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Computer Instruction in Handwriting, Spelling, and Composing for Students with Specific Learning Disabilities in Grades 4 to 9

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Abstract

Effectiveness of iPad computerized writing instruction was evaluated for 4th to 9th graders (n=35) with diagnosed specific learning disabilities (SLDs) affecting writing: dysgraphia (impaired handwriting), dyslexia (impaired spelling), and oral and written language learning disability (OWL LD) (impaired syntax composing). Each of the 18 two-hour lessons had multiple learning activities aimed at improving *subword*- (handwriting), *word*- (spelling), and *syntax*- (sentence composing) *level language* skills by engaging all four language systems (listening, speaking, reading, and writing) to create a functional writing system. To evaluate treatment effectiveness, normed measures of handwriting, spelling, and composing were used with the exception of one non-normed alphabet writing task. Results showed that the sample as a whole improved significantly from pretest to posttest in three handwriting measures, four spelling measures, and both written and oral syntax construction measures. All but oral syntax was evaluated with pen and paper tasks, showing that the computer writing instruction transferred to better writing with pen and paper. Performance on learning activities during instruction correlated with writing outcomes; and individual students tended to improve in the impaired skill associated with their diagnosis. Thus, although computers are often used in upper elementary school and middle school in the United States (US) for accommodations (alternatives to pen and paper) for students with persisting SLDs affecting writing, this study shows computers can also be used for Tier 3 instruction to improve the writing skills of students in grades 4 to 9 with history of persisting writing disabilities.

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1 Introduction

1.1 Writing Instruction in 21st Century Information Age

The Great Debate about Reading during the Industrial Age (e.g., Chall, 1983) has been replaced with a new debate about writing in the high-tech, information age. On the one hand, many believe that handwriting is no longer fundamentally important because so many technology tools enable written communication without forming letters (e.g., press letter by index finger, thumb, or keyboard). On the other hand, others believe that handwriting has been prematurely abandoned and no longer receives sufficient instructional attention. The Common Core in the United States (US) (http://www.corestandards.org/Standards/index.htm) includes handwriting only in K to 1. Another widespread belief is that spell checks in word processing programs eliminate the need for systematic spelling instruction. Although spell checks flag typos, writers still have to draw on their knowledge of word-specific spellings (Olson, Forsberg, Wise, & Rack, 1994) to choose the correct spelling from a list of possible spellings. That knowledge, which is based on which specific letter sequences are associated with specific morphological forms, word pronunciations, and meanings, facilitates both spelling and reading (Ehri, 1980a, 1980b; Hulslander, Olson, Willcutt, & Wadsworth, 2010). A recent metaanalysis has shown that explicit spelling instruction facilitates spelling and other writing skills as well as reading (Graham & Santangelo, 2014).

In addition, although reading has received considerable national attention in the US in an era in which evidence-based educational practice is emphasized (e.g., National Reading Panel, 2000; U. S. Department of Education, National Center for Education Statistics, 1995), composing of written text has received considerably less attention. The relative lack of attention to written expression of ideas is surprising considering that computer use requires integrating writing with reading, often for communication of ideas through written sentences and text in response to reading others' written messages. Out of school, on a daily basis children and youth read written text displayed on a phone or laptop screen that others have composed and sent and then reply with the text they compose and send. In the classroom, students are expected to write about what they read. Students with persisting writing problems may struggle not only in composing texts but also in constructing the sentences in those texts (Myhill, 2009; Sandler & Graham, 2005; Scott, 2002, 2009).

1.2 Computerized Instruction in the 21st Century Information Age

Computers are typically not integrated with daily instruction in the classroom in language arts and across the content areas of the curriculum, but could be (see Wong, 2001). Results of a five year longitudinal study in which parents completed a home literacy questionnaire annually for five years (grades 1 to 5 or grades 3 to 7) showed that personal computers were used at home for homework assignments and games but rarely at school (Alston-Abel, 2009). However, simply making laptops available appears not to be sufficient without consideration of how the laptops will be used for specific kinds of instruction and instructional goals (cf., Cristia, Ibarrarán, Cueto, Santiago, Severin, 2012).

Many kinds of innovative computer technology have been developed to support all kinds of learning (for recent review, see, Aleven, Beal, & Graesser, 2013). For example, metaanalyses showed that computer technology improved math achievement, especially in elementary classrooms and for special needs students (Li, & Ma, 2010). At the middle school level, a wide range of digital technologies for reading comprehension yielded robust effect sizes for the general student body and lower effect sizes for struggling readers or students with specific learning disabilities (Pearson, Ferdig, Blomeyer, & Moran, 2005). Results for both reading and math have been somewhat mixed (see Dynarski et al., 2007), but researcher-created software tends to outperform off-the-shelf products (Pearson et al., 2005). Metaanalyses also point to the (a) advantage of combined computer technology and human-delivered instruction, and (b) the need for more professional development of educators in educational technology applications (Cheung, & Slavin, 2012).

Even for computer games, attention to and engagement in the software-supported activities remain challenges. For example, Ronimus, Kujala, Tolvanen, and Lyytinen (2014) found that computer games did not necessarily engage first and second graders until learning goals were achieved. Likewise, computer-user anxiety can be an issue in whether computer tools are used effectively for learning. Conti-Ramsden, Durkin, and Walker (2010) found in a study of use of computers at home for educational purposes that students with a history of specific language impairment (SLI) experienced more computer anxiety than typically developing peers.

However, relatively little research has been directed to computerized instruction for teaching writing skills to students with carefully diagnosed SLDs, but see MacArthur (2009) for programmatic research on applying readily accessible computer tools to the writing instruction program for struggling writers in general. Admittedly, writers' motor skills may interface with computer technology differently than does use of a pen, pencil, or fine tip marker (Sulzenbruckl, Hegele, Rinkenaurl, Heuerl, 2011). However, the nature of the user-computer interface may be different for typically developing writers and those with SLDs affecting writing in upper elementary and middle school. For example, students with dysgraphia (Richards, Berninger, Stock, Altemeier, Trivedi, & Maravilla, 2009) have been shown to have specific difficulty in sequential finger movements, which are needed for writing with pen and paper and keyboard.

Moreover, writing, even letter production, is more than a motor skill—it is also a *multimodal, multileveled language skill*. That is, writing develops through language by hand (writing), by eye (visual feedback from the written output), by ear (listening to teacher's aural instructional talk), and mouth (sounding out spelled words internally or externally or thinking aloud or subvocally to plan and translate ideas into words). Each of these language systems has subword, word, and multi-word levels (units). See Berninger (2015) and Berninger and Niedo (2014) for a visual figure capturing the four multi-leveled language systems with links to (a) different end organs for input and output, (b) a variety of cognitive representations and operations at the conscious and unconscious levels, (c) social, emotional, and motivational systems, and (d) executive functions for coordinating these complex, interacting systems.

1.3 Individual Differences among Writers during the Common Core Standards Era

It is not clear if the US Common Core State Standards for English Language Arts (http://www.corestandards.org/) are based on research evidence that takes into account the normal variation among typically developing writers (Berninger, 2009) as well as students in the upper elementary and middle school grades who struggle with writing for various reasons (e.g., Graham, & Hebert, 2010; Graham, MacArthur, & Fitzgerald, 2007; Troia, 2009). Struggling writers may have difficulty with writing because of SLDs or other reasons. Researchers have identified different learning profiles or patterns of specific learning disabilities (SLDs) related to instructional needs in children and youth whose development is otherwise in the normal range (for review, see Silliman & Berninger, 2011): *dysgraphia* (impaired handwriting) (e.g., Berninger, 2004), *dyslexia* (impaired oral word reading and written spelling) (e.g., Berninger, Nielsen, Abbott, Wijsman, & Abbott, 2008; Lyon, Shaywitz, & Shaywitz, 2003), and *oral and written language learning disability*, *OWL LD*, also called specific language impairment (*SLI*) (impaired oral and written syntax) (e.g., Butler, & Silliman, 2002; Catts, & Kamhi, 2005; Catts, Adlof, Hogan, & Ellis-Weismer, 2005; Nelson, 2010; Nelson, Helm-Estabrooks, Hotz, & Plante, 2011; Scott, 2002, 2009; Silliman, in press; Stone, Silliman, Ehren, & Apel, 2014; Thal, Bates, Goodman, & Jahn-Samilo, 1997; Tomblin, Zhang, Weiss, Catts, & Weismer, 2004).

Please note that SLDs in developing students differ from acquired disorders that impair written language: How a skill is acquired and how it becomes impaired after it was acquired are not the same. For example, *dysgraphia* refers to a developmental disorder in learning handwriting, but *agraphia* refers to loss of handwriting skill previously acquired. *Dyslexia* refers to a developmental disorder in learning word spelling (and reading), whereas *alexia* refers to an acquired disorder in which spelling and/or reading become impaired after having been acquired. *OWL LD* and *SLI* refer to developmental disorders in learning heard and spoken language during early, preschool development and written language during the school years, whereas *aphasia* refers to an acquired disorder in which specific aural/oral language processes previously intact become impaired.

Children with developmental dysgraphia have difficulty learning to form legible letters others can recognize automatically so limited working memory resources are available for other writing processes, including spelling and composing. Many children with developmental dyslexia have considerable difficulty in learning both to pronounce real words and pseudowords without meaning and spell written words (Berninger, Nielsen et al, 2008). Indeed, spelling appears to be the persisting problem faced by individuals with dyslexia (e.g., Lefly, & Pennington, 1991; Schulte-Korne et al., 1998). Individuals with dyslexia typically do not struggle with listening comprehension or oral expression of ideas because reading or spelling written words is not involved. That is, they have difficulty at the *word-level* for both converting written words to spoken words and converting spoken words they hear or have stored in memory to written words; but they do not have difficulty with language by ear (listening) or by mouth (oral expression) independent of transforming written words into spoken words or spoken words into written words. In contrast, those with OWL LD/SLI typically have difficulty with both listening and reading comprehension and both oral and written expression of ideas (Nelson, Bahr, & Van Meter, 2004), and may also have difficulty with other language skills, for example, in finding words while producing oral or written multi-word constructions.

However, all these SLDs may share a common difficulty in handwriting (e.g., Berninger, 2009; Berninger, Nielsen et al., 2008); those with dysgraphia are impaired only in handwriting not reading, but those with dyslexia and OWL LD may have difficulty with handwriting in addition to their other written language disabilities. One in five or six children may have an SLD that affects learning to write with or without co-occurring ADHD and even using writing in math and with reading (Katusic, Barbaresi, Colligan, Weaver, Leibson, Jacobsen, 2005; Katusic, Colligan, Weaver, Barbaresi, 2009; Stoeckel, Colligan, Barbaresi, Weaver, Killian, Katusic, 2013; Yoshimasu et al., 2011).

Thus, computer-provided handwriting instruction in the context of lessons that also develop spelling and composing skills may improve the writing skills of students with dysgraphia, dyslexia, and OWL LD/SLI, but further research on using computers in teaching writing to students with SLDs is needed for two reasons. First, it is common to recommend that students with persisting writing problems beyond the primary grades (1, 2, and 3 in the US) use computers as an accommodation, which is using them as an alternative for pen and paper. However, seldom do students with persisting SLDs involving writing receive explicit instruction in using computers for writing across the subjects in the curriculum. Research is needed, therefore, on the effectiveness of providing writing instruction by computer for those students with SLDs and persisting writing problems. Second, considering that not all students with writing problems have exactly the same kind of writing problem, of interest is whether computer writing instruction might be effective for individuals with specific diagnoses (dysgraphia, dyslexia, OWL LD/SLI, indicating impaired handwriting, spelling, or syntax composing respectively). That is, does using the computer to teach writing skills at different levels of language (subword, word, syntax) result in improvement on the specific impaired skills associated with a specific diagnosis?

1.4 Using Computerized Instruction to Create Multi-Leveled Functional Writing System

Programmatic research has shown the value of teaching written language in lessons aimed at all levels of language (subword letters, word spelling, and syntax/text level composing) close in time rather than focusing on an isolated writing skill without opportunity to transfer it to related skills needed to create functional writing systems (for review, see Berninger, 2009; Silliman & Berninger, 2011). Drawing on such programmatic research, the research team developed three lesson sets. The first taught handwriting. The second taught spelling. The third taught sentence construction. Students completed learning activities in each lesson set in each session in order to maximize transfer across levels of language to create or refine functional writing systems. In addition, in all lesson sets, learning activities required listening to the computer teacher's instructional talk through ear phones, reading written language on the monitor, producing written language by hand via tools for interfacing with the iPad, and, for many learning activities, orally producing sounds or written words when instructed to do so. Thus, writing was taught in the context of the earlier discussed conceptual model for integrating four language systems (by ear, by eye, by mouth, and by hand).

1.5 Research Aim

The research aim was to determine whether students with SLDS who have persisting writing problems beyond the third grade would show response to instruction (RTI) on computer lessons aimed at multiple levels of written language and the four language systems. We define RTI on basis of response to instruction rather than intervention because we are interested in instructional interventions. Currently, the controversy continues over whether to use normed measures to identify students with SLDs or even differentially diagnose different kinds of SLDs VERSUS whether to use RTI at three times during school year to determine who should receive supplementary or special educational services for SLDs. In this research we introduce another alternative that draws on (a) both normed measures and developmental, medical, educational, and medical histories for comprehensive, differential diagnostic assessment, (b) comparison of pretest-posttest gains on normed measures at completion of computer instruction; and (c) RTI for writing based on computer feedback provided during computer learning activities and stored in computer for future data analyses.

Normed measures were used for each of the three levels of language (handwriting, spelling, sentence composing) so that change could be evaluated from before to after instruction in reference to age peers. Students with SLDs may respond to instruction, but still lose ground relative to peers without SLDs, who make relatively larger gains over time. If students do show RTI to multi-level, computer-delivered writing instruction, then that is evidence supporting the value of going beyond accommodations only to specialized, computer-delivered explicit writing instruction for those with persisting writing disabilities. In addition, we evaluated whether RTI during specific learning activities designed to teach various skills was correlated with outcomes on which treatment effects were observed for the whole sample. Significant correlations between RTI for those learning activities and specific posttest outcomes would provide initial evidence that RTI during those learning activities is probably related to the observed post-treatment outcomes. We also evaluated whether individuals in specific diagnostic groups (dysgraphia, dyslexia, and OWL LD or SLI) improved on hallmark impaired skills associated with their respective SLDs. That is, is the computerized instruction effective in overcoming specific kinds of SLDs affecting writing?

2 Methods and Materials

2.1 Participants

2.1.1 Recruitment and phone screening—Participants were recruited by flyers distributed to local schools that announced opportunity to participate in a research study for students in grades 4 to 9 who had problems in handwriting, spelling, and/or written composing. Interested parents contacted the first author who conducted a phone interview approved by institutional review board (IRB) for research with human participants. The purpose of the interview was to identify students who were developing normally except for unusual difficulty with handwriting, spelling, and/or composing and had not been previously diagnosed with developmental disabilities, neurogenetic disorders other than SLDs, psychiatric disorders, brain injury, or medical disease that are associated with school learning and behavior problems but have a different etiologies (Batshaw, Roizen, Lotrecchiano, 2013) and evidence-based instructional needs than those with SLDs do (Berninger, 2015). ADHD, which frequently occurs with SLDs affecting writing, was not an exclusion criterion. Students who, based on parental phone interview seemed likely to have an SLD, were given comprehensive assessment at the university. While the student was tested to confirm eligibility and identify diagnostic group, parents completed questionnaires about the student's developmental, medical, educational, and family histories. The questionnaires were used to confirm what the parent had reported during the interview, namely that the student had history of and current persisting problems in handwriting, word spelling, and/ or oral and written language syntax.

2.1.2. Assignment to diagnostic SLD groups—Criteria based on two decades of interdisciplinary research on diagnosing SLDs affecting writing were as follows:

a. for *dysgraphia*, at or below −2/3 *SD* on two or more handwriting measures but no reading problems, and parent reported history of ongoing and current handwriting problems that first emerged in kindergarten or first grade;

b. for *dyslexia*, word reading and typically also spelling below population mean and at least 1 SD below Verbal Comprehension Index on two or more word reading and spelling measures, which tend to be below −2/3 SD, and parent reported history of ongoing and current word reading and spelling problems that first emerged in kindergarten or first grade; and

c. for *OWL LD/SLI*, at or below −2/3 SD on at least two measures of syntactic listening or reading comprehension or syntactic oral or written expression, and parent reported emergence of aural and/or oral language problems during the preschool years (typically between first and third birthdays) and history of ongoing and current problems in listening comprehension, reading comprehension, and/or written expression.

For additional information on evidence-based, differential diagnosis procedures, which include initial exclusion of students with developmental disabilities, see Silliman and Berninger (2011) and Berninger (2015). For example, students with developmental disabilities in motor function may also have problems with handwriting, but their problems are not specific to written language and tend to be more pervasive affecting activities of daily living beyond handwriting (Berninger, 2004). Computers can be used effectively in their instructional programs, but this study did not focus on that population.

With the exception of one adopted child, parents reported family history of writing, reading, and/or oral language problems, consistent with the growing body of research showing the genetic bases of these SLDs in multi-generational families (for review, see Raskind, Peters, Richards, Eckert, & Berninger, 2012). Moreover, parents reported that all participating students had had considerable intervention over the years, but still their writing problems persisted. Those in public schools tended to have Individual Education Plans (IEPs) for special education services; those in both public and private schools had had private tutoring outside of school. All who qualified for the project participated in the larger diagnostic study testing a *levels- of-language cascading model of dysgraphia (subword letter impairment), dyslexia (word spelling and reading impairment), and OWL LD (aural, oral, read, and* *written syntax impairment)*. Students whose parents decided to have their children receive the computer writing instruction participated in the current study, which was approved by the IRB where the research was conducted in compliance with the ethical and professional standards of the American Psychological Association.

2.1.3 Sample characteristics—Altogether the children ranged in age from 10 years and 4 months to 14 years and 9 months and included children who met research criteria for dysgraphia (*n*= 13), dyslexia (*n*= 17), and OWL LD (*n*= 5). The sample included 80% males. Their mothers' level of education included high school graduate (*n*=1), college (*n*=16), and more than college (*n*=18). Fathers' level of education included less than high school *(*n=4), more than high school (*n*=1), college (*n*=9), to more than college (*n*=20); this information was not available for one adopted child. Parental self-reported ethnicity of the child included Asian-American (n=1), European-American (*n*=29), Pacific Islander (*n*=1), Hispanic (*n*=1), Black (*n*=1), Asian (*n*=1), mixed (*n*= 3).

2.2 Behavioral Observations

Consistent with research of Conti-Ramsden et al. (2010) with older adolescents, many students shared spontaneously how anxiety-provoking writing is for them. Consistent with research of Ronimus et al. (2014), initially students struggled with attending to and engaging in the lessons, but, as the lessons proceeded, through input from human teachers, they appeared to be attending and engaging more consistently. We did not collect formal measures of anxiety and attention/engagement during the lessons, but see Discussion for future research directions.

2.3 Contents of Writing Instruction Organized by Evidence-Based Conceptual Framework

As explained in the introduction, the computerized writing lessons used in the current study were based on prior instructional studies that identified effective ways for human teachers to teach handwriting, spelling, and composing to students with diagnosed dysgraphia or dyslexia or OWL LD in the upper elementary or middle school grades (e.g., Berninger, Winn et al., 2008). Key to those instructional approaches was targeting instruction to each level of language, first at the subword, then word, and finally text levels close in time, so that the subword, word, and text levels can learn to work together to create functional writing systems, much as all the musical instruments in the orchestra have to work together to create music not noise. Each of the three sets of lessons generally was completed in two hour sessions after school at the university.

Using the computer platform for instruction allowed the team to provide each student frequent feedback for evaluating RTI. Computers can be programmed to provide more frequent feedback (both whether a response is correct and if not what the correct response should be) than human classroom teachers can provide for individual students' response to each item in a learning activity. Thus, in addition to using normed measures of handwriting, spelling, and composing to evaluate effectiveness of the computer lessons, we also examined the correlations between the mean level of performance on relevant learning activities (scored by the computer and stored in the computer) and posttest normed score on each handwriting, spelling, and composing outcome for which there was a group treatment effect.

2.3.1 Computerized instructional activities for handwriting—See Figure 1 for the introduction to the lesson set in lesson 1 for handwriting, which was presented aurally through ear phones and visually displayed on monitor. Also an example of the visual steps that appeared on the screen at the beginning of lessons 2 to 18 is included in Figure 1. Learning Activities in the handwriting lessons included the following for both lower case printed and cursive letters: (a) observing a letter in motion forming through animation (visual motion), (b) forming the letter keeping the strokes within the contour around the letter (kinesthetic motor control), (c) copying the displayed letter (coordinating the mind's eye and hand), (d) writing a dictated letter not displayed from memory (associating the heard letter name with grapho-motor output plan), and (e) writing the letter that came before and after a designated letter (finding, accessing, producing letter in ordered alphabet series in long-term memory). Students were randomly assigned to order of alternating mode for handwriting learning activities—index finger or stylus first for three lessons and then alternating repeatedly every three lessons with the other mode for a $3 \times 3 \times 3 \times 3 \times 3 \times 3$ design.

The first three activities were also practiced for upper case manuscript and cursive letters, but another task was substituted for the last two (c and d) on lower case letters. Students were asked to write the upper case letter at the beginning of a sentence written in the same format (manuscript or cursive). The goal was to teach application of capital letters, given the frequent complaint that students with SLDs tend not to use capitals to mark the beginning of a new sentence. The rationale for teaching both manuscript and cursive was that participants vary widely as to how much, and even if, they have had instruction in either format, but especially in cursive. Learning to write cursive also helps to recognize cursive letters that are still used (e.g., in signing legal documents and in some formats in the menu of word processing programs).

At the end of each handwriting lesson set in a session, a number appeared on the screen for the number of times during the letter tracing learning activity that the finger or stylus went outside the border lines of the letter students were forming on the screen. In addition, the total time for completing the handwriting lessons appeared on the screen. These displayed numbers were computed by the computer program as the child completed each item in a learning activity, displayed visually for the student to record on the RTI form, and stored in the computer data base for research purposes (later data analyses). For two reasons, we asked the student to record the displayed feedback on an RTI form that had blanks for each Learning Activity in the handwriting, spelling, and composing lesson sets in each of the 18 lessons. First, recording this immediate feedback served to keep students engaged and invested in their own learning process. Second, the written record of relative performing on the RTI form gave the supervising teachers immediate feedback to discuss with the students and evaluate how they were doing across learning activities in each session and across the sessions and set goals for the next session, and to show parents, who brought their children and picked them up, where gains were being made.

2.3.2 Computerized instructional activities for spelling—Within each session, the student used the same mode of writing—finger or stylus—for spelling as had been used for the previous handwriting learning activities. See Figure 2 for Introduction in Lesson 1 presented aurally through the ear phones and visually displayed on the monitor. An example of one of the learning activities—Scribes Paying Attention to Letters and Letter Order—is also included in Figure 2 because average performance on it across the 18 lessons was correlated with all four spelling outcomes that showed treatment effects. Learning Activities in word reading and spelling lessons included counting sounds in words at the syllable and phoneme level (phonological awareness), identifying letters in designated positions in written words held in the "mind's eye) (orthographic awareness), observing spoken and written words transform by adding suffixes and prefixes (morphological awareness), and integrating phonological, orthographic, and morphologic features of words to create word-specific knowledge of written words. Students engaged all their sensory and motor systems for listening (through the ear phones to the computer teacher's instructional talk), reading (through eyes), naming (through mouth), and writing (through hand) as they learned how to integrate phonological and orthographic codes in both the spelling and reading directions. The computer generated feedback for response to most phonological, orthographic, and morphological Learning Activities, for example, to drag letters to create correctly spelled words. The student recorded this feedback (number of correct responses over total number of responses) when provided by the computer on the same RTI form.

2.3.3. Computerized instructional activities for composing text—If the student had used a stylus in the prior handwriting and spelling lessons, the stylus was used again in this lesson set. If the student had used the index finger, then an attachable keyboard was used in this lesson set for composing texts. See Figure 3 for Introduction in Lesson 1 to the syntax and text levels and an example of one of the Learning Activities for teaching strategies for combining multiple words within syntactic units and across syntax and text structures in the first five learning activities. The computer generates feedback about correct responses to these items, which again the student records on the RTI form for reasons already explained. Then in the sixth Learning Activity the student learns strategies for generating the next sentence. See Niedo Jones (2014) for a summary of these strategies for writing the next sentence in relationship to a prior sentence in the text and for creating the higher-level discourse structure of the text. In the seventh Learning Activity the student composes (up to 15 minutes with prompts to continue if writing ceases before time limit). See Niedo-Jones (2014) for evidence that the students used the strategies in writing these texts.

2.4 Measures

The following measures were given to assess students' writing achievement at the subword, word, and sentence levels before and after participating in the 18 computerized writing lessons to evaluate effectiveness of the lessons within a theoretical framework of levels of language. With the exception of the alphabet 15 measures for which normed measures were not available, all measures had been nationally normed for age peers.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

Alphabet 15 seconds—This task requires writing the alphabet in order from memory in cursive, manuscript, and keyboarding, as described in Berninger et al. (2006). The raw score was based on the number of legible letters, identifiable by others out of word context for manuscript and cursive or correctly selected by keyboard, in alphabetic order during the first 15 seconds, an index of automatic access, retrieval, and production. Note that a version of this test for which the participant was asked to write the alphabet from memory in lower case manuscript letters, for which raw scores were converted to *z*-scores based on research norms, had been used in determining qualifying participants for the study.

Detailed Assessment of Speed of Handwriting (DASH) Best and Fast (Barnett, Henderson, Scheib, Schulz, 2007)—The task is to copy a sentence with all the letters of the alphabet under contrasting instructions: one's best handwriting or one's fast handwriting. Students can choose to use printing or cursive or a combination. The score is a scaled score (*M*=10, *SD*=3). Intra-class correlation coefficient for interrater agreement for *DASH Best* and for *DASH Fast* is 0.99.

Test of Orthographic Competence (TOC) (Mather, Roberts, Hammill, & Allen, 2008)—For all TOC measures, the score is a scaled score (*M*=10, *SD*=3). For the *TOC Letter-Choice* subtest (test-retest reliability .84), the task is to choose a letter in a set of four provided letters to fill in the blank in a letter series to create a correctly spelled real word (word-specific spelling). For the *TOC Sight Spelling Subtest* (test-retest reliability .91), the task is to listen to dictated words and then write missing letters in partially spelled words to create correctly spelled real words (word-specific spelling). For the *TOC Homophone Choice (ages 9 to 12) or Word Choice* (ages 13 to 16) (test-retest reliability .72 to .75), the task is to identify a correct spelling for a specific word; even though there are different norms according to age of child, the scaled scores, regardless of age of the child were analyzed (word-specific spelling). For the *TOC Word Scrambles* (test-retest reliability .88 to .90), the task is to rearrange letters in a scrambled word to create a correctly spelled real word (word-specific spelling).

WIAT 3 (Psychological Corporation, 2009)—For WIAT3 *Sentence Combining*, the task was to combine two provided sentences into one well written sentence that contains all the ideas in the two separate sentences (test-retest reliability .81). The score is a standard score (*M*=100, *SD*=15). *Sentence Combining* is sensitive to written expression of thought at the syntax level.

Clinical Evaluation of Language Function 4th Edition CELF 4 Sentence Formulation (Semel, Wiig, & Secord, 2003)—The child is given three words and asked to construct an oral sentence. Results are reported in scaled scores with a *mean* of 10 and *SD* of 3. According to the test manual, test-retest reliabilities for ages assessed range from .62 to .71.

3 Results

3.1 Effectiveness of the Computerized Writing Lessons on Group Analyses

First, we explain our approach to data analyses yoked to our specific aim of evaluating whether the computerized instruction can facilitate significant improvement from pretest to posttest in handwriting, spelling, and composing skills of students in grades 4 to 9 with persisting SLDs affecting written language. Because participants varied in age and initial skill level, we used an approach that permits comparison of the same individual over two time points (pretest and posttest) and yields conclusions across individuals for these comparisons. We report results of paired *t*-tests, for which two time points yield the same results as repeated measures within-subjects ANOVA. To estimate effect sizes we used Cohen’s f^2, the ratio of partial eta^2 / (1-partial eta^2) and descriptive language (small, medium, or large effect) as recommended by Murphy, Myors, and Wolach (2009).

Table 1 contains the means and standard deviations for each of the nationally normed measures given at pretest and posttest, which were used to analyze significance of pair-*t* tests for writing outcomes at each level of written language (subword letter production, word-specific spelling, and sentence composing). We used this formula to compute Cohen’s effect sizes: $eta^2/(1- eta^2)$= Cohen's f^2. An $f^2 = .02$ is small effect, an $f^2 = .15$ is medium effect and an $f^2=.35$ is large effect (see Murphy et al., 2009).

Letter writing outcomes—As shown in Table 1, after instruction the participating students changed significantly in writing the alphabet in cursive letters (number of legible letters in first 15 seconds, an index of automaticity) and on both *DASH* Copy Tasks—for instructions emphasizing one’s best writing and instructions emphasizing fast writing. All treatment effects for subword written level of language were of medium effect size, except for Copy Best which was of large effect size (see Table 1 for Cohen's f^2 values).

Word *spelling outcomes*. Also see Table 1 for results showing that after instruction the participating students improved on all four of the *TOC* word-specific spelling measures: choosing one of a set of letters to fill in the missing letter to spell a real word correctly; choosing a letter from one’s own memory to fill in the missing letter to spell a real word correctly; choosing the correctly spelled word among a set of words or pseudowords that sound the same when pronounced; and unscrambling letters to create a correctly spelled word. All treatment effects for word level of written language were of medium effect size (see Table 1 for Cohen's f^2 values).

Syntax/sentence composing outcomes—The participating students improved in both written and oral syntax construction. See Table 1. As shown in Table 1 all treatment effects for the syntax level of written language were of medium effect size (see Table 1 for Cohen's f^2 values).

3.2 Mode Effects

All participants were randomly assigned to alternating order of modes of writing as described for the handwriting, spelling, and composing lessons. Because mean mode effect was not statistically significant for handwriting, spelling, or composing lessons, the average scores for RTI during specific learning activities were summed across combined modes in the correlation analyses that follow.

3.3 Correlations between Mean Performance on Learning Activities and Posttest Outcomes for Treatment Effects

Correlations between computer scored and stored RTI during learning activities (mean accuracy score across 18 lessons) and posttest normed scores were analyzed to test theory-driven hypotheses about which learning activities were related to specific treatment outcomes. The rationale is that statistically significant correlations provide evidence that the Learning Activity may mediate, or contribute in some way, to learning that led to that outcome.

3.3.1 Learning activities and treatment outcomes for handwriting—Mean errors (moving finger or stylus) outside the contour of letter while forming the letter on the iPad screen were negatively correlated with both copy sentence tasks that included all the letters in the alphabet: *DASH Copy Best,* $r = -.37$, $p = .029$; and *DASH Copy Fast*, $r = -.469$, $p = .004$. The lower the copy sentence score, the more errors were made on average. Mean total time for completing all Learning Activities for handwriting in each lesson was negatively correlated with the same copy tasks: *DASH Copy Best,* $r = -.471$, $p = .004$; and *DASH Copy Fast*, $r = -.459$, $p = .006$. The lower the copy score, the longer the time it took to complete lessons on average. Overall, mean errors and total time were positively correlated, $r = .422$, $p = .012$, suggesting that difficulty with handwriting is associated with both making more errors and taking more time on average.

Of interest, however, was that certain Learning Activities for word reading and spelling were also correlated with *DASH Copy Fast*: Pattern Analysis through Ear, $r = .378$, $p = .025$, Identify Number of Phonemes, $r = .356$, $p = .036$, Musical Rhythm through Stress Patterns, $r = .356$, $p = .036$, Pay Attention to Letter Order and Position, $r = .441$, $p = .008$; and Pick Sentence with Homophone that Makes Sense, $r = .349$, $p = .040$. Thus, not only Learning Activities involving handwriting but also phonological, orthographic, and morpho/syntactic skills related to spelling may also contribute to rate of letter and word copying on a sentence copy task. These findings show the beneficial effects of lessons aimed at both the letter and word level of language.

3.3.2 Learning activities and treatment outcomes for spelling—For *TOC Letter Choice*, phonological, orthographic, morpho/syntactic, and semantic Learning Activities were significantly correlated with the posttest learning outcome: Musical Rhythm through Stress Patterns, $r = .567$, $p < .001$, Pay Attention to Letter Order and Positions, $r = .806$, $p < .001$, Real Fixes or Not, $r = .422$, $p = .012$, Choosing Correctly Spelled Word, $r = .354$, $p = .037$, Choosing If Phoneme Matches Definition, $r = .476$, $p = .004$, Sentence Word Order Construct Sentence, $r = .389$, $p = .021$, Changing Word Order, $r = .357$, $p = .035$, and Conjunction to Combine Sentences, $r = .451$, $p = .006$.

For *TOC Sight Spelling*, phonological, orthographic, morpho/syntactic, and semantic Learning Activities were significantly correlated with the posttest learning outcome: Pattern Analysis through the Ear, $r = .404$, $p = .020$, Identify Number of Phonemes, $r = .353$, $p = .044$, Pay Attention to Letter Order and Position, r= .667, p<.001, Fixes or Not, r=.379, p=.030, Choosing Correctly Spelled Word, r= .387, p=.026, Sentence with Homophone Choice That Makes Sense, r= .365, p=.037, and Conjunctions to Combine Sentences, r= .365, p=.05.

For *TOC Word Choice*, orthographic, morpho/syntactic, and semantic Learning Activities were significantly correlated with the posttest learning outcome: Pay Attention to Letter Order and Position, r=.452, p=.008, Choosing Correctly Spelled Word, r= .499, p=.03, Compound Word Awareness of How Order Signals Meaning, r=.542, p=.001, Sentence Order-- Construct Sentence, r=.492, p=.003, Pick Sentence with Homophone that Makes Sense, r= .552, p=.001, and Use Conjunctions to Combine Sentences, r= .468, p=.006.

For *TOC Word Scrambles*, phonological, orthographic, morpho/syntactic, and semantic Learning Activities correlated significantly with the learning outcome: Identify the Number of Phonemes, r= .705, p<.001, Musical Rhythm through Stress Patterns, r=.580, p<.001, Real Fixes or Not, r= .415, p=.013, Choosing Correctly Spelled Word, r= .397, p=.018, Topics and Comments—If Topics Make Sense, r=.488, p=.003, Adding Glue (Function) Words to Fit Sentence, r= .556, p=.001, Changing Word Order to Construct Sentence, r= .401, p=.017, Building Bridges-- Choose Word that Fits Sentence, r=.357, p=.035, Pick Sentence with Homonym that Makes Sense, r= .470, p=.020, and Use Conjunctions to Combine Sentences, r=.528, p=.008.

Of interest, all Learning Activities in the word reading and spelling learning activities correlated with at least one spelling outcome and often more, and Scribes Paying Attention to Letters and Letter Order (a word anagram) correlated significantly with all four spelling outcomes and is featured in Figure 2. Also of interest, several of these learning activities involving ordering words in sentences or other syntax units were also related to spelling outcomes, consistent with sequencing of elements being related to spelling (Richards et al., 2009) and value of teaching to both the word and syntax levels of language in the same lessons.

3.3.3 Learning activities and treatment outcomes for syntax composing—Both Learning Activities for word reading and spelling and syntax comprehension and construction were related to oral syntax and written syntax, providing additional evidence for the value of teaching to both the word and syntax levels of language in the same lesson. For the *CELF4 Sentence Formulation*, phonological, morphological, orthographic, and syntactic Learning Activities were correlated with the learning outcome: Pattern Analysis through Ear, r= .399, p=.021, Real Fix or Not, r= .502, p=.003, Choosing Correctly Spelled Word, r= .508, p=.003, Choose Phrase Matching Definition, r= .451, p=.009, Adding Glue (Function) Word to Fit Sentence, r= .351, p=.045, Changing Word Order to Construct Sentence, r= .592, p<.001, Building Bridges among Words to Choose Word that Fits, r= .397, p=.022, Pick Sentence with Homophone Making Sense, r= .605, p<.001, and Use Conjunctions to Combine Sentences, r= .683, p<.001.

For *WIAT3 Sentence Combining*, both automatically writing cursive letters from memory in alphabetic order and phonological, orthographic, morphological, and syntactic Learning Activities were correlated with the learning outcome: Alph 15 cursive, r= .391, p=.036, Pattern analysis through ear, *r*= .481, *p*=.004, Identify Number of Phonemes, *r*= .453, *p*=.007, Musical Rhythm of Words, *r*= .391, *p*=.033, Real Fixes or Not, *r*= .388, *p*=.023, Choosing Correctly Spelled Word, *r*= .336, *p*=.052, Choose If Phrase Matches Definition, *r*= .470, *p*=.005, Topic and Comment--Decide If Topic Makes Sense, *r*= .359, *p*=.037, Adding Glue (Function) Words to Fit Sentences, *r*= .401, *p*=.019, Changing Word Order to Construct Sentence, *r*= .491, *p*=.003, Choosing Sentence with Homophone that Makes Sense, *r*= .499, *p*=.003, and Using Conjunctions to Combine Sentences, *r*= .569, *p*=.000. These results show the value of teaching to the subword letter-, word-, and syntax- levels of language in the same lesson.

Because Changing Word Order is related to both oral and written syntax learning outcomes, it is featured in Figure 3. Thus, sequencing is important within written word spellings (word anagrams) in Figure 2 and oral and written syntax (sentence anagrams) in Figure 3.

3.4 Evaluating Effectiveness of Treatment for Specific SLDs Affecting Writing Based on Individual Analyses of Improvement in Hallmark Writing Deficits

The raw score is reported for this task given in printing (manuscript), cursive, and keyboarding formats unless the score has a *z*-behind it indicating it is a *z*-score based on research norms; alph 15 z is available only for manuscript not cursive or keyboarding. All DASH Copy, *TOC*, and *CELF4* scores are *scaled scores* with mean=10, standard deviation=3, and ranges as follows (5 and less, below average; 6 and 7, low average; 8 to 11 average; 12 to 13 above average; 14 to 15 superior; and 16 and above very superior). *WIAT3 Sentence Combining*, however, is based on a *standard score* with mean=100 and standard deviation=15 (below 80 , below average; 80 to 89 low average; 90 to 109 average; 110 to 119 above average; 120 to 129 superior; 130 and above very superior).

3.4.1 Improvement on hallmark handwriting deficits in individual students with dysgraphia (n=13)—The research question was, of the 13 participants with diagnosed handwriting impairments and history of handwriting difficulties, how many showed improvement on one or more handwriting measures? Improvement was operationalized as higher score after than before treatment; and note that often it was more than a third of a standard deviation unit (1 point for scaled score, 5 points for standard score; 0.33*z*, or even higher

Participant 1 improved in three: UW *alph15z* −1.45 to −1.28, *DASH Copy Best* 4 to 11, and *DASH Copy Fast* 3 to 5. Participant 2 improved in alph15 7 to 17 printing, 0 to 19 cursive, and 23 to 26 keyboarding, and *DASH Copy Fast 3* to 9. Participant 3 did not improve on handwriting but did improve on spelling and written composing. Participant 4 improved on alph15 from 5 to 13 printing, 1 to 11 cursive, and 11 to 22 keyboarding, *DASH Copy Best* 10 to 12, and *DASH Copy Fast* 8 to 9. Participant 5 improved on alph15 from 16 to 18 printing, 8 to 15 cursive, and 13 to 26 keyboarding, *DASH Copy Best* 10 to 12, and *DASH Copy Fast* 3 to 12. Participant 6 improved on alph15 from 7 to 16 printing, 2 to 17 cursive, and 0 to 26 keyboarding, *DASH Copy Best* 4 to 7, and *DASH Copy Fast* 3 to 7. Participant 7 improved on alph15 from 7 to 10 printing and 1 to 10 cursive, *DASH Copy Best* 6 to 14, and *DASH Copy Fast* 4 to 11. Participant 8 improved on alpha15*z* for printing −1z to .66z and on raw scores from 2 to 18 for cursive, *DASH Copy Best* 5 to 11, and *DASH Copy Fast* 7 to 9. Participant 9 improved on alph15 from 6 to 19 printing and 3 to 16 cursive, and 15 to 26 keyboarding. Participant 10 improved on alph15 from inability to print any letters to 0.249 *z* for printing from 8 to 23 cursive and 23 to 26 keyboard, and *DASH Copy Fast* 9 to 11. Participant 11 improved in raw scores on alph15 from 5 to 11 printing, 1 to 6 cursive, and 18 to 26 keyboarding, *DASH Copy Best* 7 to 9, and *DASH Copy Fast* 3 to 6. Participant 12 improved on alph15 from 5 to 11 printing, 1 to 6 cursive, and 18 to 26 keyboarding, *DASH Copy Best* 7 to 11, and *DASH Copy Fast* 3 to 9. Participant 13 improved on alph15 from 12 to 24 printing, 1 to 24 cursive, and 23 to 26 keyboarding, and *DASH Copy Best* 9 to 11.

Only one of thirteen students with persisting severe dysgraphia was not a treatment responder for computer instruction on handwriting. Most also showed improved spelling and composing as well. Thus, handwriting is treatable even in students with persisting handwriting problems in grades 4 to 9. The students with dysgraphia responded to an instructional approach that teaches to all levels of written language—subword letter formation, word spelling, and syntax composing—close in time to create a functional writing system.

3.4.2 Improvement on hallmark spelling deficits in individual students with dyslexia—Participant 1 improved on *TOC Word Scrambles* 9 to 12, *TOC Word Choice* 8 to 11, and three handwriting measures. Participant 2 improved on *TOC Letter Choice* 4 to 9, *TOC Sight Spelling* 5 to 9, and five handwriting measures. Participant 3 improved on two handwriting measures. Participant 4 improved on *TOC Word Choice* 9 to 15. Participant 5 improved on one handwriting measure. Participant 6 improved on *TOC Sight Spelling* 6 to 7, TOC *Letter Choice* 8 to 11, and one handwriting measure. Participant 7 did not improve in spelling or handwriting measures. Participant 8 improved in *TOC Word Choice* from 11 to 16 and five handwriting measures. Participant 9 improved on *TOC Letter Choice* 6 to 8, *TOC Word Scrambles* 9 to 13, *TOC Sight Spelling* 8 to 11, and *TOC Word Choice* 7 to 11. Participant 10 improved on *TOC Word Scrambles* 7 to 8, *TOC Sight Spelling* 9 to 10, and five handwriting measures. Participant 11 improved on *TOC Scrambles* 9 to 11, TOC Sight Spelling 10 to 13, and three handwriting measures. Participant 12 improved on two handwriting measures. Participant 13 improved on *TOC Word Choice* 7 to 10, *TOC Sight Spelling* 8 to 10, *TOC Letter Choice* 9 to 10, and four handwriting measures. Participant 14 improved on *TOC Word Choice* 8 to 13 and two handwriting measures. Participant 15 improved on *TOC Word Scrambles* 7 to 9, and *TOC Sight Spelling* 11 to 12. Participant 16 improved on *TOC Word Choice* 4 to 14 and three handwriting measures. Participant 17 improved on *TOC Sight* 5 to 7, *TOC Word Choice* 6 to 8, and five handwriting measures.

All but 4 of the 17 individual students with persisting, severe dyslexia were treatment responders on one or more of the spelling measures for which there was a treatment effect on the group analyses. Of the 4 non-responders on those TOC spelling measures, 3 were treatment responders on handwriting. Thus, spelling tends to be treatable even in students with persisting dyslexia in grades 4 to 9, but as has been found in other research (e.g., for review, see Berninger, Nielsen et al, 2008), spelling problems may take longer to remediate than the word decoding and reading problems. Ten (nearly 60%) of the students improved in both spelling and handwriting; and those who did not improve in spelling often showed improvement in written composition. So again there is evidence for the value of teaching to multiple levels of written language close in time to create functional writing systems for students with persisting, severe dyslexia in the upper grades.

3.4.3 Improvement in hallmark syntax deficits in individuals with OWL LD/SLI —Participant 1 improved on *CELF-4 Sentence Formulation* 1 to 8. Participant 2 improved on *CELF4 Sentence Formulation* 1 to 4. Participant 3 improved on *CELF4 Sentence Formulation* 5 to 11. Participant 4 improved on *CELF4 Sentence Formulation* 5 to 13. Participant 5 improved on *CELF4 Sentence Formulation* 6 to 8. Thus, not only was there a treatment effect related to improved oral syntax for the group as a whole who differed in the nature of their SLD, but also for individual students with longstanding and persisting oral and written language learning disabilities(OWL LD), beginning in the preschool years. All individuals with OWL LD showed improvement in oral syntax processing and production, and for participants 1, 3, and 4, the amount of the improvement was sizable. An intervention approach that aims instruction at the hallmark impairments in syntactic skills of students with OWL LD may be a necessary first step toward improving their syntactic skills for all language systems. The computerized lessons may have facilitated that improvement by employing both oral instruction (through ear phones) and written instruction (through visual displays on the monitor) and opportunities to respond using language by ear, mouth, eye, and hand. Although the students with OWL LD/SLI did not show improvement on the written syntax measures for which there was an overall group effect, they did on another measure of written syntax (see Discussion).

4 Discussion

4.1 Effectiveness of Multi-Level Writing Instruction for Students with Different SLDs

4.1.1 Treatment effects based on group analyses—Significant change was observed from before to after participating in the computer instruction in writing on two normed measures of handwriting, four normed measures of word-specific orthographic spellings, and two normed measures of syntax construction as well as one measure of handwriting based on raw scores. Thus, it may be possible to use a common set of computerized writing lessons containing learning activities tailored to instructional needs of students with dysgraphia (impaired handwriting), dyslexia (impaired spelling), or OWL LD/SLI (impaired syntax comprehension and composing) to provide effective writing instruction for all students in a classroom with SLDs affecting written language regardless of the specific diagnosis. Such application of computerized instruction would facilitate the challenge a classroom teacher faces in individualizing instruction for diverse learners, that is, differentiating instruction.

Handwriting improvement in *DASH Copy Best* was encouraging because it may reflect the students' emerging ability to self-regulate their own handwriting when they take their time to do their best. The findings for improved *word-specific spelling* are of interest for two reasons. First, prior research showed that students with dyslexia have difficulty paying attention to the letters in written words (Thomson et al., 2005). Current results show that it may be possible to teach attention to letters in specific positions in a written word and the letter sequence for the whole written word, as in the learning activities in the second set of lessons (see Figure 2). Second, currently much evidence-based reading instruction emphasizes oral reading (pronouncing words on lists without context clues and oral reading of passages with context clues), but beginning in fourth grade and thereafter there is a transition to increasing silent reading (Denton et al., 2011; Hale, Skinner, Williams, Hawkins, Neddenriep, and Dizer, 2007; Hiebert et al., 2012; Rasinski, Samuels, Hiebert, Petscher, & Feller, 2011) and written composing (Berninger et al., 2008; Graham, 1990; Graham & Harris, 2009; Troia, 2009; Wong, Butler, Ficzere, & Kuperis, 1996). Both silent reading and written composing draw on word-specific spellings, which integrate phonological, orthographic, morphological, and semantic information (e.g., Bear, Ivernezzi, Templeton, & Johnston, 2000; Henry, 2010) and can be assessed with *TOC Letter choice*, *TOC Sight Spelling, TOC Word Choice, and TOC Scrambles* .

Handwriting and/or spelling problems may interfere with development of composing skills, but some may also have impaired composing beyond those transcription (handwriting and spelling) skills (Berninger, 2009; Graham, 1990; Graham & Harris, 2009; Scott, 2002, 2009; Troia, 2009). However, specialized computerized writing instruction aimed at both transcription (handwriting and spelling) and sentence composing transferred to improved syntax- level composing on the sentence combining task for the group as a whole. Also, although text-level, normed measures of writing were not included in the current study, recent dissertation research has found, based on linguistic coding by a human teacher, effects of the computer instruction for sentence-writing strategies on composing longer texts (Niedo Jones, 2014).

4.1.2. Individual student response to instruction aimed at hallmark impairments in writing skills for their diagnosis—Based on change in scores from pretest to posttest for individual students, those with dysgraphia were robust responders to handwriting instruction, with only one not responding on a handwriting measure. Nearly 60% with dyslexia were treatment responders to spelling instruction. All those with OWL LD/SLI showed treatment response for their underlying oral language syntax impairments. That is, treatment effects were observed on this measure, which has lower test-retest reliability than other measures in the test battery, on both group analyses and individual student analyses. Also of interest, although the individual student analyses for those with OWL LD did not show improvement on the *WIAT3 Sentence Combining* task, as found for the total sample, on another measure of written sentence composition, *Woodcock Johnson Writing Fluency, Third Edition* (Woodcock, McGrew, & Mather, 2001) given in the larger assessment study, individual students with OWL LD/SLI did show pretest-posttest gains. *WJ3 Writing Fluency*, which is timed, is otherwise a written analogue of *CELF 4 Sentence Formulation*, which is not timed, in that for both tasks the student is given three words and asked to construct a sentence in writing or orally, respectively.

4.1.3 Conclusions based on comparing group and individual student effects— The current study provides proof of concept that computer instruction in the upper elementary and middle school grades can be used to provide evidence-based writing instruction for students with SLDs affecting writing in general and also individualized instruction aimed at the instructional needs in writing for those with dysgraphia, dyslexia, or OWL LD. Being able to show treatment effects for students with persisting writing disabilities in general as well as individual students with SLDs affecting writing will become increasingly important now that the US Department of Education (Duncan, 2014) has announced new compliance criteria for special education that require showing improved achievement of individual students. Computer instruction has potential for helping schools provide the necessary instruction that is individually tailored to specific writing impairments to bring about achievement gains in writing. Although research findings based on group data analyses may inform educational policy, evaluation of individual student improvement is also necessary in daily educational practice. In the current research we model the application of both approaches.

4.2 Educational Significance of Findings

In the current educational climate that touts the value of evidence-based literacy instruction, evidence-based reading instruction has been emphasized. All too often writing is left behind, even though meta-analysis has shown that writing instruction transfers to improved reading (Graham & Hebert, 2010). Moreover, in the US students with SLDs affecting writing are often given the accommodation of using a laptop but not explicit instruction in using an iPad or other lap top computer for the various kinds of writing assignments students in grades 4 to 9 are expected to complete in language arts or content areas of the curriculum. The current results show that students in grades 4 to 9 with persisting SLDs affecting writing responded to explicit computer instruction in writing, just as they had in prior research with human teachers (Berninger, Winn et al., 2008). Thus, these students should be provided with explicit writing instruction aimed at all levels of language, ranging from letter writing to spelling to composing. That is, instead of wondering if handwriting should be taught in the computer age, computers could be used to teach handwriting! Also, although handwriting is typically thought to be learned early in schooling, many students may need periodic handwriting tune-ups to sustain gains in the upper elementary and middle school grades, just as automobiles need periodic tune-ups to function efficiently. Research should be conducted on effective ways to provide such tune-ups for writing by both pens//pencils and computer tools during the upper elementary and middle school grades. Moreover, these modes of letter production should be taught along with spelling and sentence composing close in time to create functional writing systems for idea expression and written communication.

4.3 Limitations and Future Research Directions

One limitation was that this study was conducted after school when participants may have been tired after attending school all day and with populations whose parents can bring their children to the university to participate in research. Additional research is needed on use of the computer instruction in writing during the school day and with populations whose parents cannot bring them to the university for research studies. Although parental level of education, one socioeconomic (SES) indicator, showed that most parents were highly educated, consistent with SLDs occurring across all SES groups even when parents are college graduates, the computerized writing lessons may also benefit students of lower SES in school settings, as is now being investigated.

Another limitation was that the computer instruction was offered only once a week distributed over five months. Future research might address whether increasing number of lessons per week (e.g. two or three) or number of lessons overall might result in larger effect sizes. However, given the students' history of persistent writing problems despite considerable prior intervention, the current moderate effect sizes provide hope that the SLDs affecting writing are treatable even during the upper elementary and middle school grades. Also, in the current study, iPads were used to deliver instruction and students used a keyboard during many learning activities, but no explicit keyboard instruction was provided. All students looked at the keys to find letters on the alph15 task. Research is needed on effective ways to teach students touch typing without looking at the keys and applying touch typing in classroom writing activities and homework.

Consistent with Ronimus et al. (2014), lead teachers during the computer writing lessons noted that many students initially struggled to pay attention to and engage in the computerized instruction and self-regulate their learning. However, when those teachers taught participants strategies for attending to and engaging in the computerized learning activities, the students visibly improved in self-regulation of their attention. Strategies taught included teachers' verbal prompts to pay attention to the computer-teacher instruction, verbal prompts to engage in the learning activities as instructed, and behavioral reinforcement for attending, engaging, and completing learning activities. Thus, students with SLDs impairing writing skills may benefit from a hybrid human- and computer-teacher, just as Cheung and Slavin (2012) concluded. The computer teacher allows students to proceed through the lessons at their own pace and receive frequent feedback about their performance even when many students with or without different kinds of writing impairments are in the same class, but the human teacher can monitor whether the student is paying attention to and engaging in the lessons. However, more research is needed to evaluate how teachers can facilitate student attention and engagement in computer instruction that is not games. Also, more research is needed on the anxiety associated with a chronic struggle in writing and whether computerized writing instruction alleviates the anxiety more than paper and pen writing instruction during middle childhood and adolescence.

For all writing skills—producing letters, spelling words, and composing sentences and text — more research is needed on effective practices for sustaining gains following treatment responding, both in the current and subsequent school years. Effective approaches should be studied for both (a) ongoing responding to other-guided, teacher instruction, and (b) developing independent self-regulated writing. Reaching these two goals may depend on studies of writing instruction delivered to both students and educators (professional development for teaching writing), just as Cheung and Slavin (2012) concluded. Technology tools may provide valuable support for both of these goals.

Finally, the added value of hybrid approaches—for teaching use of multiple writing tools through combined human and computerized instruction—should be a topic of continued investigation. The future research questions should not be whether handwriting or keyboarding should be taught (both should be) or whether humans or computers are better at teaching writing (both can contribute). Rather important questions to address in future research for both students with and without SLDs impairing writing are what is the added value of hybrid human and technology teachers for writing instruction and what are the most effective kinds of instruction for creating hybrid writers who are adept with multiple writing tools for multiple writing purposes?

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Highlights

- Students with specific writing disabilities respond to computer writing lessons.
- Computers can be used not only for accommodations but also for teaching writing.
- Grade 4 to 9 students with dysgraphia improved in handwriting.
- Grade 4 to 9 students with dyslexia improved in spelling.
- Grade 4 to 9 students with oral syntax disability improved in that skill.

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Introduction to Lesson LIM Lesson 1 (audio input through earphones and visual display on monitor): Some people think that because we now have computers that produce letters we do not need handwriting. This Computerized program is based on a different view—computers can teach handwriting as well or better than teachers! Also, just like car engines that need periodic tune-ups to work efficiently, so does handwriting. So whether you are just learning to form the letters so that they are legible (others can recognize them) and automatic (you form the same way every time without effort and quickly) OR you are reviewing them for a Tune-UP, these computerized activities should help you. We will start with manuscript which is printed letters and then work on cursive letters. You will use two modes of letter formation—using your pointing finger to form them or stylus that is like a pen or pencil—in writing letters on the ipad you use. In each lesson we will give you feedback as to how well you are doing.

Introduction to Lesson LIM Lessons 2 to 18

You will start Part 1 of each lesson with a 5-Step Letter Writing Warm-Up just like athletes do exercises before the game and musicians practice scales before the concert. The reason is that letters are the building blocks for the words we read and spell and the sentences and texts we read and write.

For each lower case letter of the alphabet, you will go through 4 Steps for printing the letter and then the same 4-Steps for writing the letter in cursive.

For Step 1, you will view the named letter in motion as it forms.

For Step 2, you will use your finger or stylus to trace the motion of the letter as it forms, using your eyes to make sure your hand stays inside the border of the letter maze. Your eyes will get feedback if you go outside the border.

For Step 3, you will close your eyes and see the named letter in your mind's eye so it gets coded into memory. Then you will open your eyes and write the named letter and compare what you write with the model letter form you studied.

For Step 4, you will write the letter that comes before or after another named letter. Because letters are stored in alphabetic order in the mind, this step will help you find and write letters faster.

Finally you will do Step 5 with capital letters for the same letters as in Steps 1 to 3—first in printing and then in cursive. After you repeat Steps 1 to 3 for each of the capital letters, you will write the printed capital letter at the beginning of the sentence in printing and the cursive capital at the beginning of the sentence in cursive. The reasons sentences begin with capital letters is that capital letters mark the beginning of idea units at the beginning of a sentence.

The computer will prompt you for each step. Let's get started!

LESSONS 1, 4, 7, 10, 13, 16 Teach: a, i, r, a, j, s, b, k, t

Probes Before b, j, s, b, k, t, c, l, u

After a, h, q, s, i, r, a, j, s

LESSONS 2, 5, 8, 11, 14, 17 Teach c, l, u, d, m, v, e, n, w

Probes Before d, m, v, e, n, w, f, o, x

After b, k, t, c, l, u, d, m, v

LESSONS 3, 6, 9, 12, 15, 18 Teach f, o, x, g, p, y, h, q, z

Probes Before g, p, y, h, q, z, l, r, g

After e, n, w, f, o, x, g, p, y

Figure 1.
Letters in Motion (LIM) in HAWK (Help Assistance for Writing Knowledge)™

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WISE WORDS

Introduction to Words in Motion before Lesson 1 (through ear phones and displayed visually on monitor)

Both spoken and written words are codes. The codes for spoken words exist in the *mind's ear* in memory, and when produced through the mouth, in the outer world where others can hear them. The codes for written words exist in the *mind's eye* in memory, and when produced through the hand, in the outer world where others can see them.

You will begin each lesson for Words in Motion by developing your pattern analysis abilities. First you will drum the number of syllables in a word, number of phonemes in a syllable, and stress patterns of the musical melody of syllables. Then, you will judge whether written words have spelling patterns allowed in English. Second, you will learn code-cracking in the written spelling direction. In the process you will learn one way the brain teaches itself through Talking Eyes and Ears and Writing Ears and Hands. Third, you will learn to Explode Words into multiple units within spoken words, within written words, and bridges between the spoken and written words. Fourth, you will learn multiple ways that these units can be used to spell words so that you have flexible strategies to use in spelling words. Fifth, you will learn strategies for transforming words into new forms, just like caterpillars are transformed into butterflies!

Instructions for Scribes Paying Attention to Letter Order and Letter Position Task VD: Letter sequence gives you clues to correct spelling. Look at the misspelled word with scrambled letters in the word box on the monitor. In the word box with the writing mode you are using write the correctly spelled word with the letters in the right order. When you are done hit the Done! Box. The computer teacher will give you feedback about whether your spelling is correct.

Lesson	Scrambled Word	Correctly Spelled Word for Feedback
1	eht uyo hvea rmof rhwee	the you have from where

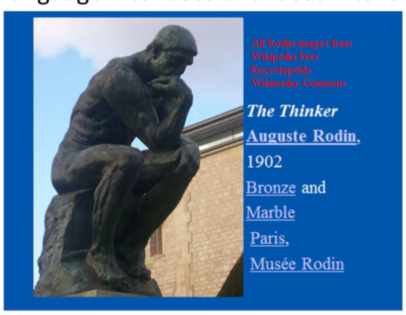
Figure 2.

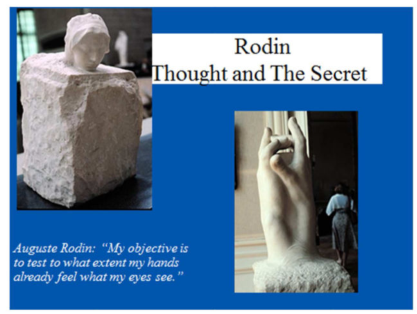
Words in Motion (WIM) in HAWK (Help Assistance for Writing Knowledge)™

WISE WORDS

Introduction at Beginning of Lesson 1 of Minds in Motion (through ear phones and displayed visually on monitor)

Minds are time machines in constant motion—thinking in present, finding information in memory from the past, and imagining the future! Through our thinking hands, writing can guide the journey of minds through time and space! Your computerized teacher will guide your mind in motion through seven activities that should improve your reading comprehension and written composition. The first four activities will teach you how to use words to express complete thoughts in sentences. The fifth activity will give you practice in interpreting sentences by paying attention to each word—its spelling, sounds, fixes, and vocabulary meaning—as well as its context—that is, the other words in the sentence. Also, both understanding written language and writing language require thinking about ideas and translating language into ideas and ideas into language.





The sixth and seventh activities require that you write independently about your own ideas and experiences that you first read about or first listen about-- content in school subjects such as math, science, and social studies. Minds can make meaning and express what they are thinking through their hands—through written language, art, music, dance and other kinds of movements. After the seventh activity you will be given an opportunity to express your ideas in art that illustrates your writing.

Now you will start the first Minds in Motion lesson set.
Hit Start Learning (green).
When you are done with the lesson, hit Done (green). Kokopelli will dance when you finish each learning activity.
Tap Proceed on the screen to continue to another learning activity or to let the teacher know you need a break.

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Instructions for Learning Activity Changing Word Order

Introduction Oral Instructions for Judging Correct English Word Order (through earphones and displayed visually in lesson 1)

The order of words helps you to build sentences—putting words together to express complete ideas. At the top of the monitor you will see a Box with a Scrambled Sentence. With your finger drag the words into the correct word order for a meaningful sentence. The computer teacher will give you feedback as to what the correct answer is.

Hit **Start Learning** (green)

Written Instructions Displayed on Screen (Lessons 2 to 18)

Step 1**:** Drag each word into a word box so that the order of the word makes a meaningful sentence.

Step 2: Listen for feedback from computer teacher.

Hit **Start Learning** (green)

Sentence Anagrams (record time to complete task)

Lesson	**Scrambled Sentence Box**	**Correct Word Order** **(oral and visual feedback)**
1	her like music people	***People like her music***

Figure 3.

Minds in Motion (MIM) in HAWK (Help Assistance for Writing Knowledge)™

Table 1

Descriptive and Inferential Statistics for Pretest and Posttest Means (N=35) See Table Notes.

	Pretest M (SD)	Posttest M (SD)	t (p-value)	f^2
Handwriting				
Alphabet 15 cursive	2.27 (3.12)	3.26 (3.01)	−2.42 *p*=.022	0.20
DASH Copy Fast	5.66 (2.73)	6.75 (2.88)	−2.43 *p*=.020	0.17
DASH Copy Best	8.00 (3.25)	9.31 (2.87)	−3.70 *p*=.001	0.40
Word Spelling				
TOC Letter Choice	8.03 (3.33)	9.00 (4.20)	−2.89 *p*=.007	0.27
TOC Sight Spelling	8.13 (3.26)	9.26 (2.93)	−3.15 *p*=.004	0.33
TOC Word Choice	9.17 (3.28)	10.53 (4.02)	−2.23 *p*=.030	0.17
TOC Word Scrambles	8.78 (2.65)	9.65 (3.22)	−2.82 *p*=.008	0.25
Written Sentence Syntax Composing				
WIAT 3 Sent Comb[a]	94.18 (14.46)	99.59 (13.72)	−2.436 *p*=.030	0.17
Oral Syntax Composing				
CELF-4 Sent Form[b]	10.03 (3.64)	11.67 (2.73)	−2.869 *p*=.0071	0.25

Notes:Scale *M*=10, *SD*=3 except for WIAT 3 *M*=100, *SD*=15 and raw score for Alphabet 15 seconds).

[a]Sent Comb=Sentence Combining

[b]Sent Form=Sentence Formulation