Connelly,[b] & Virginia W. Berninger[a]

[a]University of Washington

[b]Oxford Brookes University

[c]University of London

Correspondence:

Virginia Berninger

322 Miller Box 353600

University of Washington

Seattle, WA 98195-3600

vwb@u.washington.edu

fax: 206 616 6311

email addresses of co-authors:

Zac Alstad zacharyalstad@gmail.com,

"Elizabeth A. Sanders" <lizz@u.washington.edu>

Anna Barnett <abarnett@brookes.ac.uk>

Vince Connelly vconnelly@brookes.ac.uk

Acknowledgements: This research was supported by HD P50HD071764 and HD25858 from the *Eunice Kennedy Shriver* National Institute of Child Health and Human Development (NICHD) at the National Institutes of Health (NIH) , USA.

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing*.

Abstract

Although handwriting is typically taught during early childhood and keyboarding may not be taught explicitly, both may be relevant to writing development in the later grades. Thus, Study 1 investigated automatic production of the ordered alphabet from memory for manuscript (unjoined), cursive (joined), and keyboard letter modes (alphabet 15 sec) and their relationships with each other and spelling and composing in typically developing writers in grades 4 to 7 (N = 113). Study 2 compared students with dysgraphia (impaired handwriting, n=27), dyslexia (impaired word spelling, n=40), or oral and written language learning disability (OWL LD) (impaired syntax composing, n=11) or controls without specific writing disabilities (n=10) in grades 4 to 9 (N=88) on the same alphabet 15 modes, manner of copying (best or fast), spelling, and sentence composing. In Study 1, sequential multilevel model regressions of predictor alphabet 15 letter production/selection modes on spelling and composition outcomes, measured annually from grade 4 to grade 7 (ages 9 to 13 years), showed that only the cursive mode *uniquely*, positively, and consistently predicted both spelling and composing in each grade. For composing, in grade 4 manuscript mode was positively predictive and in grades 5-7 keyboard selection was. In Study 2 all letter production modes correlated with each other and one's best and fast sentence copying, spelling, and timed sentence composing. The groups with specific writing disabilities differed from control group on alphabet 15 manuscript mode, copy fast, and timed sentence composing. The dysgraphia and dyslexia groups differed on copying sentences in one's best handwriting, with the dysgraphia group scoring lower. The educational and theoretical significance of the findings are discussed for multiple modes and manners of letter

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

production/selection of the alphabet that support spelling and composing beyond the early grades in students with and without specific writing disabilities.

Modes of Alphabet Letter Production during Middle Childhood and Adolescence: Interrelationships with Each Other and Other Writing Skills

Situating the Research in Writing Development

Handwriting is typically taught early in schooling, but often not during middle childhood and adolescence. Although students may use keyboards, they may learn to do so through implicit experience outside the classroom rather than through explicit instruction in the classroom. Thus, two studies investigated developing writers' continuing development of handwriting and keyboarding skills at a stage of writing development when students may not receive explicit handwriting or keyboarding instruction. Three modes of letter production—manuscript handwriting (unjoined letters), cursive (joined letters), and keyboard (letter selection)—were studied because many developing writers may use these. The term letter production is used because, whether a letter is formed by serial component strokes or selected by pressing a key with a letter form, the outcome is a letter that can be viewed visually for feedback.

In both studies, these letter production modes were investigated for a task that instructed children to write the alphabet from memory as quickly as they could without sacrificing legibility. The rationale was based on prior research in the United States (US) showing that the number of legible manuscript letters in correct order during the first 15 seconds, an index of automatic letter access, retrieval, and production, was related to the other writing skills during early and middle childhood (for review see Berninger, 2009). However, both studies investigated

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing*.

not only the inter-relationships among the letter production modes, but also the relationships between each letter production mode and writing skills involving other levels of language—words composed of letters and sentences composed of words and letters. Whereas the first study examined relationships between letter production modes and word spelling and composing, which draws on word, sentence, and text skills, the second study examined relationships between letter production modes and word spelling, sentence copying, and sentence composing. Study 2 expanded the concept of letter production mode to *manner of production*—best or fast—on a sentence copying task containing all 26 letters of the alphabet.

Whereas Study 1 focused only on typically developing writers, Study 2 compared typically developing writers to students with three kinds of specific learning disabilities (SLDs) impairing written language: dysgraphia (impaired subword letter writing), dyslexia (impaired word spelling), or oral and written language learning disability (OWL LD). Conclusions about letter production mode during middle childhood and adolescence may depend on whether developing writers do or do not have SLDs impairing written language.

STUDY 1

Now that many kinds of technology tools for producing and selecting letters by hand and fingers to construct written words and written texts are widely available, many doubt that teaching and learning traditional handwriting in manuscript or cursive still matters. For example, in the US the Common Core Language Arts Standards, http://www.corestandards.org/ Cached, call for teaching handwriting only in kindergarten and first grade. An unexamined assumption underlying these standards is that keyboarding is what matters in the Information Age and that learning to print unconnected letters is an easily learnable skill that can be mastered in two years

early in writing development. Another assumption is that keyboarding can be learned just by using a keyboard, for example, at home for games or homework, and keyboarding does not need to be taught explicitly. However, these assumptions are not necessarily evidence based.

To begin with, longitudinal studies of writing, whether conducted over restricted time intervals within the same grade (e.g., Lerkkanen, Rasku-Puttonen, Aunola, & Nurmi; 2004; Treiman, 1993), across just two adjacent grade levels at a time (e.g., Abbott, Berninger, & Fayol, 2010), across two or three nonadjacent grades (Langer, 1986), or four years (e.g., Mehta, Foorman, Branum-Martin, & Taylor, 2005; Sprenger-Charolles, Siegel, Be´chennec, & Serniclaes, 2003), showed that writing skills in general develop over time and not always in a simple linear fashion. For example, handwriting, when reassessed throughout elementary school, was found to be variable from year to year, especially after third grade when formal handwriting instruction ceases (e.g., Blöte & Hamstra-Bletz, 1991; Maeland & Karlsdottir, 1991; Marr & Cernak, 2003). Thus, additional longitudinal studies of handwriting development beyond the early formal handwriting instruction years are timely for contemporary educational policy.

Moreover, the current longitudinal study examined keyboarding as well as two modes of handwriting—unjoined manuscript letters without connecting strokes and joined cursive letters with connecting strokes. Relatively few studies exist on implicit acquisition of keyboarding skills during middle childhood and early adolescence. For the importance of explicit, systematic writing instruction rather than implicit, incidental writing instruction during middle childhood and adolescence, see Graham and Perrin (2007). Thus, it would be valuable to study finding alphabet letters on keyboard in the absence of explicit keyboard instruction to use as baseline for future studies on explicit instruction in keyboarding.

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

At the same time, handwriting is only one writing skill, but is a subword writing skill that may enable learning other writing skills such as word spelling and composing of sentences and larger texts. Lerkkanen et al. (2004) conducted one of the few longitudinal studies of more than one level of language in writing. Five repeated measures of word spelling and text composing were collected across first grade in a Finnish-speaking sample; composition was modestly correlated with itself across time points. Mehta et al. (2005) also considered multiple levels of language longitudinally but across four grade levels and found that a text-level composition factor was not related to the word-level spelling factor. However, in another longitudinal study of multiple writing and reading skills at different levels of language, the longitudinal structural equation model that considered multiple paths from writing skills simultaneously fit better than autoregression models that included only autoregressive paths for each separate writing skill alone; in contrast to Mehta et al. and Lerkkanen et al., a relationship between spelling and composing factors was observed (Abbott et al., 2010). Also, see Pontart Bidet-Ildei, Lambert, Morisset, Flouret, and Alamargot (2013) for a review of research showing relationships between handwriting and spelling in the lower secondary grades, and Medwell, Strand, and Wray (2009) for review of research showing the relationships between handwriting and composition.

Thus, there is need for more research about the longitudinal relationships of handwriting and keyboard modes of letter production to word spelling and composing after handwriting instruction ceases. Accordingly, Study 1 was designed for two specific research aims. The first was to evaluate the interrelationships of the three modes of letter production (referred to as letter production/selection to differentiation formation stroke by stroke and selection on key) and how these interrelationships may change across successive grade levels beginning at grade 4 (the last

year of formal handwriting instruction for the participating children), and continuing after handwriting instruction ended from grades 5 to 7. The second was to examine possible differences in the relationships between each of the three letter production/selection modes and different writing outcomes: word-spelling or syntax- and text- composing. The first hypothesis tested was that the interrelationships among the modes would be stable because no further handwriting instruction or any keyboarding instruction was provided. The second hypothesis was that cursive (joined) letter production would have stronger relationships to word spelling than either manuscript (unjoined) letter production or keyboard selection would because automatic access to the connecting strokes in cursive letter forms stored in memory helps link the sequenced individual letters in a word spelling more than automatic access for manuscript letter forms without connecting strokes does.

Method

Participants. Letters announcing a research opportunity were sent to parents of students entering third grade in a large urban school system near the university. Parents interested in having their children participate in the longitudinal study contacted the last author who conducted a phone interview to screen for children who had no history of significant reading or writing difficulties in kindergarten, first, or second grade. Children who had history of such difficulties were excluded from participation in this study but were referred to other appropriate studies. Those who completed informed consent, which had been approved by the institutional review board at the university, came to the university where they completed a battery of tasks annually from grades 3 to 7 (ages 8 to 12). Although children were first assessed in third grade (*N*= 113, 57 girls and 56 boys), when

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

cursive handwriting instruction was then introduced in US schools, we could not assume all children had had instruction in all the cursive letters by the third or fourth month of third grade when assessments were conducted for this study. By fourth grade (second year of the study) all children had had instruction in all the cursive letters. Thus, manuscript, cursive, and keyboard modes of letter production/selection were analyzed for the same children when they were in fourth (n=110; 57 girls and 53 boys, M age= 116.02 months, SD=3.72), fifth (n=106; 54 girls and 52 boys, M age= 127.44 months, SD=3.73), sixth (n=105; 53 girls and 52 boys, M age= 139.70 months, SD=3.74), and seventh (n=99; 50 girls and 49 boys, M age= 151.29 months, SD=3.73) grades. Attrition over four years (n=11) was related to families moving to places that made it difficult for them to continue participation.

The participants reflected diversity, representative of the region in in which this research was conducted, in self-reported ethnicity (Asian-American 21.2%; African-American, 9.7%, European American, 65.5%, Hispanic, 0.9%, and other, 2.7%). Parental level of education ranged from less than a high school education or graduated from high school (7%) to more than a high school education but less than a college education (13%), to an undergraduate education (37%) to completion of a graduate degree (33%). Information on parental level of education was missing for the other parents.

Each year the parents completed questionnaires about home literacy activities and school programs that year. According to these parent questionnaires, all participating children used computers at home—for games and homework—and none were receiving instruction in keyboarding at school or using computers during their writing or reading activities in the classroom.

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

Procedures. Each year the students completed the measures in the same standard order with frequent talk, movement, and snack breaks. Total assessment time, which also included reading and other measures not included in the current study, was equivalent to a half day in the morning or afternoon at school.

Predictor measures. An alphabet writing task was used that is scored for number of legible lower case manuscript letters in correct alphabetic order in the first fifteen seconds when asked to write the alphabet from memory. This task is thought to reflect automatic letter access, retrieval, and production before strategic, controlled, resource-draining processing takes over. See Schneider and Shriffin (1977) and Shriffin and Schneider (1977) for this important distinction between automatic and strategic, controlled processing. Past longitudinal and cross-sectional research with children showed that the score during the first 15 seconds was more predictive than total time or total legibility on this task for explaining unique variance in text composing (for review, see Berninger, 2009). However, in the current study this task was extended to include lower case cursive and keyboard alphabet production as well. Due to a lack of national norms for these other two letter production mode tasks, raw scores were first examined for patterns, but then data from the longitudinal research sample were used to convert raw scores into *z*-scores for grade to use in the multi-level modeling.

For the *Alphabet 15 Task—manuscript mode*—children were instructed to print the lower case letters of the alphabet from memory in order as quickly as they could without sacrificing legibility, that is, so that others could identify the letters even if they did not occur in word context. The score was the number of correct handwritten letters in 15 seconds (legible and in correct order) in writing the alphabet from memory.

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

For the *Alphabet Writing Task—cursive mode*—children were instructed to write the alphabet in lower case cursive letters from memory in order as quickly as they could, but so that others could identify the letters out of word context. The score was the number of correct letters in 15 seconds (legible and in correct order) in writing the alphabet from memory. For each handwriting mode, the raw score was checked by two raters who discussed any disagreements until consensus was reached.

For *Alphabet Writing 15 Task—keyboard mode*—children were given a plastic covered drawing of a keyboard with one capital manuscript letter per key just as on a real keyboard of the same size and layout and were instructed to tap the keys in order to produce all the letters of the alphabet in alphabetic order. No mention of lower case format was made because on standard keyboards all letters are in uppercase manuscript format. The examiner recorded on a response record which key was tapped and the order in which each key was tapped. The score was the number of correct keys tapped in the correct order in 15 seconds. All of the children could produce the alphabet by keyboard by looking at the letters while selecting them (i.e., the hunt and peck method). None used touch typing approach of selecting letter without looking at the keys in the diagram.

*Outcome measures***.** Two spelling measures and one composition measure were administered. Children used handwriting for all the outcome measures, but could use their preferred handwriting—manuscript, cursive, or a mix. An earlier cross sectional study in the US showed that, in grades 5 to 9 when formal handwriting instruction ceased, many children adopted a mix of the two writing systems during composing (Graham, Berninger, & Weintraub, 1998).

The first spelling measure, *Word-Choice*, was experimenter-designed and required no

letter production—only circling the correctly spelled real word among three choices, all of which when pronounced sounded like a real word, but only one of which was a correctly spelled real word. Grade-based norms from the longitudinal research sample were used to convert raw scores into *z*-scores. This task assesses spelling ability apart from handwriting skills needed for spelling a dictated word in writing.

The remaining two outcome measures were from the *Wechsler Individual Achievement Test, Second Edition* (WIAT II, Psychological Corporation, 2001) and were administered according to criteria in the test manual for establishing basals and ceilings for start and stop points. For the second spelling measure, *WIAT II Spelling,* the task was to spell in handwriting a word dictated orally, then used in a sentence context, and then orally dictated again by the examiner. So semantics related to sentence context and handwriting played a greater role in this spelling task than on *Word Choice*. Words to be spelled increased in difficulty on this measure, and raw scores were converted to age-based, norm-referenced standard scores ($M = 100$, $SD = 15$). The test manual reports an average reliability coefficient of .94.

The final outcome measure, *WIAT II Written Expression*, involves three tasks that comprise a composition composite, including Written Word Fluency, Sentence Combining, and Paragraph Writing. For *Written Word Fluency*, the child generated, in writing, as many words as possible within a given time limit for a designated category. Thus, this task measures written word finding, a process that contributes to composing. For *Sentence Combining*, the child combined two or three separate sentences to create one new syntactically correct sentence with the same meaning. Thus, this task assesses sentence construction which also contributes to composing. See Myhill (2008) for research showing the value of including sentence combining

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

in writing assessment. For *Paragraph Writing* the child wrote about a prompt within a given time limit (15 minutes); however, children seldom wrote for the time allowed, so this was not a measure of compositional fluency. A detailed coding scheme in the test manual was used to score for quality of content and organization on this measure, scoring procedures in the test manual were used to score the written word fluency and sentence combining measures. Raw scores from the three measures were combined and converted to an age-based, norm-referenced standard score ($M = 100$, $SD = 15$) for the multiple levels of language beyond subword letters contributing to composing text. Reliability coefficients in the manual range from .81 to .87.

There was some missing data for some of the measures for some of the children. In the data analyses section we discuss how the missing data were handled.

Data Analyses

To test whether there were significant, unique relationships between letter production/selection modes and writing outcomes, as well as whether these relationships might differ by grade level (i.e., whether there was any interaction among mode and grade), for children from grades 4 to 7 (upper elementary and middle school), we employed a set of three sequential multilevel models in which measurements for each grade level (Level 1) were nested within students (Level 2). This modeling method is analogous to a least-squares repeated-measures ANOVA approach; however, the multilevel model approach allows us to test more flexibly within-grade relationships between letter production/selection modes and writing outcomes (recall that all predictor and outcome measures were assessed at every grade level of the student). Furthermore, multilevel modeling allowed us to incorporate more student data (i.e.,

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

even those with one or two missing data points) due to its use of full information maximum likelihood estimation.

For our first model, we entered a set of effect coded grade levels [as a set of three categorical variables in which grade 7 was treated as the reference group (-1) to determine the approximate percent of variance grade level accounted for; grade was not used as a time-oriented predictor as we were not interested in modeling growth in the writing outcomes]. In our second model, we added the three letter production/selection mode predictors, standardized within grade, to determine the unique contribution of modes beyond grade difference effects. In our final model, we added a set of interaction terms to determine whether letter selection/production modes' effects on the outcomes depended on grade level. Hence, our multilevel models are also analogous to traditional multiple regression with sequential predictor entry (while accounting for non-independence due to students' multiple grade level data). *SPSS 18* was used for all descriptive analyses and traditional regression analyses, and *HLM 7* was used for all multilevel models (maximum likelihood estimates reported). An alpha level of .05 was adopted for all analyses.

Results

Descriptive Statistics and Zero-Order Correlations

To begin, raw scores were examined for each letter production/selection mode on the alphabet 15 seconds task in grade 4 (manuscript, *M*=6.70, *SD*=2.84; cursive, *M*=3.19, *SD*=2.93; keyboard, *M*=12.10, *SD*=5.10), grade 5 (manuscript, *M*=8.71, *SD*=3.67; cursive, *M*=4.76, *SD*=4.01; keyboard, *M*=14.92, *SD*=5.44), grade 6 (manuscript, *M*=10.08, *SD*=3.27; cursive, *M*=5.31, SD=4.65; keyboard, *M*=18.54, *SD*=5.06), and grade 7 (manuscript, *M*=10.66, *SD*=4.10;

cursive, *M*=5.91, *SD*=4.56; keyboard, *M*=21.93, *SD*=4.07). At each grade level, more letters were selected on keys within the 15 second time limit than were produced in handwriting; and more manuscript letters were produced than cursive letters in the same time limit.

Then z-scores were computed because the number of correct letters selected or produced does not address whether each mode is or is not related to the word spelling and composing measures. *Z*-scores, unlike the raw scores take into account not only the mean score but also the variability within a mode within a grade level. Table 1 displays the observed norm-referenced standard/scaled/z-score means and standard deviations of each predictor and outcome variable used in our analyses by grade level. As can be seen, the sample was slightly above average across writing skills, with norm-referenced standard scores averaging in approximately the 75th percentile. Across mode variables, the sample was similarly above average on manuscript handwriting in grades 4 – 6, but closer to normative (50th percentile) on the remaining variables. Consistently at each grade level, even though manuscript mode was given first, students performed at a higher mean level on manuscript letter production than cursive letter production, consistent with the relative amount of cumulative experience they had had in cursive compared to manuscript. At the time the study was conducted manuscript handwriting was taught in first and second grade and cursive handwriting in third and fourth grade, but students could use whichever they preferred or a combination on their school written assignments. Although keyboarding was not used during their literacy instruction at school, consistently they selected more letters in alphabet order in 15 seconds then they formed stroke by stroke in either manuscript or cursive mode. Forming most likely requires more time than simply finding and selecting by touch a letter when time is held constant. As reported earlier, the relative pattern

across modes of number of correct letters produced in correct order within 15 seconds remained constant across the four grade levels studied, with keyboard highest and cursive lowest.

Insert Tables 1 and 2 about here.

Table 2 reports correlations by grade level and their *p*-values for statistical significance. All three letter production/selection modes have modest positive correlations with each other as well as the writing outcomes. The three writing outcomes are correlated with one another at every grade level except grade 7, for which the word choice task has lower correlations overall with dictated spelling and written expression than at the other grade levels. On the word choice task, manuscript mode is predictive at grades 6 and 7, cursive mode at grades 4 and 6, and keyboard mode at grades 4, 5, and 6. On spelling and written expression, both cursive and keyboard modes are predictive at all grade levels, whereas manuscript mode is predictive only for grade 5 and grade 6 spelling. Finally, on written expression, manuscript mode is predictive for all grades except grade 5. These data of course do not clarify which, if any, of the modes of letter production/selection are uniquely predictive of writing skills. They do show, however, that there may be some individual and developmental differences in the interrelationships of letter production modes and word and text writing skills.

Multilevel Models across Grade Levels

Multilevel (mixed) models incorporated student data from all grades 4 to 7 with measurements at Level 1 and students at Level 2 such that student dependencies across grades were accounted for. Data could be used for more children consistently across all models (even if there is a missing outcome at one or more grade levels) due to use of maximum likelihood

estimation of model parameters, which can be tested directly for grade level differences in the relationships among predictors and outcomes. Data from 109 of the original 113 students were available for all analyses. In these models we used only Level 1 letter production/selection mode predictors, with grade level effect coded into a set of three predictors (grade 7 used as reference group) as the first block (Model 1), and each mode of letter production/selection standardized within grade as the second block (Model 2). Interactions among the effect coded set of grade levels and standardized modes were computed and entered as the final block (Model 3). All outcomes were left in their original values (unstandardized). Finally, approximate R^2 change values were calculated to determine the percentage of variance explained by each block.

Model 1 (Grade Level Effects). As shown in Table 3, Model 1, grade level effects were observed for Grade 4 on word choice (word choice was higher in grade 4 than the average across other grades by 0.23 points), as well as on written expression (scores were lower for grade 4 compared to average of other grades by 1.66 points). The only other significant grade level effect in Model 1 was for grade 6 to be significantly higher than the average of other grades by 2.89 points on written expression. Although not shown in Table 4, the approximate percent of variance that grade level accounted for in the three outcomes compared to baseline was 7.4% for word choice, 0.2% for spelling, and 14.2% for written expression.

Insert Table 3 about here.

---

*Model 2 (Letter Production Mode Effects)***.** Prior to analyzing the set of modes in a combined fashion, we examined the significance of each mode separately, controlling for grade level. Results of these models (not shown in Table 3 for brevity, but available from second

author upon request), revealed that 1) manuscript and cursive modes were each significantly predictive of word choice when entered individually, but keyboard mode was not (coefficient *t*-test *p*-values < .05, with each accounting for 3.4% and 13.4% of variance, respectively); 2) only cursive mode significantly predicted dictated spelling (accounting for 8.4% of the variance); and 3) all three modes predicted written expression, when entered in isolation (with manuscript, cursive, and keyboard accounting for 4.4%, 13.3%, and 5.7% of the variance, respectively). However, again, these were tested in isolation of each other.

Model 2 (Table 3), which folds in all three mode effects after controlling for grade level, showed that combined mode effects accounted for a total of 15.7% of the variance in word choice, 10.4% of the variance in spelling, and 16.8% in written expression. Strikingly*, cursive mode was the only consistently unique predictor of all three writing outcomes*. On word choice, the model estimate (coefficient) implies that, for every standard deviation increase in cursive mode for any given grade, an average of 0.05 points increase in word choice is predicted. For spelling, every standard deviation increase in cursive mode implies a 1.66-point increase. Similarly, for written expression, a 2.31-point increase is anticipated for every standard deviation increase in cursive mode.

Model 3 (Grade X Mode Interactions). Our final model, Model 3, incorporated grade by mode interactions to determine whether letter production/selection mode effects were dependent on grade level. Model results (Table 3) showed that interactions altogether accounted only for a very small proportion of variance in the outcomes (1.5%, 0.5%, and 1.6% in word choice, spelling, and multi-leveled written expression/composition, respectively). This said, there were two significant interactions detected for written expression pertaining to manuscript and cursive

modes. To better understand these interactions (particularly given that grade level is a multi-category predictor), we computed model-implied values for each grade level by levels of each of the modes (one standard deviation below average, the mean, and one standard deviation above average, the mean), although we note that only two of the modes exhibited significant interactions (i.e., we have graphed levels of non-significant keyboarding for reader interest).

Insert Figures 1 and 2 about here.

As can be seen in Panel A of Figure 1 (predicted values of written expression by levels of within-grade manuscript skills for each grade level), in grade 4 the relationship between manuscript mode and written expression was quite positive (predicted values show a difference between low and high levels of manuscript mode of 6.06 points), whereas there was only a negligible relationship between manuscript mode and written expression in any of the three other grades. To test this pattern more explicitly, we conducted a follow-up model on written expression in which we used a dichotomized grade variable as either grade 4 or all other grades (effect coded), manuscript mode (standardized within grade), and their interaction. Results of this model showed that there were significant effects for all three terms; hence the effect of manuscript mode was significant irrespective of grade. However, the 2-way interaction between grade and manuscript mode was clearly ordinal: for students with average manuscript mode skills, the average increase in written expression going from low to high-skilled manuscript mode in grade 4 was 7.37 points, compared to only an average increase of 2.09 points for high versus. lower skilled manuscript mode across the other three grade levels.

In terms of cursive mode, Panel B of Figure 1 (predicted values of written expression by levels of within-grade cursive skills for each grade level) illustrates a positive relationship between cursive mode and other writing skills in all grade levels. However, in grade 6 the relationship was lower than in other grades (a difference of 1.70 points on writing between low and high cursive mode skills for grade 6 compared to differences of 4.67, 5.35, and 7.59 points for grades 4, 5, and 7, respectively). Again, to test this pattern more explicitly, we conducted a follow-up model in which we used a dichotomized grade variable as either grade 6 or all other grades (effect coded), cursive mode (standardized within grade), and their interaction. Results of this model showed that there were significant effects for cursive mode and its interaction with grade level, but not for grade level itself, showing that the effect of cursive was significant irrespective of grade. However, the 2-way interaction between grade and manuscript mode was again clearly ordinal: for students with average cursive mode skills, the average increase in written expression going from low to high-skilled manuscript in grade 6 was 2.54 points, compared to a larger average increase of 6.39 points for high versus lower skilled manuscript mode across the other three grade levels.

Finally, although there were no significant unique effects of keyboard or interactions between that mode and grade level on written expression, Panel C of Figure 1 shows that there was a pattern of positive effects between keyboard and written expression for grades 5 through 7, but negligible for grade 4. The fact that keyboard mode was not uniquely predictive, but yet was predictive in isolation of the other modes (see earlier discussion) shows the pattern of its positive effects on written expression, albeit smaller compared with the other two modes. Hence, it is not that keyboard mode is inconsequential to writing development in grades 5 to 7, but rather, that its

effects on written expression are not significant in the presence of the other predictors (cursive mode in particular).

*Post-hoc: Further Consideration of Relationships among Modes***.** As one final post-hoc follow-up to these data, we wondered if manuscript and cursive modes were each predictive of keyboard selection mode. After controlling for grade level, even though no grade level differences were found on keyboard mode, both manuscript and cursive modes were predictive of keyboard mode when entered in isolation (accounting for 5.8% and 9.0% of the variance in keyboard mode, respectively) as well as in combination with each other (together accounting for a total of 11.1% of the variance in letter production/selection skills). The coefficient estimates (not shown; available upon request from second author) implied that, for every standard deviation increase in manuscript mode, there was a 0.10-point increase on keyboard letter selection mode predicted ($p < .05$), and for every standard deviation increase in cursive mode, there was a 0.16-point increase predicted ($p < .01$). Finally, when we entered grade by mode interactions (similar to our earlier models for writing outcomes), we found only one significant interaction between grade level and cursive on keyboard mode. Model-implied values, illustrated in Figure 2, show that the positive effect between cursive and keyboard modes tends to differ in magnitude among the four grade levels, with the strongest relationship appearing in grade 5 (a difference of 0.70 points in letter selection on keyboard for high vs. low skills in cursive), and a reverse relationship (somewhat negligible: a difference of 0.14 points in keyboard mode favoring lower cursive mode skills) appearing in grade 7.

Discussion

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

Generalizing the findings should be restricted to typically developing writers who have received explicit instruction in both manuscript and cursive handwriting and have had experience in using computers but not explicit instruction in keyboarding at school. Furthermore conclusions should be restricted to the three modes studied—manuscript, cursive, and keyboard—on the alphabet 15 seconds task, a measure of automatic access, retrieval, and production/selection of letters (see Introduction). Nevertheless, the findings are enlightening.

The first hypothesis was not supported with evidence of stable maintenance of letter production/selection skills. Rather these skills continued to develop beyond the early grades. The raw scores showed grade to grade increases in each mode but these were variable in size despite the consistent pattern of keyboard selection > manuscript production > cursive production. The multi-level modeling provided evidence of dynamic plasticity (intra-individual and inter-individual variation), as is typically found in developmental studies, rather than simple linear trajectories (see Introduction).

Results were generally consistent with the second hypothesis that cursive alphabet letters stored in memory *may* be related to word spelling. Manuscript mode was related to the multi-level composing measure rather than word spelling alone, as has been reported in research in three English-speaking countries: (a) findings of Medwell et al. (2009) in UK; (b) Jones and Christensen (1999) in Australia; and (c) cross-sectional research findings in the US, which had shown this task explains unique variance in length and quality of text composing during fourth grade (Berninger, Cartwright, Yates, Swanson, & Abbott, 1994). The findings for cursive handwriting's unique contribution to word spelling, when other modes were included as predictors, are consistent with (a) the tested prediction that the connecting strokes of cursive may

help link letters in spelling words, (b) Pontart et al.(2013)'s research showing a relationship between handwriting and spelling; (c) observations over a half century ago that cursive writing is associated with quality of written expression of ideas (Harms, 1946; Horowitz & Berkowitz, 1964), and (d) the persisting belief among many that teaching cursive writing facilitates word spelling. However, cursive writing was not only related to word spelling but also to multi-level text composing with involves spelling words but also sequencing words in sentences and sequences sentences.

We elaborate on the claim in (a) above that the findings are consistent with that hypothesis rather than proving it. Alphabet letter forms may be stored in memory not only in an ordered series but also in different formats. The alphabet 15 seconds task used in this study assesses access and retrieval to individual items in that ordered series and the relationships of production format (mode) to other writing skills; those relationships may change from grade 4 to 7 in ways not neatly captured by sequential grade levels alone. Manuscript lower case format may be more related to word reading than spelling because it is the format of much printed matter used in reading tasks (see Berninger, 2009). Cursive lower case format with connecting strokes for linking single letters to other letters before and after them in the letter sequence in a word-specific spelling may be uniquely related to the sequential production of letters in spelling words, as observed in the current study, even when other modes were entered as predictors. Finding and pressing selected capital manuscript formats on keys may support faster letter production process as the pattern of raw scores shows. Of course, more research is needed on these various possibilities. For example, the effects of training both manuscript and cursive letter

production modes on accuracy and rate of copying and spelling dictated words in manuscript and cursive could be investigated.

At the same time, the results support the advantage of becoming a *hybrid writer skilled at multiple modes of letter production/selection*. Importantly, *by seventh grade students were comparably skilled with all three modes*, consistent with Christensen (2004)'s research showing an advantage for keyboarding emerging in early adolescence. Many factors *may* contribute to which modes work best for whom, including current skill level with each mode, instructional history, home literacy experiences, and individual differences in language variables. For example, mode effects may depend on the developmental level of the writer and his or her experience with the various writing tools (Connelly, Gee, & Walsh, 2007). Either very slow handwriting (Connelly, Dockrell, & Barnett, 2005) or keyboarding (Grabowski, 2008) can impede college students' and adult's composing (Weintraub, Gilmour-Grill, & Weiss, 2010), as is likely with students during middle childhood and early adolescence as well.

Experiments comparing mean levels of performance between composing by handwriting (pen) and by keyboarding have shown advantages for handwriting (usual manuscript and/or cursive) over keyboarding at different levels of language and writing tasks: (a) transcription speed during composing (Connelly et al., 2007), (b) length of compositions and rate of word production during text composing (Berninger, Abbott, Augsburger, & Garcia, 2009) and number of ideas expressed (Hayes & Berninger, 2010). Yet, no significant differences were found between computer keyboard and for composing single sentences when students could use manuscript, cursive, or a mix for handwriting (Berninger et al., 2009). Thus, each letter production mode may have potential contributions to becoming a hybrid writer. Also, the

posthoc analyses showed that learning to form the manuscript and cursive letters may contribute to keyboarding, supporting the hypothesis that keyboard letter selection skills are learned in tandem with manuscript and cursive in grades 4 through 7. Indeed, all three modes may be and become interrelated during writing development, as the current study shows.

Overall, the current results based on development of writing skills at a time that explicit handwriting instruction was provided in grades 1 to 4 suggests that current US policy downplaying the importance of explicit, ongoing manuscript and cursive handwriting and keyboarding instruction does not appear to be evidence-based. All too often, both handwriting and keyboarding have been left behind, which may be one factor contributing to developing writers not passing annual yearly progress tests in writing, especially now that they are increasingly computer administered and require keyboarding skills. Results may also be relevant to other countries like England also dealing with National Curriculum issues related to writing (see Medwell et al., 2009). One complication in comparing results across countries is that countries vary in their handwriting instruction practices. In contrast to the US, in some countries in Europe children learn cursive (script) at the beginning of schooling and use it throughout their schooling (e.g., Rieben et al., 2005). Clearly more research on the typical development of handwriting and its relationship to other writing skills is needed across many countries, as is now being spearheaded by Rui Alvez who heads the COST Action in Europe with focus on handwriting (e.g., Limpo & Alvez, 2013). Future research will hopefully shed further insight into whether developing writers do best on those letter production skills that are taught over time, with transfer to spelling and composing in mind, and periodic reviews.

STUDY 2

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

We turn now to a study of students with specific learning disabilities (SLDs) impairing writing at the subword handwriting level, word spelling level, and/or sentence composing levels to investigate how they may differ from typically developing writers and what their instructional needs might be in learning modes of letter production. In Study 2 we also expand the notion of letter production mode beyond letter formation and selection when writing the alphabet from memory to include manner of production as well—one's best or one's fast writing when copying a sentence containing all 26 letters of the alphabet. Three research questions were addressed related to the correlations between the modes of letter production, between the modes and measures of sentence copying, spelling, and composing, and between children with and without specific learning disabilities affecting writing (handwriting, spelling, or composing).

Method

Participant Recruitment and Characteristics

Participants in grades 4 to 9 (ages 9 to 14) were recruited via flyers distributed to local schools for assessment related to written language. Interested parents contacted the last author and were interviewed over the phone to make an initial determination of whether the child would probably qualify for the study. Qualifications included persisting struggle with some aspect of written language (handwriting, spelling, and/or composition) or lack of SLD affecting written language. ADHD was not an exclusion criterion, but children with neurogenetic conditions such as autism, fragile X, or Down's syndrome, or brain injuries or other brain disorders were not included. Then children who granted assent and whose parent granted informed consent, using procedures approved by the Institutional Review Board, were given an assessment with writing measures at the university. While the child was being assessed by trained and supervised

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

graduate research assistants, parents completed questionnaires about developmental, medical, family, and educational histories. Altogether 29 females and 59 males completed the assessments.

Children were assigned to groups using a differential diagnosis model, based on a model of cascading levels of language such that only subword written language was impaired, only word level not syntax level written language was impaired, or syntax level of language was impaired; this model is based on two decades of interdisciplinary research at many sites (for review of evidence, see Berninger & Richards, 2010; Silliman & Berninger, 2011). For *dysgraphia* (a word of Greek origin meaning impaired letter writing), students had to score below -2/3 SD (25^{th} %tile) on at least two handwriting measures, but not show signs of reading or oral language impairment; their parents had to report a history of ongoing difficulties with handwriting but not with word reading, reading comprehension, or oral language. For *dyslexia* (a word of Greek origin meaning impaired word skills), the students had to score below -2/3 SD (25^{th} %tile) or, if cognitive ability was very high, below the population mean (50^{th} %tile), based on research showing that high cognitive ability may mask dyslexia (e.g., van Viersen, Kroesbergen, Slot, de Bree, 2014), on at least two word spelling and/or reading measures but not show signs of impaired listening comprehension or oral expression; their parents had to report a history of ongoing difficulties with word spelling and/or reading which emerged at transition to schooling, but not with listening comprehension or oral expression. For Oral and Written Language Learning Disability (*OWL LD*), students had to score below -2/3 SD (25^{th} %tile) on at least two listening comprehension, reading comprehension, oral expression, and/or written expression measures; and their parents had to report oral language problems emerging in the

preschool years and continuing in the present. The control group of typical oral and written language learners (OWLs) had to score at or above -2/3 SD (25th %tile) on all listening, oral expression, reading, and writing skills; and their parents had to report a history of learning oral and written language without any struggles.

Altogether 27 met the criteria for dysgraphia group, 40 met the criteria for dyslexia group, 11 met the criteria for OWL LD (SLI), and 10 met criteria for typically developing students without SLDs (OWLs control group). None of the children with dysgraphia had history of developmental motor disabilities apart from their handwriting difficulties. The parental-reported racial identities of these children, representative of the region in US where the study was conducted, included White *(n*=69), Multi-Race (*n*=14), Asian (*n*=3), Native Hawaiian or Other Pacific Islander (*n*=1), and Black or African American (*n*=1). Mothers' levels of education included high school graduate (2.2%), more than high school (3.3%), college (41%), more than college (48.9%), and unknown (4.4%). Fathers' levels of education included high school graduate (4.4%), more than high school (7.8%), college (41.1%), more than college (36.7%), and unknown (7.8%).

Measures

The following measures were given to (a) assess the relationships between each of the three alphabet letter production tasks with each other (first research question) and with other writing skills—sentence copying, spelling, and sentence composing (second research question); and (b) evaluate differences between groups with and without specific writing disabilities (SLDs) defined on basis of levels of language—impaired subword handwriting, impaired word spelling, or impaired syntax composing (third research question).

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

Alphabet 15 writing task. See Study 1 for administration. Correct number of the constant 26 letters was scored rather than z-scores because the earlier longitudinal study did not have norms beyond grade 7.

Detailed Assessment of Speed of Handwriting (DASH) Copy Best and Fast (Barnett, Henderson, Scheib, Schulz, 2007). The task is to copy a sentence containing all 26 letters of the alphabet under contrasting instructions: one's 'best' handwriting or 'fast' handwriting for two minutes. Note that this task assesses ability to write legible letters in both word and sentence context when the student does not have to rely on long-term memory to the extent required by the alphabet 15 task. These sentence copy tasks have important ecological validity for use of handwriting in classrooms for the following reasons: (a) students copy written language from sources for many instructional activities and written assignments; (b) students are asked to use their *usual* handwriting, either printing manuscript (unjoined) letters or writing cursive (joined or partially joined letters) or a combination; and (c) the same task can be compared when the writer is asked to engage executive functions for controlled processing to produce quality handwriting and when asked to write quickly as speed plays a role in some students being able to complete written assignments in a timely fashion. The raw score is converted to a scaled score (M=10, SD=3). Intra-class correlation coefficient for interrater agreement for *DASH Copy Best* and for *DASH Copy Fast* is 0.99. UK norms were used to transform raw scores into standard scores. Again, in the current study, the copy tasks were administered in a constant order with *Copy Best* first and *Copy Fast* second, and each score was checked by two raters who discussed any disagreements until consensus was reached.

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

Woodcock Johnson Psychoeducational Battery, 3rd Edition, WJ III (Woodcock, McGrew & Mather, 2001). The *WJ III Spell Sounds* subtest (reliability coefficient of .76) assesses ability to spell dictated pseudowords, that is, nonwords with phonology, orthography, and morphology but without semantic meaning. The *WJ III Writing Fluency* task is to compose a written sentence for each set of three provided words, which are to be used without changing them in any way. There is a 7 minute time limit. Test-retest reliability is .88.

WIAT III (Pearson, 2009). For *WIAT III Spelling*, the task is to spell in writing dictated real words, pronounced alone, then in a sentence, and then alone (test-retest reliability is on average .96 in ages studied). This task, in contrast to *WJ III Spell Sounds*, is sensitive to semantic meaning as well as phonology, orthography, and morphology. The score is a standard score (M=100, SD=15). For *WIAT III Sentence Combining*, the task is to combine two provided sentences into one well written sentence that contains all the ideas in the two separate sentences. The score (test-retest reliability .81) is a standard score (M=100, SD=15).

Data Analyses

Initially, correlations between each of the letter production modes, between each of the sentence copy tasks, and between the letter production modes and sentence copy tasks were examined. Then, correlations between each of these and the word spelling and syntax composing tasks were examined. Finally, ANOVA was used to evaluate for each letter production measure whether there was a significant main effect for the four groups. For those letter production measures for which there were significant main effect for group, each of the SLD groups was compared to the control group and to each other to identify how each of the SLD groups might differ in the nature of their letter production impairments.

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

Results

Research Question 1: Correlations among Letter Production Modes

Raw scores for each mode of letter production on the alphabet task (first 15 seconds) were significantly, but moderately, correlated with each of the other modes: forming unjoined manuscript letters and joined cursive letters, $r(84)=0.49$, $p<.001$; forming unjoined manuscript letters and keyboard letter selection, $r(79)=0.27$, $p=.01$; and forming cursive joined letters and keyboard selection, $r(79)=.22$, $p<.05$.

Of great interest, both copy tasks were not only significantly correlated with each other, but also the magnitude of the correlation was higher $r(79)=.73$, $p<.001$, than among the letter writing modes on the alphabet 15 task. However, each of the three letter production modes on the alphabet 15 task was significantly, but moderately, correlated with both copy tasks. For DASH *Copy Best*, $r(85)=.40$, $p<.001$ for forming unjoined manuscript letters; $r(85)=.24$, $p<.05$ for forming joined cursive letters; and $r(80)=.36$, $p=.001$ for keyboard letter selection. For *DASH Copy Fast*, $r(85)=.50$, $p<.001$ for forming unjoined manuscript letters; $r(85)=.34$, $p=.001$ for forming joined cursive letters; and $r(80)=0.39$, $p<.001$ for keyboard letter selection.

To summarize, all the letter production/selection measures were significantly correlated with each other. However, the magnitude of the correlations was smaller across modes for the alphabet 15 task, suggesting individual differences in automatic, legible alphabet letter writing as a function of letter production mode. In contrast, the construct validity of the sentence copy tasks was documented by the sizable magnitude of the correlation between them: About 50% of the variance was shared across *DASH Copy Best* and *DASH Copy Fast*. Yet each also captured

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

additional unique variance related to whether or not instructions emphasized speed (*Copy Fast*) or self-regulation (*Copy Bes*t).

Research Question 2: Correlations among Letter Production and Other Writing Tasks

Alphabet writing from memory. As shown in Table 4, each letter production mode on the alphabet 15 task was significantly correlated with both spelling tasks (dictated pseudowords and dictated real words), sentence combining, and writing fluency (timed sentence construction from three words).

Insert Table 4 about here.

Sentence copy tasks. As also shown in Table 4, *DASH Copy Best a*nd *DASH Copy Fast* were also significantly correlated with both of the spelling tasks (dictated pseudowords and dictated real words), sentence combining, and writing fluency (timed sentence construction from three words). Not only automatic access to ordered letters stored in long-term memory but also ability to copy written words in sentence syntax that contains all 26 letters of the alphabet in one's best and one's fast handwriting is related to spelling and sentence composing.

Comparing the relationships of letter production modes to other writing tasks. To summarize, all five letter production/selection tasks were significantly correlated with all the other levels of written language assessed—two word spelling and two sentence composing tasks. Thus, handwriting and keyboarding out of word or sentence context and handwriting in word and sentence context have significant relationships with other levels of written language. Overall, the results provide support for the value of assessing multiple modes of letter production/selection and handwriting skills and other writing skills –spelling and sentence composing—in older

students (ages 9 to 14) as part of comprehensive assessment for purposes of diagnosis and instructional planning for written language instruction.

Research Question 3: Letter Production/Selection in Students with and without Specific Learning Disabilities (SLDs)

Table 5 summarizes the measures on which ANOVA yielded main effects for all four groups, comparisons between typically developing students without SLDs (controls) and each group with specific kinds of SLDs, and each of the SLD groups compared to each other. The SLDs studied involve impaired sub-word letter writing (dysgraphia), word spelling and reading (dyslexia), and syntax-level sentence construction and comprehension (OWL LD also referred to as specific language impairment SLI). These comparisons are organized by letter production/selection tasks and other writing skills. These comparisons are now discussed for each of the measures showing a main effect for all four groups.

Insert Table 5 about here.

Mode of letter production/selection on alphabet 15 task. All three groups with SLDs differed significantly from typically developing writers on the alphabet 15 task for forming unjoined lower case manuscript letters by pen. Impairment in this skill may be a marker of all three SLDs studied in a US sample. However, they did not differ when producing the alphabet in cursive or by keyboard. Although not shown in Table 5, comparison of means and SDs for cursive writing and keyboarding across the four groups was instructive even though there was not a significant difference among the four groups. The mean number of correctly produced alphabet letters in 15 seconds was consistently considerably lower for cursive handwriting and

considerably higher for keyboarding (with looking at the keys) than for manuscript writing, which is shown in Table 5: For cursive handwriting, mean number of correct cursive letters was 4 (*SD*=3.7) in typical oral and written language learner (control) group; 2.35 (*SD*=3.17) in dysgraphia group, 1.44 (*SD*=2.74) in dyslexia group, and 0.73 (*SD*=1.49) in OWL LD group. For keyboard letter selection, mean number of correctly selected letters by keyboard was 19.6 (*SD*=6.20) in control group; 17.12 (*SD*=7.40) in dysgraphia group; 15.76 (*SD*=5.37) in dyslexia group; and 18.50 (*SD*=7.34) in OWL LD group. Note that SD's for manuscript letters shown in Table 5 were also larger than for cursive and smaller than for keyboard letter selection.

Like students in Study 1, these students had not had explicit instruction in keyboarding, but still are faster at selecting letters rather than forming letters. Unlike the students in Study 1, many of these students had not had instruction in cursive because of changing instructional practices related to handwriting. Moreover, the variable size of *SD's* for cursive and keyboarding across groups may explain in part why the group effects were not statistically significant as they were for manuscript handwriting, for which SD's were more comparable across groups (see Table 5). This variability calls attention to the sizable individual differences in some letter production modes during middle childhood and adolescence, which should also be recognized and considered in instructional planning.

Copy sentence tasks. All three groups with SLDs differed significantly from the typically developing writers on *DASH Copy Fast*. Impairment in copying speed may also be a marker of all three SLDs studied. Of note, even though *Copy Fast* was given second, mean scores were lower on *Copy Fast* than *Copy Best*. Speed was relatively impaired even with practice on copying the same sentence. However, only groups with dysgraphia and dyslexia differed

significantly from the typically developing writers on *DASH Copy Best;* and those with dysgraphia were significantly lower than those with dyslexia. See Table 5. Even when they try their best, students with dysgraphia may have more difficulty in producing quality handwriting.

Timed written sentence construction. All three groups with SLDs differed significantly from the typically developing writers on the timed measure of written sentence syntax construction from provided words (*WJ III Writing Fluency*). Impairment in this task may also be a marker of all three SLDs. However, the group with OWL LD was significantly more impaired than the group with dysgraphia or dyslexia on this task which required sentence syntax construction (see Scott, 2009 for this hallmark sentence syntax impairment in children with SLI, which is also referred to as OWL LD). Groups did not differ significantly in *WIAT III Sentence Combinin*g on which two syntactically formed sentences are provided and the task is to combine them into one syntactically acceptable sentence that contains all the ideas in each one separately; but the student does not have to construct syntax from three provided single words.

Discussion

First Research Question

The five letter production/selection measures are significantly correlated with each other, providing construct validity that these handwriting measures are assessing a common construct. However, they were not perfectly correlated, showing that they do not assess exactly the same aspects of handwriting. Thus, the three alphabet letter production/selection tasks and two sentence copying tasks did not provide redundant information about handwriting skills.

Overall the alphabet 15 seconds task by manuscript and by cursive modes were more correlated with each other than either one of them was with keyboard letter selection (about a 2

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

to 1 magnitude, which when squared translates into about 25% shared variance compared to about 4% to 9% variance, respectively). Forming letters and selecting letters during automatic access to the ordered series of alphabet letters are not completely identical processes. *DASH Copy Best* was more correlated with production of unjoined manuscript letters either by pen or by keyboard letter selection than production of cursive alphabet letters by pen. This finding may reflect, in part, Study 2 participants' relative lack of instruction in cursive writing. *DASH Copy Fast* was somewhat more correlated with production of unjoined letters by pen than was either the cursive or keyboard mode. Having more experience in using manuscript letters may account for this finding in an era when some instruction is provided in manuscript writing but rarely in cursive or keyboard in the school culture studied. In addition, comparing the same task when performed under contrasting instructions that require use of executive functions for strategic control to produce one's best handwriting versus speed in production to produce one's fast handwriting provides helpful diagnostic information.

Of interest, copying letters in a sentence in one's best handwriting and one's fast handwriting using one's usual writing (manuscript, cursive, or combined) was more highly correlated than was producing the alphabet from memory in manuscript and in cursive letters. One possible explanation for these findings might be that the alphabet 15 task is more dependent on access to and retrieval of letter forms from long-term memory without any prior visual cues to what the letter form product should look like, whereas writers have access to visual cues during sentence copying. Another possible explanation is that the word spelling and syntax in the sentence from which the letters are copied provide helpful contextual linguistic cues for letter production beyond the visual cues. At the grade and age levels studied, developing writers have

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

acquired a great deal of knowledge of word-specific spellings as well as of letter-form production; and the word-specific spellings may facilitate accuracy as well as speed of letter production on sentence copy tasks.

In conclusion, both assessment of copying a sentence with all the letters of alphabet and of writing the alphabet from memory in manuscript, cursive, and keyboard may contribute to assessment of letter production skills during middle childhood and adolescence. Moreover, the sentence copying tasks are particularly sensitive to the word spelling and syntax composing processes in students with persisting SLDs affecting written language. Comparison of copying sentences in one's best and one's fast usual handwriting (manner of production) should be part of standard assessments of students with SLDs. Also future research should address whether performance on the copy tasks is related to quality of notes taken when reading source material for written reports required at school during middle childhood and adolescence.

Second Research Question

The handwriting skills were significantly correlated with writing skills at other levels of language—word spelling (both dictated nonwords and real words) and sentence composing (sentence combining and sentence construction fluency) in Study 2. Thus, assessing handwriting contributes to understanding an individual's profile of language learning across levels of written language for writing in students with and without SLDs impairing written language learning.

Third Research Question

Students with dysgraphia, dyslexia, and OWL LD differed from controls on multiple letter production tasks: alphabet 15 seconds manuscript mode task and both copy tasks with one exception (OWL LD group on the *Copy Best* task--perhaps because when they took their time,

they could focus on letters and words and ignore syntax, on which they are impaired*).* Thus, although individual students may differ in which level of language shows hallmark impairment in their profile of written language skills, all students with dysgraphia, dyslexia, and OWL LD might benefit from explicit instruction in automatic manuscript letter production and fast sentence copying in usual handwriting (manuscript, cursive, or a mix) and transfer of these handwriting skills to word spelling and sentence composing.

The findings that all groups showed more variation in *SD*'s on cursive and keyboard letter production/selection than on manuscript for the alphabet 15 task suggests that there are individual differences in these letter production modes during middle childhood and adolescence, especially when cursive and keyboarding are not explicitly taught. For example, although keyboarding is routinely used for accommodations in the US, some students may actually need explicit instruction in using keyboards to produce written language at the word, sentence, and text levels. In fact, all students with and without SLDs might benefit from explicit instruction in touch typing on laptop keyboards for a variety of writing skills. Moreover, reinstatement of cursive handwriting instruction with focus on transfer to spelling should be considered for both students with and without SLDs.

Of note, none of the participants had a history of developmental motor disorders (diagnosed gross motor or fine motor disabilities), which can be differentiated from dysgraphia. Although individuals with motor impairments that are present at birth or within the first year of life or are acquired later during development are likely to struggle with the motor skills involved in writing, other individuals may fall within or above the lower limits of the normal range in gross motor and fine motor development in general, but have dysgraphia, a disorder specific to

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

producing the letter forms of written language, which may in turn interfere with their learning to spell and compose in writing. Indeed in Study 2 even though both those with dysgraphia and dyslexia differed significantly from controls on DASH Copy *Best*, those with dysgraphia were significantly lower than were those with dyslexia. Students with dyslexia have particular difficulty in self-regulating the quality of their letter production.

Failure to understand that handwriting is written language is part of the reason so many students with dysgraphia are underserved in the US and possibly elsewhere. Under current state implementation of federal guidelines for SLDs, they do not qualify for occupational or physical therapy services because their motor problems are not severe enough. It is not widely understood that letter production is not only a motor skill but also a written language skill involving both letter forms (orthographic codes) and names corresponding to a letter forms (verbal codes), which contribute to automatic retrieval (e.g., see Berninger, 2009). Nor is it understood that students with dysgraphia should also be assessed and taught by professionals with expertise in literacy. Moreover, often in the US students with dysgraphia do they often meet the eligibility criteria for SLD services, which typically are more oriented to reading than writing problems.

Educational Significance of Studies 1 and 2

Study 2, in contrast to Study 1, was conducted at a time when handwriting is often not taught in the US past the first grade because of national educational policy (the Common Core Standards). Nevertheless, participating students in Study 2, with the exception of controls, had reported histories of persisting writing problems compared to their peers at school that were documented with normed test measures. For the typically developing writers in Study 1, who did not receive handwriting instruction after fourth grade or keyboard instruction at school, it took

until seventh grade to develop comparable expertise with all three letter production modes used in the 21st century. Thus, it is understandable why a National Symposium in Handwriting Instruction was conducted in the US in 2012 to share research with educational practitioners on why teaching handwriting still matters in the Information Age (American Association of School Administrators and Zaner Bloser, Co-Sponsors, 2012).

The educational significance of Study 1 is that students need continuing handwriting instruction as well as explicit keyboard instruction (touch typing) beyond fourth grade. Given prior reports that the relative advantages of keyboards surface in early adolescence (Christiansen, 2004), effective keyboard instruction using computer laptops should be explored in middle childhood to prepare students for increasing expectations in the upper grades. The continuing handwriting and keyboard instruction does not have to be intensive, but rather can be viewed as periodic tune-ups once or twice a week when students do warm-ups, like the athletes before the game: (a) writing the alphabet from memory, (b) copying interesting target sentences containing all the letters of the alphabet, (c) writing letters that come before and after other named letters, or (d) exchanging papers and circling letters that are illegible and discussing how to make them legible to others for purposes of written communication. These warm up, tune-ups should be followed by more cognitively engaging writing tasks for authentic communication purposes. For example, following handwriting tune-ups students with SLDs can participate in Mark Twain Writers' Workshop (autobiographical and science fiction writing), Science Writers' Workshop (listening, note taking, and writing strategies), and/or Linguistic and Cultural Writing Workshops (comparing written orthographies and cultures) (see Berninger & Wolf, 2009).

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

The educational significance of Study 2 is that students with SLDs that impair writing skills (handwriting, spelling, and/or composing) may not only need accommodations (e.g., allowing more time to complete written work or using a laptop) but also continuing explicit instruction in alphabet letter access, retrieval, and production and copying words in sentence context and using multiple modes of letter production in spelling and composition instruction. Multiple modes of handwriting may strengthen the orthographic loop of working memory that supports written language learning (see Niedo, Abbott, & Berninger, 2014) by connecting the mind's eye with the serial movements of hands and fingers in producing the sequential component strokes of letter forms.

Yet sequential letter selection on a keyboard may afford an advantage in speed. A recent study showed that computerized handwriting, spelling, and composing instruction using multiple modes of letter production resulted in improved handwriting, spelling, and composing on normed measures for students with dysgraphia, dyslexia, and OWL LD (Berninger, Nagy, Tanimoto, Thompson, & Abbott, 2014). In the Information Age more attention should be given to developing hybrid writers skilled in multiple modes of letter production for a variety of writing purposes.

Theoretical Significance and Future Research Directions

The current studies did not investigate all aspects of manuscript and cursive handwriting and keyboarding, but rather focused on automatic access, retrieval, and production of ordered alphabet letters by three letter production/selection modes and two manners of copying sentences with all the letters of the alphabet. These processes were shown to be related to word level spelling and sentence/text level composing. Future research might investigate the hypotheses that

(a) developing expertise with multiple modes of letter production facilitates abstraction of cross-format letter codes underlying many kinds of skilled writing during secondary and postsecondary education; and (b) explicit touch typing benefits all developing writers during middle childhood and adolescence.

Both on-line studies of letter production studies (e.g., comparing stylus and keyboard during composing) and studies of writing products using normed measures for age or grade contribute basic and applied knowledge in an era of high stakes testing based on writing products. Moreover, in an increasingly global world, collaborations across countries, cultures, and language are potentially fruitful. Even in countries that speak the same language, variations in educational and community policy and practices can influence research results and evidence-based translation of research practice. One of the most important findings from this international collaboration is that the *DASH sentence copying* tasks, which compare best handwriting and fast handwriting, have sensitivity and specificity in diagnosing SLDs affecting written language acquisition such as dysgraphia, dyslexia, and OWL LD and identifying instructional needs. Moreover, more research is needed on effective teaching of manner of letter production—knowing both how and when to produce letters in handwriting or by keyboard very quickly or very carefully.

Hopefully, the current research will stimulate more cross-country collaborations, and handwriting and keyboarding researchers in many countries will participate in the planned sequel to the 2012 National Summit on Handwriting, a technology-supported International Summit. Handwriting should no longer be regarded as a mechanical skill that does not matter in the Information Age. Rather, schools should assess and teach hybrid letter production skills by

handwriting (unjoined and joined), both best and fast, and keyboarding across levels of language (word spelling and sentence and text composing) by hand for ALL students. Especially in the Information Age, neither handwriting nor keyboarding assessment and instruction for students with and without specific writing disabilities should be left behind.

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

References

Abbott, R., Berninger, V., & Fayol, M. (2010). Longitudinal relationships of levels of language in writing and between writing and reading in grades 1 to 7. *Journal of Educational Psychology*, *102*, 281-298.

American Association of School Administrators and Zaner Bloser (Co-Sponsors). (2012, January, 23). Educational Summit on Handwriting. Newseum, Washington, D.C.

Barnett, A., Henderson, L., Scheib, B., Schulz, C. (2007). *Detailed Assessment of Speed of Handwriting (DASH) Copy Best and Fast.* London: Pearson.

Berninger, V. (2009). Highlights of programmatic, interdisciplinary research on writing. *Learning Disabilities. Research and Practice, 24,* 68-79.

Berninger, V., Abbott, R., Augsburger, A., & Garcia, N. (2009). Comparison of pen and keyboard transcription modes in children with and without learning disabilities affecting transcription. *Learning Disability Quarterly, 32*, 123-141.

Berninger, V., Cartwright, A., Yates, C., Swanson, H.L., & Abbott, R. (1994). Developmental skills related to writing and reading acquisition in the intermediate grades: Shared and unique variance. *Reading and Writing: An Interdisciplinary Journal, 6,* 161-196.

Berninger, V., Nagy, W., Tanimoto, S., Thompson, R., & Abbott, R. (published on line October 30, 2014, hard copy in 2015). Computer handwriting, spelling, and composing instruction for students with specific learning disabilities in grades 4 to 9. *Computers and Education*, *81,* 154-168. DOI information: 10.1016/j.compedu.2014.10.00

Posted NIHMS636683 NIHMSID Publ.ID: CAE2713 http://audioslides.elsevier.com/getvideo.aspx?doi=10.1016/j.compedu.2014.10.005

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

Berninger, V., & Wolf, B. (2009). *Helping students with dyslexia and dysgraphia make connections: Differentiated instruction lesson plans in reading and writing*. Baltimore: Paul H. Brookes.

Blöte, A., & Hamstra-Bletz, L. (1991). A longitudinal study on the structure of handwriting. *Perceptual and Motor Skills, 72,* 983–994.

Christensen, C. A. (2004). Relationship between orthographic-motor integration and computer use for the production of creative and well-structured written text. *British Journal of Educational Psychology*, *74*(4), 551–564. doi:10.1348/0007099042376373

Common Core Standards http://www.corestandards.org/ Cached

Connelly, V., Dockrell, J. E., & Barnett, J. (2005). The slow handwriting of undergraduate students constrains overall performance in exam essays. *Educational Psychology*, *25*(1), 99–107. doi:10.1080/0144341042000294912

Connelly, V., Gee, D., & Walsh, E. (2007). A comparison of keyboarded and handwritten compositions and the relationship with transcription speed. *British Journal of Educational Psychology*, *77*(2), 479–492. doi:10.1348/000709906X116768

Grabowski, J. (2008). The internal structure of university students' keyboard skills. *Journal of writing research*, *1*(1), 27–52.

Graham, S., Berninger, V., & Weintraub, N. (1998). The relationship of handwriting style and speed and legibility. *Journal of Educational Research*, *91*, 290-296.

Graham, S., & Perin, D. (2007). *Writing next: Effective strategies to improve writing of adolescents in middle and high schools—A report to Carnegie Corporation of New York.* Washington, DC: Alliance for Excellent Education.

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

Hamstra-Bletz, L., & Blöte, A. W. (1990). Development of handwriting in primary school: A longitudinal study. *Perceptual and Motor Skills*, *70*(3, Pt 1), 759–770. doi:10.2466/PMS.70.3.759-770.

Hayes, J. R., & Berninger, V. (2010). Relationships between idea generation and transcription: How act of writing shapes what children write. In C. Brazerman, R. Krut, K. Lunsford, S. McLeod, S. Null, P. Rogers, & A. Stansell (Eds.), *Traditions of Writing Research* (pp 166-180). New York: Taylor and Frances/Routledge.

Jones, D., & Christensen, C. A. (1999). Relationship between automaticity in handwriting and students' ability to generate written text. *Journal of Educational Psychology*, *91*(1), 44–49. doi:10.1037/0022-0663.91.1.44

Langer, J. A. (1986). *Children reading and writing: Structures and strategies.* Norwood, NJ: Ablex.

Lerkkanen, M., Rasku-Puttonen, H., Aunola, K., & Nurmi, J. (2004). The developmental dynamics of literacy skills during the first grade. *Educational Psychology, 24,* 793–810.

Limpo, T., & Alves, R. A. (2013). Modeling writing development: Contribution of transcription and self-regulation to Portuguese students' text generation quality. *Journal of Educational Psychology, 105*, 401-413. doi: 10.1037/a0031391

Maeland, A., & Karlsdottir, R. (1991). Development of reading, spelling, and writing skills from third to sixth grade in normal and dysgraphic school children. In J. Wann, A. Wing, & N. Sovik (Eds.), *Development of graphic skills* (pp. 179–189). San Diego, CA: Academic Press.

Marr, D., & Cernak, S. (2003). Consistency of handwriting in early elementary students.

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

American Journal of Occupational Therapy, 57, 161–167.

Medwell, J., Strand, S., & Wray, D. (2009). The links between handwriting and composing for Y6 children. *Cambridge Journal of Education, 39*, 329-344.

Mehta, P., Foorman, B., Branum-Martin, L., & Taylor, W. (2005). Literacy as a unidimensional multilevel construct: Validation, sources of influence, and implications in a longitudinal study in grades 1 to 4. *Scientific Studies of Reading, 9,* 85–116.

Myhill, D. (2008). Towards a linguistic model of sentence development in writing. *Language and Education*, *22*(5), 271-288.

Niedo, J., Abbott, R., & Berninger, V. (2014) Predicting levels of reading and writing achievement in typically developing, English-speaking 2nd and 5th graders. *Learning and Individual Differences, 32C,* 54-68.. Published on line April 18, 2014

doi 10.1016/j.lindif.2014.03.013 *NIHMS ID: NIHMS580076*

Pontart, V., Bidet-Ildei, Lambert, E., Morisset, P., Flouret, L., & Alamargot, D. (2013). Influence of handwriting skills during spelling in the primary and lower secondary grades. *Frontiers in Psychology. Cognitive Science.* Doi 10.3389/fpsyg.2013.00818

Psychological Corporation. (2001). *Wechsler Individual Achievement Test, 2nd Edition* (WIAT–II). San Antonio, TX: Psychological Corporation.

Rieben, L., Ntamakiliro, L., Gonthier, B., & Fayol, M. (2005). Effects of various early writing practices on reading and spelling. *Scientific Studies* of Reading, 9, 145–166.

Scott, C. M. (2009). Language-based assessment of written expression. In G. A. Troia (Ed.), *Instruction and assessment for struggling writers: Evidence-based practices.*, Challenges in language and literacy (pp. 358–385). New York, NY US: Guilford Press.

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

Schneider, W., & Shiffrin, R. (1977). Controlled and automatic human information processing: Detection, search, and attention. *Psychological Review, 84*, 1–66.

Shriffin, R. & Schneider, W. (1977). Controlled and automatic processing II: Perceptual learning, automatic attending, and a general theory. *Psychological Review, 84*, 70-120.

Silliman, E., & Berninger, V. (2011). Cross-disciplinary dialogue about the nature of oral and written language problems in the context of developmental, academic, and phenotypic profiles*. Topics in Language Disorders, 31, 6-23*. free access at http://journals.lww.com/topicsinlanguagedisorders/Fulltext/2011/01000/Cross_Disciplinary_Dialogue_about_the_Nature_of.3.aspx

Sprenger-Charolles, L., Siegel, L., Be´chennec, D., & Serniclaes, W. (2003). Development of phonological and orthographic processing in reading aloud, in silent reading, and in spelling: A four-year longitudinal study. *Journal of Experimental Child Psychology, 84,* 194–217.

Treiman, R. (1993). *Beginning to spell: A study of first-grade children.* New York, NY: Oxford University Press.

van Viersen, S., Kroesbergen, E., Slot, E., de Bree, E. (2014). High reading skills mask dyslexia in gifted children, *Journal of Learning Disabilities*, pii: 0022219414538517. [Epub ahead of print]

Weintraub, N., Gilmour-Grill, N., & Weiss, P. L. (2010). Relationship between handwriting and keyboarding performance among fast and slow adult keyboarders. *American Journal of Occupational Therapy*, *64*(1), 123–132. doi:10.5014/ajot.64.1.12

Woodcock, R., McGrew, K., & Mather, N. (2001). *Woodcock-Johnson III Psychoeducational*

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

Cognitive Test Battery . Itasca, IL: Riverside.

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

Table 1.

Descriptive Statistics by Grade Level in Study 1

Measure	Grade 4			Grade 5			Grade 6			Grade 7		
	N	*M*	*(SD)*	*N*	*M*	*(SD)*	*N*	*M*	*(SD)*	*N*	*M*	*(SD)*
Outcomes (Writing)												
Word Choice	106	0.55	(0.54)	105	0.39	(0.43)	106	0.37	(0.53)	99	0.00	(1.00)
Spelling	109	108.97	(14.68)	105	109.08	(13.79)	106	109.20	(13.74)	99	110.57	(13.02)
Written Express	109	110.27	(14.90)	106	111.54	(14.55)	106	114.48	(11.73)	99	111.05	(14.27)
Predictors (Transcription)												
Manuscript	109	0.56	(1.00)	106	0.75	(1.06)	106	0.90	(0.93)	98	0.00	(1.00)
Cursive	102	0.00	(1.00)	102	0.00	(1.00)	103	-0.01	(0.99)	98	0.00	(1.00)
Keyboarding	110	0.00	(1.00)	105	0.00	(1.00)	106	0.00	(1.00)	99	0.00	(1.00)

Note. N = 113 students in original sample followed longitudinally (109 with sufficient initial data available for analysis); Word Choice = z-score based on research sample; Spelling = standard score from WIAT-2; Written Expression = standard score from WIAT-2; Manuscript, Cursive, and Keyboard Alphabet 15 seconds = z-scores based on research sample .

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

Table 2.
Zero-Order Correlations by Grade Level in Study 1

Grade 4	*1.*	*2.*	*3.*	*4.*	*5.*	*6.*
1. Word Choice	--					
2. Spelling	.69***	--				
3. Written Express	.53***	.61***	--			
4. Manuscript	.16	.16	.34***	--		
5. Cursive	.24*	.27**	.33***	.33***	--	
6. Keyboarding	.25**	.27**	.24*	.24*	.30**	--
Grade 5	*1.*	*2.*	*3.*	*4.*	*5.*	*6.*
1. Word Choice	--					
2. Spelling	.66***	--				
3. Written Express	.54***	.65***	--			
4. Manuscript	.17	.32***	.16	--		
5. Cursive	.16	.25*	.28**	.43***	--	
6. Keyboarding	.21*	.29**	.28**	.21*	.38***	--
Grade 6	*1.*	*2.*	*3.*	*4.*	*5.*	*6.*
1. Word Choice	--					
2. Spelling	.54***	--				
3. Written Express	.49***	.59***	--			
4. Manuscript	.23*	.19	.27**	--		
5. Cursive	.22*	.21*	.22*	.30**	--	
6. Keyboarding	.40***	.41***	.48***	.34***	.27**	--
Grade 7	*1.*	*2.*	*3.*	*4.*	*5.*	*6.*
1. Word Choice	--					
2. Spelling	.32***	--				
3. Written Express	.15	.52***	--			
4. Manuscript	.21*	.18	.22*	--		
5. Cursive	.12	.21*	.34***	.43***	--	
6. Keyboarding	.06	.29**	.23*	.29**	.10	--

Note. Pearson's *r* correlations reported based on available data for each grade level and measure; Word Choice = z-score based on research sample; Spelling = standard score from WIAT-2; Written Expression = standard score from WIAT-2; Manuscript, Cursive, and Keyboard Alphabet Writing=15-seconds=z-score based on research sample.
* $p < .05$, ** $p < .01$, *** $p < .001$.

Alstad, Z.., Sanders, E., Abbott, R., Barnett, A., Hendersen, S., Connelly, V., & Berninger, V. (in press). Modes of alphabet letter production during middle childhood and adolescence: Interrelationships with each other and other writing skills. *Journal of Writing.*

Table 3.

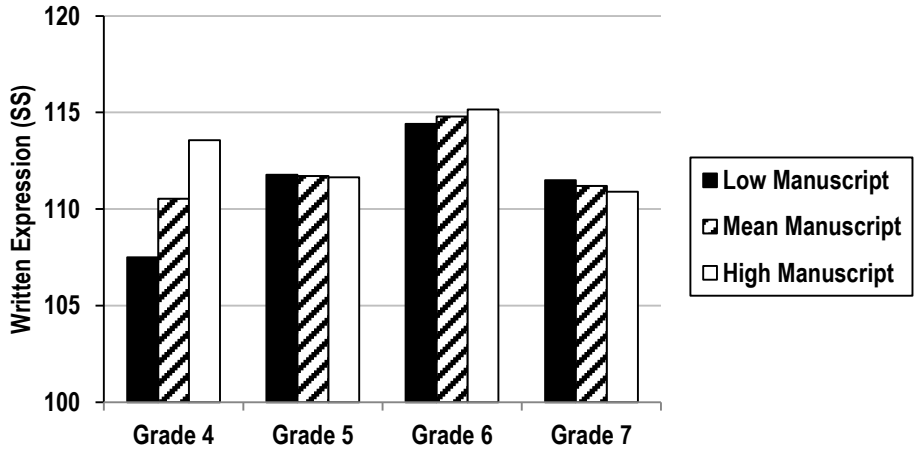
Multilevel Model Results across Grade Levels in Study 1

	Word Choice			Spelling			Written Expression		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Fixed Effects	*Coeff*	*Coeff*	*Coeff*	*Coeff*	*Coeff*	*Coeff*	*Coeff*	*Coeff*	*Coeff*
Block 1									
Conditional Mean	0.32***	0.34***	0.34***	109.08***	109.25***	109.26***	111.69***	112.06***	112.06***
Grade 4	0.23***	0.23***	0.23***	-0.15	-0.27	-0.24	-1.66*	-1.47	-1.52
Grade 5	0.06	0.05	0.05	-0.45	-0.41	-0.43	-0.32	-0.36	-0.35
Grade 6	0.05	0.07*	0.07*	-0.08	-0.07	-0.07	2.89***	2.71***	2.73***
Block 2									
Manuscript		0.06	0.07		0.34	0.39		0.99	0.76
Cursive		0.05*	0.04		1.66***	1.62***		2.31**	2.41**
Keyboard		0.03	0.04		0.45	0.50		1.08	1.14
Block 3									
Grade 4 * Manuscript			-0.05			-0.41			2.27*
Grade 5 * Manuscript			-0.01			0.72			-0.83
Grade 6 * Manuscript			-0.06			-0.08			-0.38
Grade 4 * Cursive			0.03			-0.08			-0.08
Grade 5 * Cursive			-0.03			-0.33			0.26
Grade 6 * Cursive			0.01			0.34			-1.57*
Grade 4 * Keybrd			0.04			-0.12			-1.10
Grade 5 * Keybrd			0.03			0.68			0.51
Grade 6 * Keybrd			0.01			0.00			0.77
Random Effects	*Var*	*Var*	*Var*	*Var*	*Var*	*Var*	*Var*	*Var*	*Var*
Between Students	0.16***	0.10***	0.10***	166.57***	148.17***	147.77***	113.27***	80.08***	80.55***
Within Students	0.28	0.27	0.27	22.85	21.51	21.04	82.35	82.68	79.68
Approximate R^2 Change		15.7%	1.5%		10.4%	0.5%		16.8%	1.6%

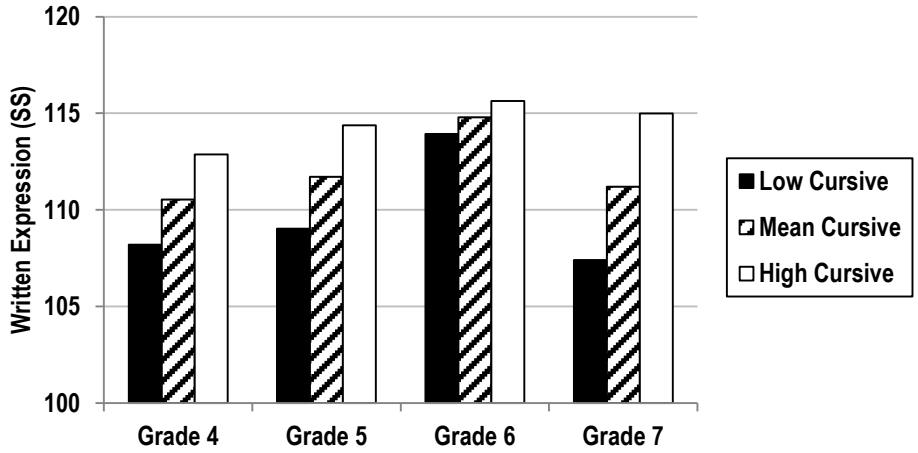
Note. *N*=109 students with sufficient data available for analysis across all grade levels. Word Choice = norm-referenced z-score based on research sample; Spelling = standard score from WIAT-2; Written Expression = standard score from WIAT-2; Manuscript, Cursive, and Keyboard Alphabet 15 seconds = z-scores based on research sample. All parameters estimate in *HLM 7* using full maximum likelihood. Grade levels effect-coded (grade 7 = -1; all others +1), and Manuscript, Cursive, and Keyboard standardized within grade level. Approximate R^2 Change calculated as the sum of the variance components in more complex model divided by the sum of the variance components in simpler model, subtracted from 1. * $p < .05$, ** $p < .01$, *** $p < .001$.

Figure 1. *Predicted Written Expression by Modes of Transcription and Grade Level*

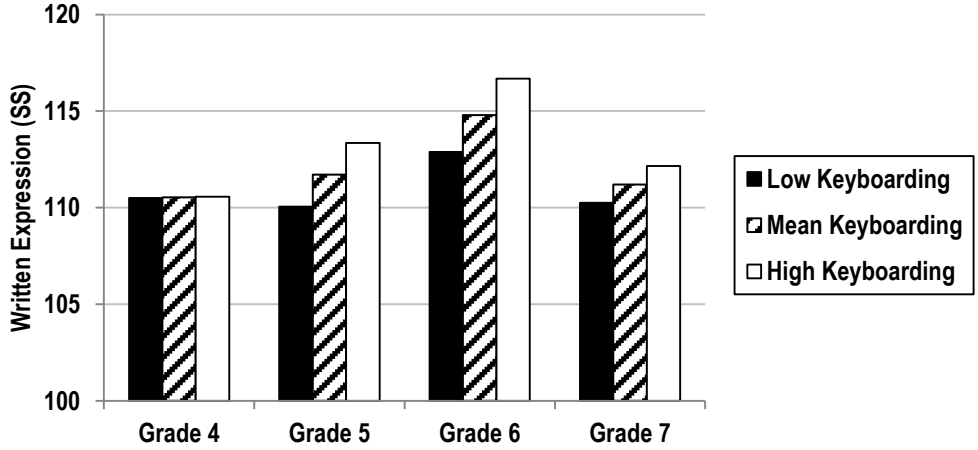
Panel A: Levels of Manuscript



Panel B: Levels of Cursive



Panel C: Levels of Keyboarding



Note. Significant unique main effect of cursive on written expression found (across all grades); significant Grade-by-Mode interactions detected for grade 4 manuscript and grade 6 keyboarding.

Figure 2. *Predicted Keyboarding Skill by Cursive Skill Level and Grade*

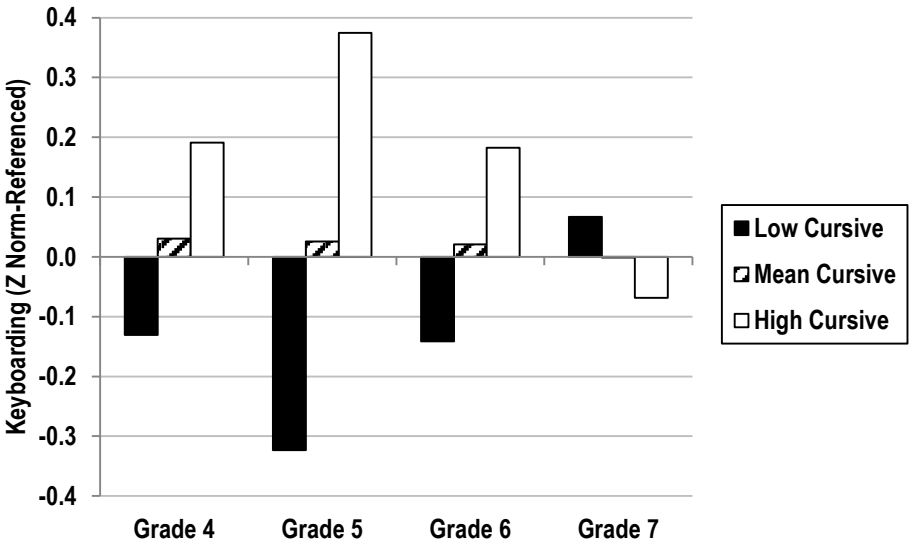


Table 4.
Zero-order Correlations among Letter Production Modes and Other Writing Outcomes in Study 2

	Letter Writing Modes				
	Alphabet 15 (raw score)			DASH (standard score)	
Writing Task	Manuscript	Cursive	Keyboard	Copy Best	Copy Fastest
Spell Dictated Pseudowords	.33**	.33**	.25*	.27**	.27**
Spell Dictated Real Words	.30**	.34**	.32**	.29**	.35***
Written Sentence Syntax					
Combining	.26*	.33**	.16	.35***	.26**
Fluency	.27**	.23*	.33**	.47***	.52***

Note. *N*=88 students, grades 4-9. * $p < .05$, ** $p < .01$, *** $p < .001$.

Table 5.

Descriptive Statistics and Results for SLD Group Comparisons with Controls as well as SLD Group Comparisons on Measures for which ANOVA Yielded a Significant Main Effect for the Four Groups in Study 2

	Control (n = 10)		Dysgraphia (n = 27)		Dyslexia (n = 40)		OWL LD/SLI (n = 11)		Comparisons of Each SLD Group with the Others
Measures	*M*	*(SD)*	*M*	*(SD)*	*M*	*(SD)*	*M*	*(SD)*	
Letter Writing									
Alphabet 15 Manuscript	13.91	(6.41)	7.85	(4.22)***	8.92	(4.76)**	8.18	(4.35)**	ns
Copy Best	11.45	(2.46)	8.63	(3.16)*	9.10	(3.73)*	9.27	(3.88)ns	Dysgraphia <Dyslexia
Copy Fast	11.09	(1.87)	6.41	(2.90)***	6.93	(3.32)***	7.09	(3.96)**	ns
Written Sentence Syntax Fluency	109.82	(8.21)	98.65	(13.02)**	93.33	11.39***	82.10	(16.47)***	OWL < Dysgraphia OWL < Dyslexia

Note. *N*=88 students, grades 4-9. One-way analyses of variance showed main effect of Group on all measures shown above (no significant differences found for Alphabet 15 Cursive or Keyboarding or Sentence Combining). * $p < .05$, ** $p < .01$, *** $p < .001$, ns=not significant noted above for 2-tailed *t*-tests comparing each SLD group with Control group only following ANOVA showing a significant main effect for all four groups; on right, 2-tailed *t*-tests showing significant or no significant differences between each SLD group with the others; for example, differences were detected on Copy Best between Dysgraphia and Dyslexia and on Written Sentence Syntax Fluency between OWL LD/SLI and Dysgraphia or Dyslexia.