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Relationships between Language Input and Letter Output Modes in Writing Notes and Summaries for Students in Grades 4 to 9 with Persisting Writing Disabilities

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Abstract

This study in programmatic research on technology-supported instruction first identified, through pretesting using evidence-based criteria, students with persisting specific learning disabilities (SLDs) in written language during middle childhood (grades 4-6) and early adolescence (grades 7-9). Participants then completed computerized writing instruction and posttesting. The 12 computer lessons varied output modes (letter production by stylus alternating with hunt and peck keyboarding versus by pencil with grooves alternating with touch typing on keyboard), input (read or heard source material), and task (notes or summaries). Posttesting and coded notes and summaries showed the effectiveness of computerized writing instruction on both writing tasks for multiple modes of language input and letter production output for improving letter production and related writing skills.

Situating the Study within the Assistive Technology Field

Federal legislation defines an assistive technology (AT) device as “any item, piece of equipment, or product system, whether acquired commercially, modified, or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities” (Assistive Technology Act of 2004, P.L. 108-364). This definition of AT is broad enough to include instructional approaches aimed at alleviating skill deficits in reading, writing, and math as well as strategies to compensate for (or bypass) areas of difficulty. Historically however, research on AT and students with specific learning disabilities (SLDs) has focused predominantly on AT as a compensatory tool (Raskind & Bryant, 2002). For example, research on application of computers to writing has addressed whether (a) students with SLDs produced higher quality written language products with

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word processors than by conventional means of pencil/pen and paper (Collins, 1990; MacArthur & Graham, 1987; Margalit & Roth, 1989); and (b) specific technology tools such as text-to-speech (Leong, 1995; Raskind & Higgins, 1995), spell checkers (MacArthur, Graham, Haynes, & DeLaPaz, 1996), optical character recognition/speech synthesis (Elkind, Cohen, & Murray, 1993; Higgins & Raskind, 1997), speech recognition (De La Paz, 1999; Higgins & Raskind, 1995; Raskind & Higgins, 1999), and word prediction, (MacArthur, 1998), effectively support students with SLDs in their writing. Although there are limited studies on the use of AT (e.g., word processing) in conjunction with instructional interventions for writing (e.g., Self- Regulated Strategy Development, MacArthur, Schwartz, & Graham, 1991; MacArthur, Graham, Schwartz, & Shafer, 1995), relatively little research has focused on use of AT for teaching writing to students with SLDs. The lack of research in this area is particularly unfortunate considering the advent and proliferation of mobile technologies (e.g., smart phones, tablets, smart watches, smart/digital pens), along with a variety of integrated input methods (finger-interaction, touch screens, stylus, voice recognition, miniaturized and virtual keyboards (Kennedy & Deshler, 2010). However, recent studies (e.g., Berninger,, Nagy, Tanimoto, Thompson, & Abbott, 2015; Higgins & Raskind, 2005; Tanimoto, Thompson, Berninger, Nagy, & Abbott, 2015), along with the current one, are evaluating the use of AT in writing instruction for students with SLDs.

Situating the Study in the Use of Technology in Literacy Instruction

On the one hand, technology is often used in elementary and middle school classrooms for accommodations for students with disabilities. On the other hand, technology can be used for instructional purposes. The current study is part of programmatic research in an interdisciplinary center on learning disabilities for which the broad research aim is to develop and evaluate technology-supported reading and writing instruction for students with and without specific learning disabilities in the upper elementary grades (4 to 6) and middle school grades (7 to 9)[1]. As such, this research was designed to draw on a prior longitudinal study and cross sectional studies of typical reading and writing development by the same research group and related instructional studies. In the longitudinal study grades 1 to 7 and cross-sectional study grades 1 to 9 and instructional studies, we observed considerable variation in reading and writing instructional practices within and across schools, with some teaching reading and writing at different times of the day and some integrating reading and writing instruction. However, we also observed that many teachers make assignments that require integrating reading and writing without teaching explicit strategies for how to do so. For example, students read an assigned text and summarize it (e.g., Snow, 2002) or read source material and write a science or social studies report about it (e.g., Altemeier, Jones, Abbott, & Berninger, 2006). Later in high school and postsecondary education, writing is often integrated with listening to instructional talk (e.g., Mulcahy-Ernt & Caverly, 2009; Piolat, Olive, & Kellogg, 2005; Thomsas, Iventosch, & Rohwer, 1987), but without earlier preparation during upper elementary or middle school for note-taking based on listening to teacher talk. Explicit instruction in taking notes from either read source material (for writing

[1]We acknowledge that some school districts still organize elementary schools to end at grade 6 and middle school to begin at grade 7, but other school districts organize elementary schools to end at grade 5 and middle school to begin at grade 6. However, we used these grade levels to represent the distinction between middle childhood and early adolescence within developmental psychology.

reports) or heard source material from teachers (for studying for tests) was rarely observed in classrooms or reported by teachers over the years.

Secondary and postsecondary students often use note-taking (Palmatier & Bennett, 1974; Van Meter, Yokoi, & Pressley, 1994) to make written records of important information presented in lecture or other oral text. Among college students, for example, most perceive note-taking to be an important educational activity (Van Meter et al., 1994) and a vast majority take notes in classes (Palmatier & Bennett, 1974); an unpublished survey in 2013 found that 99.54% of 435 college students reported taking lecture notes (Peverly, personal communication, November 1, 2015). Good test performance is related to recording and/or reviewing notes from *lecture* and *aural text* (Bretzing & Kulhavy, 1981; Fisher & Harris, 1973; Kiewra, DuBois, Christian, McShane, Meyerhoffer & Roskelley, 1991; Peverly, Garner et al., 2014; Peverly, Ramaswamyet al., 2007; Peverly & Sumowski, 2012; Peverly, Vekaria et al, 2013; Rickards & Friedman, 1978). In older students, handwriting speed, language comprehension, and attention are related to better quality notes (Peverly, Garner et al., 2014; Peverly, Ramaswamy et al. 2007; Peverly & Sumowski, 2012; Peverly, Vekaria et al., 2013).

Yet, relatively little research exists on how note-taking emerges during literacy development, beginning in the upper elementary and middle school grades, either for read source material when writing reports or heard source material while listening to teacher talk. Nor is there much research on effective ways to teach note-taking during those grades. Moreover, little research exists on how multiple modes of letter production—by pencil (pen) or computer stylus or keyboard (hunting and pecking versus touch typing) may facilitate note-taking during middle childhood and adolescence. Research has shown that students at the transition from early childhood to middle childhood (Altemeier et al., 2006) and during middle childhood and early adolescence (Brown, Day, & Jones, 1983) can take notes in handwriting when reading source material and use the notes to write summaries; but much remains to be learned about which output mode is most effective when taking notes about read sources.

Although both children and adults show a relative advantage for handwriting over keyboard in *learning to write letters* (for review, see James, Jao, & Berninger, 2015), research findings are mixed regarding the role of handwriting versus keyboarding in generating written products (i.e., composing) and note-taking during lectures. During the elementary school grades, students compose longer texts of better quality in handwriting than by keyboard (Berninger, Abbott, Augsburger, & Garcia, 2009; Connelly, Gee, & Walsh, 2007); but in the upper grades of middle school they compose better by keyboard (Christensen, 2004). Bui, Myserson and Hale (2013) showed a relative advantage for keyboarding over handwriting during note-taking in lectures in that college students recorded more idea units in notes when keyboarding and then did better on an immediate written recall test and a short answer test. However, advantages for handwriting versus typing notes during lectures have also been found in college students (Mueller & Oppenheimer, 2014). Of relevance in interpreting any of these findings regarding composing and note taking, from a developmental perspective, is that neither the studies with children nor with older students have controlled for whether the writers are hunting and pecking (looking at keys as they search and select by pressing a letter on a key) or are touch typing (looking at the screen and visually displayed letter they selected but not at the keys on the keyboard).

Thus, the aim of the current study was to examine issues related to the relationship of mode of language input (read source materials or heard instructional talk) and mode of letter production output (stylus versus a pencil with indented grooves to facilitate pencil grip and somatosensory feedback OR keyboarding by hunting and pecking on keys versus by touch typing). These relationships were investigated for two writing tasks (note taking and summary writing) for students in upper elementary and middle school with persisting SLDs interfering with their writing. Recent research showed that both students with and without SLDs can benefit from touch typing instruction (Marom & Weintraub, 2015), which could be integrated with literacy instruction beginning in the intermediate grades.

Situating the Study within Technology Considerations

Hardware Platform

The Apple iPad 2 was chosen as the hardware platform for our computerized writing lessons because it (a) is relatively inexpensive; (b) has a touch interface; (c) can offer web access; and (d) is generally more accessible than desktops or other laptops. Also, most participating children in our studies are familiar with it and its touch interface and have generally responded favorably to using the iPads. Moreover, there is a widespread belief that iPads can be effective educational tools, which research has supported (e.g., Berninger, Nagy, Tanimoto, Thompson, & Abbott, 2015). Touch interfaces offer affordances, such as the pinch-and-zoom feature, that are easier for developing writers to operate than a mouse.

From a hardware perspective, the iPad 2s do have several drawbacks, however. First, they do not have pressure-sensitive screens, which measure or provide feedback for the pressure that students use while they write. Second, iPad 2s do not have a reliable method to differentiate between touch and stylus-based input. The program provides prompts and teachers try to monitor that students use the correct method, but the device itself cannot enforce this. Third, iPad 2's can struggle to run more modern iterations of web software, resulting in forced reboots that occasionally cause lost data or time. Despite these drawbacks the iPads were chosen because the advantages outweighed the drawbacks for the research aims of the current study.

Software Platform

The HAWK™ software system is written largely in Javascript and PHP, and is hosted from a secure server running in the University of Washington Computer Science and Engineering Department. Students access the learning materials by logging in under a unique, anonymized ID, after which any data the student generates while progressing through the lessons is sent to and stored in the server's MySQL database under his or her ID. HAWK™ is written in web code primarily to make it as platform-agnostic as possible; a flexible platform tends to be better able to adapt to new technologies. HAWK™ can run as-is on a wide variety of devices, including cell phones, tablet PC's, laptops, and desktop computers, providing an advantage over native iOS apps that can only run on iOS devices.

Web software does have its own limitations, however, including the following: (a) Apple imposes several harsh restrictions on any web-based multimedia that runs on the mobile version of the Safari web browser. (b) Devices running iOS prohibit more than one sound from being played at once in their browsers, preventing addition of a sound effect while an audio lecture is playing.

(c) An iPad is only able to cache one audio file in memory at a time, thus requiring that any sounds that will be played soon be grouped into a single file and pre-loaded. (d) The iPad's Wifi-only internet connectivity makes the consistent, on-time loading of a sound file unlikely, requiring extra attention be given to the balance of pre-loading audio vs. overly long preload times. (e) Web programs also have more restricted access to system features. A web program cannot easily access an iPad's microphone or camera, for example.

Situating Current Study within Programmatic Research on Computerized Instruction

The current research involved the third and fourth cohort in a five-year program project with sequential cohort acquisition. All four cohorts were recruited and assigned to diagnostic groups using the same procedures. All cohorts used HAWK™ Letters in Motion, Words in Motion, and Minds in Motion Computerized Lessons. However, each of the cohorts has used a slightly different iteration of the computer lessons so that the research team could evaluate which features were most effective. The first iteration (cohort 1) showed that computer lessons could be used to teach handwriting to students with and without SLDs; but (b) no differences were found between use of finger tracing on the screen and writing by stylus in letter production (Berninger et al., 2015). Iteration 2 (cohort 2) differed only in that motor control activities with mazes used in iteration 1 were eliminated. Iteration 3 (cohort 3), which was retained in iteration 4 (cohort 4), introduced solid and dotted lines on screen to assist in proportionality and placements of written strokes. Comparison of iteration 3 and 4 showed those lines on the screen improved the writing outcomes (Tanimoto et al., 2015). In the current study, iteration 3 used with cohort 3 is compared to iteration 4 used with cohort 4 to assess effects of stylus (cohort 3) versus groovy pencil (cohort 4) and hunting and pecking (cohort 3) versus touch typing without looking at the keys (cohort 4). This comparison is relevant to the increasingly greater writing tool options than keyboard versus handwriting with conventional pencil/ pen on paper (Thompson, Tanimoto, Berninger, & Nagy, 2015). Otherwise, the computerized writing lessons were the same and the same research inclusion criteria were used to qualify students for participation as in all the prior cohorts. However, in this article we refer to cohort 3 as group A and cohort 4 as group B because these comparisons can be made independent of prior comparisons across iterations and cohorts.

We compared the just described output modes for two kinds of writing activities (integrated with reading source material and integrated with listening to source material), both of which have ecological validity for the kinds of writing tasks students are often expected to do at school and in homework during the upper elementary grades 4 to 6 (middle childhood) and middle school grades 7 to 9 (early adolescence)[1]. The computerized lessons provided explicit, computerized instruction for writing the next sentence in creating the notes and summaries. For both tasks the length and content of the source material was comparable.

The first research question addressed whether modes of letter production during computer learning activities would be related to changes in letter production skill and related writing skills assessed at pretest and posttest. The hypothesis tested was that more improvement would be observed from pretest to posttest in group B (touch typing alternating with groovy pencil) than in Group A (hunting and pecking alternating with stylus). The dependent measures for testing these hypotheses, which are described in the methods, included (a) raw scores of researcher-designed tasks of alphabet writing in manuscript (un-joined printed letters), cursive (joined letters), and letters produced by typing on a keyboard; and (b) normed measures of handwriting and related fluency of written sentence composing.

The second research question addressed effects of three researcher-manipulated independent variables: (a) output modes of letter production (stylus alternating with hunting and pecking on keys versus groovy pencil alternating with touch typing), (b) input modes (read versus heard texts), and (c) writing tasks (notes versus summaries). The first hypothesis was that students would write more words in notes and summaries when they read source material than heard source materials. The second hypothesis was that they would write more words in summaries than notes. The third hypothesis was that Group B (alternating between touch typing and groovy pencil) would write more than Group A (alternating between hunting and pecking and stylus). The dependent measures for testing these hypotheses, which are described in the methods, included coded variable for decipherable words, probably correctly spelled words, and correctly transcribed words in letter production and spelling.

Method

Participants

Ascertainment and qualification—Participants were recruited through flyers distributed to local schools. Interested parents of students in grades 4 to 9 were screened by phone interview to determine if their child would likely qualify as having a specific learning disability (SLD) and if so then an appointment was scheduled for assessment at the university. Both performance on multiple handwriting, spelling, and written composition measures on the assessment battery and developmental and educational history were taken into account in identifying SLDs on the basis of a cascading levels of language diagnostic model described in Berninger, Richards, and Abbott (2015). According to this model some individuals with SLDs have dysgraphia (subword letter production impairment), some have dyslexia (word reading and spelling impairment), and some have oral and written language learning disability (OWL LD) (syntactic impairment); but each of these impairments (falling below the average range)[2] can interfere with writing development that draws on all the levels of language. However, the SLD is specific as denoted by the initial S in that except for these written language struggles these children are typically developing. Some children with developmental disabilities struggle with writing but for other reasons—they are outside the normal range in one or more domains of development (Berninger, 2015). Characteristics of participants in Group A and Group B in the current study are described next, followed by a

[2]Based on evidence from a family genetics study in the case of twice exceptional (intellectually gifted and having an SLD in written language) verbal comprehension index and phenotypes related to handwriting and spelling are also used to identify students who meet twice exceptional criteria (Berninger & Abbott 2013).

section on the measures that were administered at pretest to determine SLD diagnosis and at posttest after completion of the computerized instruction to assess changes from before to after completion of the instruction.

Description of participants in Group A and Group B in current study—The comprehensive assessment showed that all had persistent difficulty with letter production alone and/or in words throughout their educational history, all had received considerable help with their writing struggles during the early grades at school and/or from tutors outside school, and met research criteria for SLD in written language based on two decades of interdisciplinary research. In addition, their written work during assessment and response to the computerized writing instruction in early lessons were consistent with this diagnosis In all cases, the SLDs were persisting in grade 4 and beyond despite early intervention in or outside of school. Altogether 11 (7 girls, 4 boys) qualified for group A and 16 (6 girls, 10 boys) qualified for group B. Their parents were well educated (most having a college degree) but many had a family history of SLDs. With two exceptions all were of European American heritage, but were in some cases immigrants or adoptees from Europe fluent in English.

Assessment Used at Pretest and Postest

Alphabet 15 for manuscript, cursive, and keyboard—raw scores only—(Berninger, Richards et al., 2015). The task is to print or write in cursive the alphabet in order as quickly as possible but so that others can recognize your letters or to type the alphabet in order on a keyboard. It is scored for number of legible or accurate letters in correct alphabetic order at the 15 second stop point. Note that Group A students did not wear a blindfold during administration of this task and were observed to hunt and peck; but this task was adapted for Group B students who wore a blind fold and had to perform the task solely by touch without looking at keys on a real keyboard. Raw scores for number of correct letters in alphabetic order were recorded for each format for writing the alphabet from memory. Thus, the research team could compare effects of computer lessons on hunting and pecking during the alphabet task (Group A) versus touch typing during the alphabet task (Group B).

Alphabet 15 z—(Berninger, Richards et al., 2015). The manuscript version of the prior task is the only one for which research norms exist for grades 4 to 9, which allows conversion to *z*-scores.

DASH 2 Copy Sentence Best and Copy Fast—(Barnett, Henderson, Scheib, & Schulz, 2007). Students are instructed to copy a sentence with all the letters of the alphabet in it as often as they can within a one-minute time limit and then continue to the two- minute time limit. Students use their usual handwriting (manuscript or joined letters also referred to as cursive). First they were asked to perform this task in their very best handwriting. Then they were asked to perform the same task in their fast handwriting. Raw scores were converted to scaled scores (M=10, SD=3).

Copy Paragraph at 30 seconds, 60 seconds, and 90 seconds—(Berninger et al., 2006). The task is to copy a paragraph, which is scored for number of cumulated legible letters correctly copied at 30 seconds, at 60 seconds, and at 90 seconds. The raw scores on this measure of sustaining handwriting over time show how many legible letters have been copied cumulatively at completion of each of those successive time points.

WJ 3 Writing Fluency—(Woodcock, McGrew, & Mather, 2001). Handwriting speed is related to sustained composing over time, with which many students with SLDs in written language struggle; this inability to sustain writing over time may account for the frequently reported observation that they do not complete written work or complete it in a timely fashion (Abbott & Berninger, 1993). This task requires composing a written sentence for each set of three provided words, which are to be used without changing them in any way. Thus it is also sensitive to ability to combine words in syntactic structures when engaging in sustained writing (Berninger, Richards et al. 2015; Berninger, Nagy et al., 2015). There is a 7 minute time limit. The standard score (M=100, SD=15) is based on the number of correctly formed sentences within the time limit.

Output and Input Modes and Writing Tasks during Instruction

For comparisons of writing by stylus and groovy pencil (manipulated independent variable for output mode), three outcomes (dependent measures) were coded for writing by pencil: (a) number of decipherable words whether correctly spelled or each letter recognizable out of word context; (b) number of words probably spelled correctly, but proportionality of strokes, features that differentiate a letter from other letters, and/or positioning made it difficult to be sure what the letter was; and (c) number of words correctly transcribed in that all letters would be legible outside the word context and the word was correctly spelled. However, for comparisons of hunting and pecking and touch typing by keyboard, only the first two outcomes (dependent measures) were coded—number of decipherable words whether spelled correctly and number of correctly spelled words—because with keyboards, letter legibility is not an issue. Interrater reliabilities for these coding schemes in the programmatic research program have been 100% after training. The coder for this study participated in those training studies.

Procedures during Computer Writing Lessons

In each of twelve lessons on average once a week over a 3 ½ to 4 month period, participants completed a handwriting lesson and two composing activities—note taking or writing summaries of read or heard source material equated for number of words. For handwriting, Group A wrote by stylus on lines on the iPad screen created by first two co-authors (Tanimoto et al., 2015) and Group B wrote by pencil on paper (dubbed the groovy pencil because of its grooves to facilitate hand grip and somatosensory feedback, available from Amazon, Dixon Ticonderoga, and some Office Depot Stores). Lessons taught forming each of the 26 letters through visual and motion cues for letter formation and retrieval from memory for manuscript or cursive letters. The composing lessons required writing notes and a summary for two kinds of source material—written texts that were read from displays on stands right beside the iPad or oral texts that were heard. Participants were instructed by the computer teacher (heard through ear phones) to (a) first write notes about what they read and then to write a summary of the read text (Integrated Reading-Writing, IRW) or (b) first write notes about what they were hearing and then write a summary of the heard text (Integrated Listening-Writing, ILW). All source material—read or heard—was based on content areas of the curriculum—the first six on the history of math in human civilization and the last six on world geography and cultures. Both groups alternated between handwriting and typing with spell check turned off during keyboarding. For typewriting, Group A could look at the keys; but Group B could look only at what appeared on the screen after a key press and not at the keys. Lead teachers monitored compliance and if a student looked at keys redirected the student to focus only on the monitor. Only Group B had a touch typing warm up which provided practice in typing without looking at the keys.

During the touch typing warm up students wore blindfolds so that they could not look at the keys and had to learn their spatial location solely through somatosensory touch. First, they placed their fingers on their right and left hands over each corresponding key on right and left sides of keyboard in touch typing position in home (middle row); as the computer teacher named each letter on that row but in a different order than on keyboard, the student typed the letter and looked for visual feedback on the screen. Second, the same procedures were followed for the bottom row. Third, the same procedures were followed for the top row. Finally, with the blindfold on, the student typed the alphabet in order from memory using keys from right and left and all three rows.

Group B used touch typing to record notes and write summaries but without wearing blindfold; they were instructed to not look at the keys and only look at written text on stand just to the right of the iPad screen or at the screen to view notes written. Teaching assistants were assigned to specific students to monitor and if students looked at keys to redirect their gaze to the screen; in general students complied and rarely had to be reminded. Otherwise, students in both groups A and B completed the same HAWK™ lessons to teach to all levels of language close in time and to create functional writing systems (Berninger at al., 2015; Tanimoto et al., 2015).

Data Analyses

First research question and related hypotheses

A series of Mixed ANOVAs with group as a between- participant independent variable and time as a within participant variable from pretest to posttest were conducted on each of the dependent outcome measures listed in the prior section on assessment measures. These included normed measures which permit comparison of individuals to age or grade peers in a sample with age and grade variation. Data from all 27 students across the two groups (see participants section) were used in these analyses.

Second research question and related hypotheses

Mixed ANOVAs were also performed on the coded transcription outcome measures from time 1 to time 2 (within participants) for two designs: (a) input modes for source texts (visual or auditory, within participants), and output modes (groups A and B, between participants) for note taking; and (b) writing tasks (notes and summaries, within participants), input modes for source texts (visual or auditory, within participants), and output modes (groups A and B, between participants). For these analyses all 11 participants in the first group and 11 participants in the second group who had usable coded data for all coded measures and variables analyzed were used.

Results

Pretest-Posttest Change on Letter Production Measures in Assessment Battery

Pretest-posttest comparisons of writing alphabet from memory in different formats—For manuscript writing, only the main effect for time was significant: $F(1, 25)=19.21$, $p<.001$. Both those who received instruction with computer stylus (time 1 $M=10.00$, $SD=5.62$; time 2 $M=13.36$, $SD=6.22$) and groovy pencil (time 1 $M=10.69$, $SD=4.38$; time 2 $M=14.31$, $SD=7.04$) improved from before to after the computerized writing instruction. For cursive writing, only the main effect for time was significant: $F(1, 25)=16.60$, $p<.001$. Both those who received instruction with computer stylus (time 1 $M=1.82$, $SD= 2.44$; time 2 $M=4.16$, $SD= 2.68$) and groovy pencil (time 1 $M=3.06$, $SD=3.02$; time 2 $M=6.50$, SD=4.72) improved from before to after the computerized writing instruction. For keyboarding, both those who received instruction with computer stylus (time 1 $M=15.18$, $SD=6.69$; time 2 $M=16.09$, $SD=7.37$) and groovy pencil (time 1 $M=1.94$, $SD=1.06$; time 2 $M=5.13$, SD=3.70) improved from before to after the computerized writing instruction.

Only for keyboarding was an effect related to mode of letter production observed, $F(1, 25)=47.50$, $p<.001$. The group who used hunting and pecking started out higher and remained so. However, although the cohort x time interaction did not reach statistical significance, examination of a trend across time revealed an instructive pattern. For keyboarding, those who could use hunting and pecking during assessment and instruction started out much higher and made relatively little improvement (time 1 $M=15.18$, $SD=6.69$; time 2 $M=16.09$, $SD=7.37$), whereas those who were required to use touch typing started out extremely low and made relatively more improvement but remained at a lower level of performance (time 1 $M=1.94$, $SD=1.06$; time 2 $M=5.13$, SD=3.70) from before to after the computerized writing instruction.

Alphabet 15 seconds z-score, a research measure for orthographic loop of working memory—(Berninger, 2009). Only the main effect for time was significant: $F(1, 25)=18.59$, $p<.001$. Both those who received instruction with computer stylus (time 1 $M= -.97$, $SD=.77$; time 2 $M=-.39$, $SD=.82$) and groovy pencil (time 1 $M=-.94$, $SD=.57$; time 2 $M= -.35$, $SD=.57$) improved from before to after the computerized writing instruction.

Copy tasks—Only time was significant for copying sentences in one's best handwriting. Both those who received instruction with computer stylus (time 1 $M= 7.55$, $SD=3.21$; time 2= $M=9.91$, $SD=4.68$) and groovy pencil (time 1 $M=9.56$, $SD=3.74$; time 2 $M=10.81$, $SD=3.69$ improved from before to after the computerized writing instruction.

For sustained copying of a paragraph over time, main effects for time and for seconds (at 30 seconds, at 60 seconds, and at 90 seconds), and the interaction between time and seconds were statistically significant: time, $F(1, 23)=15.80$, $p=.001$; for seconds, $F(1, 23)=74.41$, $p<.001$; and for time x seconds, $F(1, 23)=7.55$, $p=.01$. As shown in Table 1, both groups improved over time and number of accumulating legible letters increased over the time intervals in seconds, but the increases from pretest to posttest were relatively more sizable as the time intervals in seconds increased.

Writing fluency for sentence composing—Only the main effect for time was significant for fluency for composing written sentences. Both those who received instruction with computer stylus (time 1 $M=87.09$, $SD=15.88$; time 2= $M=95.18$, $SD=15.01$) and groovy pencil (time 1 $M=91.87$, $SD=12.53$; time 2 $M=96.31$, $SD=17.00$) improved from before to after the computerized writing instruction.

Interrelationships among Input and Output Modes and Writing Tasks Relationships

Input and output modes for note-taking—For note-taking when listening to source material, a significant output mode effect was found for the number of decipherable words, $F(1, 20)=22.44$, $p<.001$: Group A $M=13.40$, $SD=13.40$; Group B M=22.40, $SD=18.39$. Group B, which alternated between using a groovy pencil or touch typing to record notes, produced more decipherable words than group A, which used stylus or hunt and peck. No effects for listening mode were found for correctly spelled words or words with correct spelling and each letter legible out of word context (only applies to writing by pencil). Nor were main effects for time or interactions with time found for listening mode. No main effects or interactions were found for reading input mode when taking notes.

Input and output modes for writing notes versus summaries—However, when both writing tasks were considered for reading source material, main effects were found for writing task—notes versus summaries— on number of decipherable words $F(1,20)=9.92$, $p<.01$, and number of correctly spelled words, $F(1, 20)= 12.97$, $p=.002$. Both groups wrote more decipherable words in summaries (Group A $M=27.95$, $SD=12.61$; Group B $M=43.29$, $SD=23.34$) than notes (Group A $M=17.37$, $SD=16.97$; Group B $M = 21.71$ $SD=22.33$) and more correctly spelled words in summaries (Group A $M=55.34$, $SD=44.38$; Group B $M=44.31$, $SD=35.04$) than notes (Group A $M=22.82$, $SD=19.12$; Group B $M=28.54$, $SD=16.97$).

When both writing tasks were considered for listening to source material, only the number of decipherable words was significant, $F(1, 20)=7.98$, $p=.01$. Both groups wrote more decipherable words in summaries (Group A $M=43.58$, $SD=34.39$; Group B $M=37.93$, $SD=41.87$) than notes (Group A $M= 13.40$, $SD=8.38$; Group B $M=22.40$, $SD=18.39$). No other significant effects were found on coded outcomes for mode of input—listening or reading source material—or mode of output used.

Discussion

First Research Question

The first research question addressed whether modes of letter production during computer learning activities were related to changes in letter production skill and related writing skills assessed at pretest and posttest. The tested hypothesis was not confirmed. Participants improved in their letter production and related writing skills (time effects) but these were not related to nature of output modes they used (group effects). The results showed that, following the computerized writing instruction, students improved on multiple letter production skills (all assessed except copy sentence fast), both researcher-designed and normed. For manuscript and cursive writing assessment measures, students with SLDs interfering with written language improved from before to after instruction in manuscript and cursive writing, orthographic loop for automatic letter writing (the alphabet 15 z score based on manuscript writing), copy sentences in best writing, sustained paragraph copying over time, and written sentence composing fluency. This finding shows the effectiveness for students with persisting SLDs in written language of ongoing instruction in letter production using both computer styluses and pencils with grooves as well as looking at keys on keyboards and using styluses.

Now the educational significance of these findings is considered. Collectively they support teaching students with SLDs in written language to become hybrid writers in the Information Age—skilled at using multiple tools. Furthermore, they support the overall aim of this study to show that accommodation alone is not sufficient for letter production problems in students with SLDs in written language. Rather, ongoing instruction is also warranted for students with persisting problems in letter production alone or in word context. Not only do the students improve in their writing skills but also computerized lessons can be effective in helping them do so!

A frequent problem experienced by students with letter production problems is failure to complete written assignments. See prior research on this issue in the section on comprehensive assessment measures in the Methods. The findings related to sustaining handwriting over 30 second, 60 second, and 90 second intervals and in composing fluency are, therefore, instructive for two reasons. First the main effect for time shows that computerized letter production instruction can help students with persisting SLDs affecting writing improve in sustaining their handwriting. Second, the interaction between time and accumulating intervals in seconds showed that ability to copy letters legibly improved relatively more as the student engaged in sustained handwriting for longer time intervals. Both the main effect and interaction results suggest that with appropriate handwriting instruction the students may be more able to sustain their writing to complete written assignments.

However, for keyboarding on the alphabet task, although students improved whether they were allowed to hunt and peck or were required to touch type, those who could hunt and peck started out much higher and remained higher. When examining the patterns of change for those who were and were not required to use touch typing, the results showed that touch typing was associated with substantially lower performance at pretest and a trend toward relatively greater gains than was hunting and pecking. This finding provides support for teaching touch typing to students with persisting writing disabilities and justification for doing more research on how to do so effectively, which will most likely require more than a warm-up before composing. In other words, future research should address the dosage issue —of how many lessons in touch typing it takes to become proficient—and the pedagogical issue of the most effective way to do so. Clearly the pretest-posttest assessment data indicates that touch typing had not been integrated with literacy instruction for students with SLDs interfering with writing who participated in the current study. They scored very low on the initial assessment and made modest gains after a very modest intervention. Nevertheless the current findings provide preliminary evidence to justify further research on this issue of most effective ways to use keyboards during middle childhood and early adolescence.

Second Research Question

The second research question addressed the interrelationships among input modes (reading or listening), output modes (Group A or Group B treatments), and writing tasks (notes or summaries). The first hypothesis that participants would write more when they read than listened to source material was not confirmed. For summaries, participants wrote more decipherable words in summaries than notes whether they read or heard the source material. That is, the effect of mode of input was related to the nature of the writing task. Indeed, the second hypothesis that the participants would write more in summaries than notes was confirmed for both modes of input. Both groups A and B wrote more decipherable words and correctly spelled words in summaries than notes whether they read or heard the source material.

The third hypothesis that the output modes used by Group B would increase length of notes based on the coding scheme for transcription skills (letter production and word spelling) was only partly confirmed—for taking notes for heard source material. The only group treatment effect was found for number of decipherable words during listening mode on the note taking writing task. Group B (alternating groovy pencil and touch typing) recorded more decipherable words in their notes than group A (alternating stylus and hunt and peck) when they heard source material.

Further research is also needed to evaluate if the finding replicates that students with SLDs in written language during middle childhood and early adolescence write more in summaries than notes even when given explicit instruction in strategies for both. Additional research is also needed on the most effective ways to teach strategies for note taking geared to writing reports and other written assignments for students with SLDs in written language during middle childhood and early adolescence. The finding related to the third tested hypothesis also points to the importance of explicit instruction in note-taking for listening to instructional talk across the content areas, beginning in the upper elementary grades. The finding of a relationship between alternating touch typing and groovy pencils and writing notes about heard source material provides preliminary evidence for its potential benefits of both modes of letter, word, and text production for note-taking when listening to teachers; but again additional research is needed on this issue for students with persisting SLDs in writing and at different grades levels in their schooling at the elementary, secondary, and postsecondary levels of education and in multiple countries in our global world.

Implications, Limitations, and Future Directions

Overall, the results showed that computerized instruction in letter production, note- taking, and writing summaries can improve letter production and written sentence composing outcomes on normed measures, which compare students with SLDs in writing with students without SLDs in nationally normed achievement measures for age or grade, as well as *z*-scores from research measures based on typically developing writers. These findings generalize to students with carefully diagnosed SLDs in writing for whom developmental disabilities and motor disorders related to medical disorders have been carefully ruled out (Berninger, 2015; Berninger, Richards et al., 2015). While the current study is a necessary first step to provide validation of a proof of a concept, future research is needed to extend this work, as well as the work of other research groups, on computer-supported writing instruction, to general education inclusive settings in schools and the use of computerized instruction for the writing, reading, and oral language skills needed in math (cf., Bryant et al., 2015) and other STEM subjects.

The most important lesson learned from this research is that accommodations alone are not sufficient for students with persisting writing disabilities. They do learn from computerized writing instruction and can benefit from instruction that incorporates multiple modes of language input for source material and multiple modes of output—stylus, groovy pencils, and keyboarding (also see Berninger, 2013). They also need learning activities to develop note-taking beginning in upper elementary and continuing through middle schools so they have the necessary skills for note-taking for written assignments at school and homework and test taking in the secondary and postsecondary grades.

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Table 1

Means (*M*), and Standard Deviations (*SD*) for Pretest and Posttest Measures for UW Copy Paragraph at 30 seconds, 60 seconds, and 90 seconds

Group A—Time 1		
	M	**SD**
30 sec	26.67	12.85
60 sec	50.56	19.07
90 sec	73.11	29.83
Group A- Time 2		
30 sec	34.00	21.32
60 sec	70.33	30.35
90 sec	102.22	43.11
Group B-Time 1		
30 sec	25.44	12.14
60 sec	54.75	23.83
90 sec	81.50	35.98
Group B-Time 2		
30 sec	34.06	15.10
60 sec	65.94	29.85
90sec	98.25	42.62