5-28-2020

The Effects of Handwriting and Typing Practice on Transcriptional Fluency and Written Product Outcomes

Brian Klein
Illinois State University, brianjklein@gmail.com

THE EFFECTS OF HANDWRITING AND TYPING PRACTICE ON TRANSCRIPTIONAL FLUENCY AND WRITTEN PRODUCT OUTCOMES

BRIAN KLEIN

119 Pages

A child's handwriting fluency may have implications on his or her quality of writing. The same may be true of typing fluency. The current study examines the effects of handwriting and typing practice on early elementary school children's transcriptional fluency and written product outcomes. Three classrooms of second-grade students were assessed in both domains before and after a 40-day intervention. Measures were taken in both handwriting and typing modes. One classroom practiced handwriting, one practiced typing, and a third served as a control group. Data were analyzed to determine differences in transcriptional fluency and written product outcomes across time and between groups. No statistically significant improvements in fluency were observed among the handwriting group, yet results yielded statistically significant improvement in the coherence of stories. Statistically significant improvements in fluency were observed among the typing group, but no product outcome improvements were observed. Additionally, improvements on some product outcome variables on handwritten assessments among students who practiced handwriting were greater than improvements on the same variables on typed assessments among students who practiced typing.

KEYWORDS: transcription, text generation, writing development, handwriting, typing, written expression

THE EFFECTS OF HANDWRITING AND TYPING PRACTICE ON TRANSCRIPTIONAL FLUENCY AND WRITTEN PRODUCT OUTCOMES

BRIAN KLEIN

A Dissertation Submitted in Partial
Fulfillment of the Requirements
for the Degree of

DOCTOR OF PHILOSOPHY

Department of Psychology

ILLINOIS STATE UNIVERSITY

2021

THE EFFECTS OF HANDWRITING AND TYPING PRACTICE ON TRANSCRIPTIONAL FLUENCY AND WRITTEN PRODUCT OUTCOMES

BRIAN KLEIN

COMMITTEE MEMBERS:

Gary Cates, Chair

Greg Braswell

Julie Campbell

Deborah MacPhee

CONTENTS

TABLES

CHAPTER I: INTRODUCTION

Learning to write is one of the foundational elements of early literacy skills (Gerde, Bingham, & Wasik, 2012). According to the National Early Literacy Panel report, writing is one of a few early literacy skills, along with alphabet knowledge and phonological awareness, that predicts later literacy development (NELP, 2008). But learning to write, like learning to read, takes years of practice. A child will progress through many stages before he or she can pick up a pencil and write a full sentence (Gerde et al., 2012). The child begins by writing small marks or drawing pictures. Next comes continuous scribbles, which evolve into letter-like symbols, then actual letters. Invented spelling precedes accurate spelling before those words are used in complete sentences. One general aim of the current study is to examine how learning these emergent writing skills and becoming fluent in them is essential in the development of written expression. But while handwriting fluency is important, it’s necessary to consider typing as another prominent mode of composition, the use of which typically starts later in a child’s life (Stevenson & Just, 2014). While there are some similarities between handwriting and typing regarding motor movements, there are also important differences (Stevenson & Just, 2014; Kiefer et al., 2015). Another aim of the current study to is examine the written product outcomes—variables like the number of words written and the complexity of sentences—when either mode is used.

Despite its importance to the process of building early literacy skills, regular broad writing practice in early childhood classrooms is not common (Gerde et al., 2012). In preschool, handwriting is the most common component taught, but only 58% of teachers reported doing so (Bingham, Quinn, & Gerde, 2017). Furthermore, those lessons most often entail simple modeling, rather than detailed instruction on the strokes necessary for each letter. In early elementary grades, writing is something of a forgotten subject matter compared to reading and math (Gerde et al., 2012). Writing is not often part of the daily routine in first-, second-, and third-grade classrooms. Spelling, grammar, punctuation, and capitalization are the most common components covered, with about a third of teachers addressing handwriting (Cutler & Graham, 2008). Acknowledging its place as a foundational academic skill, the Nation Commission on Writing (2003) suggested that elementary education teachers double their writing time. There is also evidence that writing skill deficits are a lingering concern as a student progresses through school. Based on a study by the National Center for Education Statistics (2012), most high school students are below a "proficient" level of writing.

Given the combination of skills required, many different approaches have been taken to measure the quality of the written product. There are at least four categories of assessment to consider. Classroom teachers who grade writing samples like narrative stories and descriptive essays tend to use holistic assessment methods, which assign one overall score to the written product (Ritchey & Coker, 2013). Other teachers use analytic assessment methods, which assign scores to somewhat subjective domains—for instance, areas like "ideas," "organization," "voice," and "word choice." A third kind of assessment approach, curriculum-based measures, provide scores for more easily quantifiable variables like total words written, correct writing sequences, and words spelled correctly (Epsin et al, 2004). A fourth approach, theory-based assessment, focuses on both the process and the product (Berninger & Whitaker, 1992). In this approach, the interaction of a number of variables, including transcription skill, language ability, and working memory are examined. The current study will incorporate the latter two approaches when assessing the merits of a student's written product.

While various theories suggest a wide range of contributors to the final written product, the writing process for a young child can be distilled down to two operations: transcription and text generation (Abbott & Berninger, 1993). Transcription refers to the process of forming graphic symbols that represent language held in working memory. The output of transcription, whether by handwriting or typing, is letters and words. Text generation refers to the process of mentally forming the clauses and sentences within working memory. A revision of this model later incorporated executive function into the process (Berninger et al., 2002). In this iteration, executive function and transcription form the two base points of a triangle topped by text generation. Each of these three contributing factors operate within working memory. Research on the interaction of these processes has found that building fluency of transcription skills can lead to better text generation—both length and quality of text (Berninger et al., 1997; Santangelo & Graham, 2016). Once a child becomes fluent with the mechanics of producing text, the brain is allowed to allocate more mental resources to the linguistic and cognitive processes (Berninger, 1999; Fayol, Alamargot, & Berninger, 2012; Christensen, 2004; Berninger, 1993; Wicki et al., 2014). It's important to note the fluency of handwriting, and not the legibility, is the variable of interest. Legibility of handwriting is not significantly correlated with fluency (Wicki, Lichtsteiner, Geiger, & Müller, 2014). A child with more fluent handwriting skills will produce longer and higher-quality written products than less fluent peers (Alves et al., 2016). At the same time, a child with more fluent typing skills will produce longer and higher-quality written products than less fluent peers (Christensen, 2004). But most of the research on transcription to date has been on handwriting. More research can be done to understand the relationship between transcription and text generation in the typing mode. The current study seeks to test this general hypothesis: whether becoming more fluent in transcription in either handwriting or typing leads to better written products in the respective mode.

With a lack of attention given to writing in the classroom (Gerde et al., 2012), students stand to miss out valuable writing practice. Engagement in a skill is a necessary part of building fluency in that skill (Haring & Eaton, 1978). If a child is not fluent in forming a particular letter, that skill is of limited use in settings that require generalization, like writing a full word that uses that letter. And writing, a process that employs a range of more narrow skill sets, requires many years of practice before a child can progress from letter-like scribbles to full, articulate sentences (Palmis, Danna, Velay, & Longcamp, 2017). As a writer develops, the mean velocity of the pen stroke increases and continuous strokes become longer. For instance, a 5-year-old child experiences many more stops and pen lifts than a 7- or 9-year-old child. But a child's neurodevelopmental skills only account for a portion of the quality and length of the written output. Linguistic skills and cognitive abilities also play a role (Berninger, 1994). Each of these three elements—neurodevelopmental, linguistic, and cognitive—may act as a constraint on the final written product. Deficits in any one area can hinder the product. Within the neurodevelopmental domain, difficulties with orthographic coding, neuromotor function, and visual-motor integration can impede the overall process (Abbott & Berninger, 1993). There is evidence that when these skills are fluent, working-memory processes are saved for higher order functions (Berninger, 1999; Fayol, Alamargot, & Berninger, 2012; Christensen, 2004; Abbott & Berninger, 1993; Wicki et al., 2014). Linguistic deficits can also constrain the written product (Berninger, 1994). Linguistic skills can be categorized within three levels: the word level, the sentence level, and the text level (Berninger, Mizokawa, Bragg, Cartwright, & Yates, 1994; Whitaker & Berninger, 1994). Intraindividual differences in skills across these levels is common

(Whitaker & Berninger, 1994). Meaning, a child's vocabulary may be more advanced than his or her ability to compose a complex sentence. Lastly, issues with cognitive processes can constrain the written product (Berninger, 1994). Difficulties with inattention or working memory capacity can play a role in the writing process. For the purposes of this study, the neurodevelopmental processes—the motor mechanics of writing—will be examined as a possible constraint to written product outcomes.

Examining the neurodevelopmental component means taking a close look at transcription and how it factors into the overall process of writing. Transcription has been identified as the foremost constraint on written outcomes in early elementary school children (Berninger, 1999; Graham et al., 1997). As the process of forming graphic symbols that represent language, transcription factors heavily in both handwriting and spelling (Abbott & Berninger, 1993; Brooks, Vaughn, & Berninger, 1999). The current study will look at handwriting rather than spelling—and handwriting fluency in particular, rather than handwriting legibility. Handwriting fluency refers to the rate of accurately forming the appropriate letters and words with a pen or pencil. Usually this skill is measured by counting the number of letters produced per minute on a copying task. Studies have shown that handwriting fluency correlates more highly with compositional outcomes than spelling accuracy (Berninger et al., 1992), is more responsive to intervention than spelling (Brooks et al., 1999), and more directly linked to future writing skills than spelling (Berninger et al., 1991; Berninger, 1994).

The current study will focus on transcriptional fluency of both handwriting and typing. It will examine the written product outcomes, both in terms of length and quality, when young children practice their transcriptional skills. But the two modes differ in important ways. The objective of handwriting is to control the hand and wrist in such a way as to guide a pen or pencil on a particular path (Phillips, Gallucci, & Bradshaw, 1999). A child is typically more proficient with either the right or left hand, though no significant differences have been found between right-handers and left-handers (O'Mahony, Dempsey, & Killeen, 2008). To increase handwriting fluency, targeted instruction of how to write each letter has been shown to be effective (Graham et al., 2000). Other research has found that both handwriting fluency and written expression scores increase when intervention targets transcription skills (Jones & Christensen, 1999; Santangelo & Graham, 2016). The theory suggests that when transcription skills become fluent, greater access is allowed to linguistic and cognitive processes (Berninger, 1999; Fayol et al., 2012; Christensen, 2004; Abbott & Berninger, 1993; Wicki et al., 2014), resulting in better written products.

While most studies of transcription have focused on handwriting, a few have also examined typing as a mode of transcription. Typing on a computer with a word processor has become an increasingly common mode of writing among students (Berninger & Winn, 2006). While typing requires motor movements of the fingers, the process is less complex than handwriting (Stevenson & Just, 2014). As a result, typing sometimes serves as an alternative for children with handwriting difficulties. Typing may require simpler motions, but motor skills are essential to both processes, as evidence by a correlation between handwriting fluency and typing fluency. In addition, in the same way that handwriting practice builds handwriting fluency, typing practice builds typing fluency. What is more, studies have found a link between typing fluency and typed composition outcomes (Christensen, 2004; Connelly, Gee, & Walsh, 2007).

There was a time when the promise of keyboards and word processing software led some to believe typing might benefit the quality of written products (Connelly, Gee, & Walsh, 2007), but research has not found that to be the case. Instead, the literature points to advantages of handwritten products over typed products. Research suggests that handwritten texts tend to be longer (Alves et al., 2016), and higher quality (Connelly et al., 2007; Alves et al., 2016) than typed texts. Handwriting holds advantages over typing when learning letters, too. Results suggest young children recognize letters they wrote by hand better than letters they typed (Longcamp, Zerbato-Purdou, & Velay, 2005). The current study will examine both the handwriting fluency and typing fluency of students as well as the written outcomes in either mode of composition.

While many studies have measured writing behaviors—the actual written production or responses to familiar letters—other studies suggest neuropsychological advantages to handwriting (James, 2017). These studies, which typically use functional magnetic resonance imaging (fMRI), have found handwriting serves to link visual processing with motor experience in a way typing does not. Neuroimaging has revealed, among participants who write by hand, more robust brain activation patterns that include specific language centers. For instance, certain "reading circuit" regions of the brain activate after letters have been handwritten, but not after letters have been typed (James & Engelhardt, 2012). When letters are handwritten, they are stored as "motor images" in the left dorsal premotor cortex (Palmis et al., 2017). This area is more active during linguistic tasks with writing movements than linguistic tasks without writing movements. Interestingly, when handwriting becomes fluent, more efficient brain activity is found (Berninger & Winn, 2006). A similar study to Longcamp and colleagues' (2005) research on letter learning found that adults recognized new characters they write by hand better than new characters they type (Longcamp et al., 2008). Results, which included fMRI data, also suggested that certain language-specific regions were more active during handwriting.

The current literature suggests children who build fluency in transcription skills—whether by handwriting or by typing—may stand to improve their written output by granting greater access to language and cognitive abilities (Berninger, 1999; Fayol et al., 2012; Christensen, 2004; Abbott & Berninger, 1993; Wicki et al., 2014). Moreover, with apparent neuropsychological advantages, building handwriting fluency may be more beneficial than building typing fluency on written product outcomes (Longcamp et al., 2005; James, 2010). One purpose of this study is to examine the effects of transcriptional skill practice on handwriting and typing fluency. Another purpose is to examine the effects of transcriptional skill practice on written product outcomes in handwritten and typed texts. Lastly, the current study will compare the expected written product outcome gains between either mode of composition.

CHAPTER II: REVIEW OF RELATED LITERATURE

The current study seeks to test transcriptional fluency and written product outcomes among second-grade students. It would add to and expand upon current understanding of transcription and text generation at this early age. Furthermore, it would test whether these principles are consistent across handwriting and typing. Results would also provide insight on whether handwriting holds any advantage over typing for students of this age. But first, it is important to consider past findings in a few pertinent areas: writing instruction and assessment in the classroom, developmental theories of writing, and the neuropsychology of writing.

Writing in the Classroom

Many studies have suggested a strong association between writing skills and early literacy skills (Gerde et al., 2012). In fact, writing proficiency in preschool predicts growth in letter knowledge (Diamond, Gerde, & Powell, 2008), while writing proficiency in kindergarten predicts decoding, spelling, and reading comprehension in first grade (Shatil, Share, & Levin, 2000). While writing enhances early literacy skills on the path to reading, it is a skill that does not receive much attention. Many classrooms feature the materials necessary for writing, but early childhood teachers do not often make writing a part of the daily routine (Gerde & Bingham, 2012). Without steady practice in written language, children may be missing out on building literacy skills.

Instruction

Supervised writing practice begins in preschool. A study by Bingham, Quinn, and Gerde (2017) of preschool writing instruction found that handwriting was the most common component addressed (58% of teachers), followed by spelling (35.6%) and composing (6.7%). The majority of teacher support provided within each area was described by the study as “low-level.” An instance of low-level instruction is modeling the correct letter formation. A teacher may form the letter ‘A’ for a student. On the other hand, “high-level” instruction includes drawing attention to the formation of that letter (“Look, an ‘A’ has three lines.”). But research detailing teachers’ instructional habits at such early ages is sparse.

Citing a lack of research on instructional practices, Cutler and Graham (2008) studied time spent writing in primary grade classrooms. The researchers administered a survey to 294 first- through third-grade teachers in the United States. Results found that 65% of teachers do not use a commercial program to teach writing, but rather design their own curriculum. Responses varied regarding the aspects of writing on which teachers spent the most time. About half of teachers (51%) reported that they work on spelling skills on a daily basis. Approximately the same proportion work on grammar skills (51%), punctuation skills (49%), and capitalization skills (48%) every day. Only about a third (35%) of teachers reported working on handwriting skills on a daily basis. Interestingly, analyses found more handwriting practice in first and third grade than second grade. The study, unfortunately, did not report how much time was spent each day on the various writing skills that were being practiced. The teachers did report, however, spending 105 minutes per week (21 minutes per day) “writing text that was a paragraph length or longer.” The most common writing activities were writing stories (96.1% of teachers), drawing a picture and writing text based on that picture (94.9%), and writing letters to another person (88.8%). Fewer than half of the teachers (42.7%) reported copying text as a writing activity. The 105-minute figure is a median, as the researchers cited a considerable range—from 0 minutes to 380 minutes per week.

Traditionally viewed as one of the bedrock academic skills, along with reading and math, writing seems to be the least practiced of the three. A report by the National Commission on

Writing (2003) encouraged elementary school teachers to “double” the amount of time students spend writing. It could be argued that the academic consequences of limited time devoted to writing during elementary school years are reflected in the current written achievement of older students. Only 30% of eighth- and 12th-grade students performed at or above the “proficient” level in writing, based on the most recent National Assessment of Educational Progress (National Center for Education Statistics, 2012). In addition, college instructors estimate that half of high school graduates lack the skills to meet college-level writing demands (Achieve, Inc., 2005). But measuring proficiency can be difficult. It is clear there are many approaches to assessing the merits of a written product.

Assessment

Based on the complexity of the writing assignment, assessment may take many forms. Ritchey and Coker (2013) divide the assessment of classroom writing samples into three categories: holistic, analytic, or measures of production and accuracy. For the purposes of this discussion, a fourth approach will be considered: theory-driven assessment (Berninger & Whitaker, 1992). Each approach has its own strengths and weaknesses.

A holistic assessment requires the rater to designate a score for the overall quality of the written product, without focusing on any one dimension of the written product. The philosophy behind such an approach suggests a written product is more than the sum of its parts (Espin, Weissenburger, & Benson, 2004). Scoring in this manner takes into account a relative ranking of the product compared to other written products, overlooking the nuances of the writing. However, such simplicity comes at a cost. Studies have produced a wide range (.13 to .94) in reliability coefficients for holistic scoring approaches. Similarly, the predictive validity of such measures is questionable.

An analytic approach to assessment requires the rater to judge individual elements of a text on a scale, typically from 1 to 5 (Ritchey & Coker, 2013). Writing dimensions often include some variation of the following: ideas, usage, organization, wording, and style (Epsin et al., 2004). Each written product receives a score for each dimension, which provides some indication of the student's strengths and weaknesses as a writer. Perhaps as a result, analytic scoring approaches have returned higher reliability estimates than holistic approaches. However, analytic scores have suffered from low validity estimates (Ritchey & Coker, 2013). In addition, the argument has been made that analytic scales tend not to assess distinct dimensions of writing, as evidence by high correlations between dimensions. For instance, there may be little difference between "usage," "wording," and "style" in the mind of the reviewer.

Measures of production and accuracy are the basis of curriculum-based measures (CBMs) (Ritchey & Coker, 2013). This approach provides a more systematic evaluation of written products than holistic or analytic approaches. Because these assessments can be used often and reliably, they are often used in schools within a problem-solving model (Malecki & Jewell, 2003). The rater using a CBM approach measures dimensions like total words written, words spelled correctly, and correct writing sequences. A correct writing sequence is a sequence between adjoining words that is semantically and syntactically appropriate within the context of the sentence. This approach provides a more sensitive measure of progress over time (Epsin et al., 2004).

The fourth approach—theory-driven assessment—examines both the writing process and written product of a child. Traditionally, writing researchers and classroom teachers have been more interested in evaluating the processes behind a child's writing (Berninger, Whitaker, Feng, Swanson, & Abbott, 1996). One such theory-driven assessment highlights the translation process as the most central process behind a child's written output. This process refers to the skills associated with forming the appropriate language within working memory and turning it into orthographic symbols—letters and words (Abbott & Berninger, 1993). Translation can be divided into at least two components: transcription and text generation. At its essence, a theory-driven assessment approach seeks to quantify the neurodevelopmental, linguistic, and cognitive components involved in writing. Such an approach may yield a vast assortment of measures, which may include orthographic coding, neuromotor function, fine motor skills, oral language skills, and verbal intelligence. Theory-driven assessment also seeks to assign value to the quality of a written product, but there is little uniformity of methods.

Clearly, there are many ways to assess a written product. Some measures account for more reliably quantified variables, like total words written, correct writing sequences, and words spelled correctly (Malecki & Jewell, 2003). Other measures assign value to quality, whether by examining predetermined domains (Ritchey & Coker, 2013) or as a whole (Espin, Weissenburger, & Benson, 2004). Still others measure the processes, like transcription and text generation, behind the writing (Berninger & Whitaker, 1992). The current study will examine written product outcomes using a number of these variables. But before going much further, a more complete review of developmental models of writing is required.

Developmental Theories of Writing

Perhaps the most influential model of the development of writing skills is the one presented—and since modified—by Hayes and Flower (1980). The researchers sought to explain the writing process at all ages, finding that each writer engaged in three components: planning, translating, and revising. In the planning stage, the writer responds to a prompt by consulting his or her memory, setting goals, and creating a plan. Translating refers to the production of written language in line with the developed plan. In the revising stage, the writer reviews and edits the translated text. It is important to note Hayes and Flower suggested these as recursive components rather than sequential stages. Specifically, a writer does not simply move from one stage to the next, but continually revisits each stage until the written product is complete.

Transcription and Text Generation

This three-part model, though, was not found to adequately describe the developing writer. First, planning and revising components are not often seen among writers before age 12 (Berninger, Mizokawa, & Bragg, 1991). Young children do not tend to spend time thinking about what they will write or how to improve what they have written. In addition, further research found evidence of a more nuanced translation stage, which could be divided into transcription and text generation (Berninger et al., 1992). Transcription refers to the retrieval of orthographic symbols (letters) and the motor output mechanics of producing those symbols (Abbott & Berninger, 1993). Text generation refers to the process of transforming ideas into linguistic representations in working memory. The two processes work in tandem and ultimately result in the written product. But reaching the point of composing articulate sentences takes time. A child spends thousands of hours practicing the craft before he or she can write words fluently (Palmis et al., 2017). Broadly, the development of graphic output can be divided into three stages (Berninger, 1994). In the first stage, a child draws pictures to express thoughts. In the second stage, a child begins to use invented spellings of single words, which marks the emergence of transcription. In the third stage, a child successfully strings together multiple words (usually a combination of invented and conventional spelling) to form phrases, clauses, and sentences, which marks the emergence of text generation. As such, early transcription skills necessarily emerge before text generation skills.

While transcription precedes text generation, the two components then develop at the same time, in some cases at different rates (Berninger, Fuller, & Whitaker, 1996). In some instances, text generation develops more quickly than transcription. In these cases, children write unintelligible words yet read their composition out loud without issue. In other instances, transcription outpaces text generation. In these cases, children write little when asked to write a story and indicate they can't think of anything else when prompted to write more. Yet, the written product is legible.

The "simple view of writing" emerged a few years later (Berninger et al., 2002), incorporating a dimension of executive function into the equation. This model brought together research from a range of research backgrounds, including cognitive, developmental, neuropsychological, and educational psychology. The model represented writing as a triangle in the working memory. Self-regulation executive function joined transcription and text generation as a third informant of the written product. Self-regulation assists a writer in setting goals, making plans, and monitoring progress.

This triangular model of the writing process itself has been updated and expanded to incorporate more variables, but the essential translation process—the interaction between transcription and text generation—remains the same. Hayes and Berninger (2014) presented a process involving three levels: the resource level, the process level, and the control level. The resource level is populated by general cognitive processes, of which the researchers identify four: attention, long-term memory, working memory, and reading. Each resource indirectly relates to the written product. Attention refers to the writer's ability to maintain focus on the task. Long-term memory can be thought of as storage for a number of components the writer may engage with to craft the written product. Those components include knowledge of pertinent facts, motor planning, knowledge of letter forms, spelling, vocabulary, and grammar. Working memory refers to a stable in which required information is balanced in order carry out a task—the space where ideas become language. A fourth resource, reading, is a component used by writers during their composition. A writer who has written down a partial sentence often rereads those words before completing the sentence.

The control level refers to contributors that help structure the form of the written piece (Hayes & Berninger, 2014). On this level, a task initiator (perhaps a teacher) provides a prompt to produce text. The planner, an internal component, sets goals for the written product. Meanwhile, writing schemas inform the genre the writer will use and strategies that help produce the written product.

Of more interest to the current study is the process level. Translation occurs on this level. Updates to the model have divided the combination of transcription and text generation into a four-part process: proposer, translator, transcriber, and evaluator (Hayes & Berninger, 2014). First, the proposer identifies ideas that might be relevant for the text at hand, though the ideas are in a nonverbal state. Input may come from the planner, task environment, or long-term memory. Next, the idea is directed to the translator, which represents the ideas as a grammatic string of language. The transcriber then takes the language strings and turns them into written text. In this step, internal language becomes output, including letters, words, clauses, and sentences. Transcription is then a mechanical process performed through either handwriting or typing. The fourth process is the evaluator, which governs each of the three other processes. If an idea, language string, or piece of written text is determined to be inadequate, it may be rejected or revised.

Multiple Levels of Constraints

The principles of translation, text generation, and transcription found in Hayes and Berninger's model (2014) provide an outline for the elements that inform a child's final written product. The model also provides a framework to understand where a child may run into obstacles. There appear to be at least three general types of constraints on a writer's final product: neurodevelopmental, linguistic, and cognitive (Berninger, 1994). The first type, neurodevelopmental, refers to skills particularly essential to transcription—orthographic coding, neuromotor function, and visual-motor integration. These three skills facilitate the process of forming the appropriate letters and words. Orthographic coding refers to identifying the letters to form a word. Neuromotor function refers to the use of fine motor movements to form those letters on a page. Visual-motor integration involves the communication between the eyes and the hands. A study of fourth-graders' handwriting found that fluency was associated not only with the speed of fine motor movements, but also orthographic skills—even as visual-motor integration was observed to have its own unique contribution (Wicki et al., 2014). That is, more fluent handwriting was associated with better letter recall from working memory. Wicki and colleagues (2014) argue this finding suggests when writing becomes fluent, working memory resources are saved for other higher-level processes. It is important to note that the researchers use the term "automaticity" rather than "fluency." The concept is the same. Both refer to a quality that features both accuracy and speed.

The second type of obstacle, linguistic processes, represent the child's capacity of language. As explained by the most recent model, transcription skills and translation skills interact to inform the written product (Hayes & Berninger, 2014). While a child's fluency of writing mechanics constrains access to language skills, the child's level of language knowledge will constrain the written product (Berninger, 1994). Evidence of language skill can be identified at the word, sentence, and text levels (Berninger, Mizokawa, Bragg, Cartwright, & Yates, 1994; Whitaker & Berninger, 1994). Whitaker & Berninger (1994) designed a coding scheme to measure translation skills at all three levels. At the word level, word choice is considered. Higher scores are assigned to words used less frequently. At the sentence level, higher scores are assigned to more complex sentences. At the text level, higher scores are assigned to more coherent text organization. The results of the study, implemented with fourth-, fifth-, and sixth-graders, found intraindividual differences between language levels. That is, word level skill was not correlated with sentence- or text-level skill. In addition, skill at the sentence level was not correlated with skill at the text level. The findings suggest proficiency at one language level is not useful in predicting proficiency at another language level. It is important to remember, though, that these results were obtained from fourth-, fifth-, and sixth-grade students. There currently appears to be no research on differences between word, sentence, and text level language skills for children in the early elementary grades (1 through 3). This is an important gap in the research to address, as children in these grades begin writing in sentences. Research of children in these grades would shed more light on language development.

The third type of obstacle on the written product, cognitive processes, largely plays a role in the planning and revision stages of writing. When applied to Hayes & Berninger's (2014) most recent model, this dynamic fits into the resource level. At this level, attention and memory interact to inform the written product. While these cognitive processes constrain the written product as a child grows older, they do not appear to factor into the written product of a child in the early elementary grades (Berninger et al., 1991; Abbott & Berninger, 1993). However, executive function also seems to factor into the writing process for young developing writers, along with transcription and text generation (Berninger et al., 2002). At least one study provides information about how executive function influences the writing of early elementary school children. Limpo and Alves (2018) examined the effects of self-regulation and transcription skill among Portuguese second-graders. The study involved three groups: one that received a self-regulation plus transcription intervention, one that only received a self-regulation intervention, and one that simply received the standard school curriculum. Self-regulation lessons taught participants a planning strategy to help generate and organize ideas. Transcription lessons included some spelling practice, but mainly focused on improving handwriting fluency. The results suggest that the self-regulation intervention, with or without transcription lessons, increased students' written expression. Interestingly, while self-regulation strategies alone improved writing scores, a combination of self-regulation strategies and transcription training was the most beneficial. But beyond this study, the literature says little about the influence of cognitive constraints, as outlined by Hayes and Berninger (2014), on writing. Few studies examine the role of cognitive processes as a constraint on the written product of young writers. By understanding these processes more fully, steps could be taken to improve the overall written product.

Elements of Transcription

Essentially the mechanics of writing, transcription plays a role in two output dimensions: handwriting and spelling (Abbott & Berninger, 1993; Brooks, Vaughn, & Berninger, 1999). It does not, however, factor into punctuation or grammar usage. When it comes to written expression, it has been argued that the fluency of handwriting is more important than its style or neatness (Medwell & Wray, 2008; Tucha, Tucha, & Lange, 2008). Fluency in a task depends on the speed and accuracy of that task. Handwriting fluency is often measured by the number of words correctly copied within a time limit (Berninger, 1994). Spelling accuracy refers to spelling words correctly.

Research suggests that the process of transcription is the foremost constraint on written output at the early elementary level (Berninger, 1999; Graham et al., 1997). Transcription contributes to 66% of the variance in compositional length and 25% of the variance in compositional quality in first, second, and third grade (Berninger, 1999). The original report refers to the former as "compositional fluency," but it would be safer to call it "length." The task required each participant to compose a written piece in 10 minutes, but did not demand participants to write as much as possible as quickly as possible. As such, the term "length" is more appropriate than "fluency." Importantly, transcription was found to contribute to a diminishing degree as children grow older. In grades 4 through 6, transcription contributes to 41% of compositional length and 42% of compositional quality. By junior high, (grades 7 and 8) it plays even less of a factor, contributing to 16% of compositional length and 18% of compositional quality. These findings suggest the mechanics of writing, and handwriting in particular, predict differences in compositional length and quality. In addition, transcription skill is more influential at younger ages. However, it seems to continue influencing writing well into secondary school (Medwell & Wray, 2008). There is also evidence that transcription may limit adult writers (Hayes & Berninger, 2014).

The current study is designed to address handwriting fluency, rather than spelling accuracy, and examining its influence on written outcomes. The reasons are many. First, handwriting is more highly correlated with compositional outcomes than spelling among students in first, second, and third grade (Berninger et al., 1992). In Berninger and colleagues' research (1992), children wrote two written samples, one with a narrative frame and one with an expository frame. Written products were assessed by measuring the number of words produced and the number of clauses produced. Overall, handwriting was much more strongly related to words and clauses in both narrative and expository pieces than spelling.

Second, between handwriting and spelling, handwriting skills have been found to be more responsive to intervention (Brooks et al., 1999). In a study of fourth- and fifth-graders with severe writing disabilities, the researchers provided tailored interventions designed to improve each of three areas: handwriting, spelling, and composition quality. Between pretests and posttests, significant improvements were found in handwriting and composition quality, but not spelling. The researchers note, however, that the participants improved from two standard deviations below the norm to one standard deviation below the norm. After approximately 24 sessions across eight months, the participants did not improve so greatly as to reach an average range for handwriting.

Third, and perhaps most importantly, deficits in handwriting have been more directly linked to future deficits in writing (Berninger et al., 1991; Berninger, 1994). Poor performance in three lower-level skills— orthographic coding, neuromotor function, and visual-motor integration—can contribute to future writing disabilities either directly or indirectly. On the one hand, inadequate proficiency in these lower-level neurodevelopmental skills may continue to require the child to expend high amounts of effort to produce written words. On the other hand, these difficulties may be marked by early frustration, which leads to a general aversion to writing. Research suggests early failure in writing can lead to lower motivation to learn, loss of self-efficacy, development of external locus of control, and avoidance of writing tasks (Jones & Christensen, 1999). Therefore, if interventions can be implemented to improve handwriting fluency among early elementary school children, it stands to reason that they will both produce better written text and be more likely to find success as writers later in life.

Handwriting as Transcription

The primary pursuit of the current study is to investigate the translation process of writing among early elementary school children. As such, transcription of text—and the neurodevelopmental underpinnings—is the constraint of greatest interest. The current study seeks to shed light on how improving transcriptional fluency may improve written output, both length and quality. The study will examine two modes of transcription: handwriting and typing. Transcriptional fluency is the rate of accurate transcriptional. For handwriting, the measurement refers to how fast a person accurately forms the appropriate letters and words with a pen or pencil. For typing, the measurement refers to how fast a person accurately types the appropriate keys.

The first mode to discuss is handwriting. Handwriting is a complex motor task that involves interrelationships between central coordination, biomechanics, and intended written product (Phillips, Gallucci, & Bradshaw, 1999). The objective of this task is to achieve control of the musculature of the hand and wrist to form the appropriate stroke. Typically, a writer is stronger with either his or her left or right hand. Functional intraindividual differences between the two hands may be a product of either the functional organization of the brain or biomechanical differences in the limbs. However, when comparing the handwriting speeds between left-handers and right-handers, no significant differences were found in early elementary school or middle school (O'Mahony, Dempsey, & Killeen, 2008). While biomechanics—the physical component of transcription—appears to factor into handwriting fluency, there is no evidence of an advantage to being either left- or right- handed. The literature addressing this area is sparse, however.

Even in early elementary school, handwriting instruction does not account for much of the classroom lessons. One survey found only 35% percent of teachers practice handwriting on a daily basis in the U.S. (Cutler & Graham, 2008). Handwriting instruction also has a low profile in the U.K. (Medwell & Wray, 2008). This suggests students are receiving little formal practice in basic transcriptional skills.

Research has suggested that improving neurodevelopmental skills involved with handwriting improves transcriptional fluency, which allows greater access to linguistic and cognitive processes (Berninger, 1999). Berninger (1999) found that the three neurodevelopmental processes—orthographic coding, neuromotor function, and visual-motor integration—contribute to 66% of the variance in compositional length and 25% of the variance in compositional quality in grades 1 through 3. But handwriting is a skill that can improve, and become faster with practice (Tucha et al., 2008). It would follow that handwriting practice should lead to higher handwriting fluency, leading to greater access to linguistic and cognitive processes, resulting in improved written output.

Graham and colleagues (2000) found that providing handwriting instruction led to handwriting fluency and compositional gains among first-graders with handwriting deficits. Participants who were given handwriting instructions for each of the letters improved their alphabet production, copying production, and sentence production under time limits more than participants who were given phonological awareness instructions. Story length was also longer among handwriting participants. No difference was found in story quality, though it should be noted the examiners assigned a single, holistic score to the quality of the story, rather than a more nuanced method.

Another study, by Jones and Christensen (1999), found that handwriting fluency accounted for 53% of the variance in story writing quality among first-graders. Moreover, when an intervention designed to target orthographic-motor skills was implemented, students with handwriting difficulties not only improved their handwriting fluency, but also improved their written expression scores. By the end of seven months, the group with handwriting difficulties achieved written expression scores comparable to the control group, which started with higher handwriting and written expression scores. Jones and Christensen's (1999) findings support the assertion by Berninger (1994) that early identification of deficits and subsequent intervention can lead to improved outcomes.

A meta-analysis performed by Santangelo and Graham (2016) lends additional evidence. Eighty studies met the researchers' criteria, which included involvement of students in kindergarten to 12th grade and an intervention designed to improve handwriting. Results suggested that the impact of handwriting instruction on fluency was statistically significant. That is, handwriting instruction leads to gains in handwriting fluency when compared to the absence of instruction or instruction unrelated to handwriting. More importantly, composition measures were also found to improve after handwriting instruction. There were statistically significant effects in writing quality, writing length, and writing fluency.

In another study, Berninger and colleagues (1997) sought causal connections between handwriting and compositional length (number of words produced). Experimental groups of first-graders were divided into one of six instructional approaches. In five of the groups, the children reproduced letters with motor movements, but the stimuli was different. In the sixth group, children engaged in phonological awareness training. The researchers found that the handwriting interventions were more effective than the phonological awareness interventions in improving writing outcomes. When children engaged in writing letters, no matter the instructional approach, their compositional length grew. These results support the idea that once a child becomes fluent in the neurodevelopmental skills behind transcription—once the mechanics of writing have gained fluency—attentional resources are freed up for higher-level linguistic and cognitive processes (Berninger, 1999). After fluency is achieved, translation skills can progress from single words to clauses, sentences, and paragraphs (Fayol et al., 2012). The fluency of handwriting results in a better written product among young children. Data from a case study suggests the same may hold true for adults (Peverly, 2006).

Typing as Transcription

Most of the literature on transcription's role in the final written product is concerned with handwriting, though typing has become an equally essential mode of transcription for students (Berninger & Winn, 2006). While forming letters with pen and paper has been an established mode of transcription for generations, the emergence of keyboards and word processors has been relatively recent. When an individual finger taps a key, a specific character is created. The motor movements are different from writing by hand, but the literary effect is the same. While typing involves motor learning, it is less complex than handwriting in the beginning stages (Stevenson & Just, 2014). Students make finger movements to particular keys, but not letter strokes. As typing skills progress, more rapid typing makes for more complex motor tasks. While typing can serve as an alternative to handwriting for children with fluency difficulties, it is clear that both handwriting and typing require some motor skills (Stevenson & Just, 2014). In fact, children who have good handwriting fluency tend to be more competent and fluent with a keyboard.

When the neurodevelopmental skills of handwriting transcription (orthographic coding, neuromotor function, and visual-motor integration) gain fluency, more attentional resources should be free for linguistic and cognitive processes (Berninger, 1994). The research on when this dynamic is evident for typing is less robust than for handwriting. First, Stevenson and Just (2014) suggested that meaningful practice in typing is necessary to building fluency. More importantly, Christensen (2004) found a significant correlation between typing fluency and typed composition quality among Australian teenagers. The results also suggested a significant correlation between typing fluency and handwriting fluency. The researchers concluded that no matter the mode of transcription, better fluency allowed access to higher-level linguistic and cognitive processes.

Connelly, Gee, and Walsh (2007) compared similar variables among British children between the ages of 4 and 11. Using a pangram copying task to measure transcriptional fluency, handwriting participants outperformed typing participants in all age groups—those who wrote by hand wrote more letters in two minutes than those who typed. In addition, a significant correlation was found between handwriting and typing fluency. In a second study narrowed to fifth- and sixth-graders, Connelly and colleagues (2007) found significant correlations between fluency and essay quality for both handwriting participants and typing participants. The fluency of either transcription was significantly correlated with the quality of the written product. Moreover, handwritten essays were of higher quality than typed essays.

The results of a study comparing handwriting and typing interventions among Portuguese second-graders offer additional evidence (Alves et al., 2016). While one group practiced handwriting and another practiced typing, it was not the study's purpose to compare within-group differences. In fact, while handwriting fluency was measured by pretests and posttests, typing fluency measures were only taken at posttest. Based on data presented in a table, however, there is evidence that compositional length and quality increased from pretest to posttest in the keyboarding group. (The data was not analyzed for significance.) It can be cautiously interpreted that the typing intervention had some benefit on these written product outcomes. More to the point of the study, the results suggested that participants in the handwriting group wrote significantly longer and higher quality texts than participants in the typing group.

Taken together, the findings of studies investigating the properties of typing as transcription suggest a lack of skill can constrain the overall task of translation—can hinder the ultimate written product. But when those low-level neurodevelopmental skills become fluent, the writer's attentional capacity can be used for higher-level processes. Furthermore, even as transcriptional fluency in both measures improve, handwritten products are longer and higher quality than typed products (Connelly et al., 2007; Alves et al., 2016). These findings suggest an advantage to forming letters by hand over forming letters by typing.

As theories of writing development have advanced, the core remains the same: a child's transcriptional skill level can impact the ultimate written product (Abbott & Berninger, 1993). Poor fluency can constrain the quality of the product (Berninger, 1994). And by building fluency in transcription, whether handwriting or typing, more working memory resources are free for higher-level processes, leading to better writing (Fayol et al., 2012; Christensen, 2004). The current study is designed with these theories in mind. It is designed to examine whether transcriptional practice leads to higher transcriptional fluency and, in turn, better written products—within either transcriptional mode. Further, however, the current study seeks to compare presumed handwritten product gains to presumed typed product gains. While the research of Connelly and colleagues (2007) and Alves and colleagues (2016) have found empirical support, other studies have found brain activation patterns that help lend support for this assertion.

Neuropsychology of Writing

Using keyboards and word processors has become an essential mode of transcription in recent years (Berninger & Winn, 2006). At one point, the word processor was thought to be a helpful tool used for the development of writing skills (Connelly et al., 2007). However, no research has suggested using word processors in the classroom has made teaching reading, spelling, or writing any more effective. In fact, there seem to be advantages to handwriting over typing (Alves et al., 2016; Connelly et al., 2007). Many of the studies discussed have examined differences based on behavioral markers like fluency and total words written. Other research has employed neuropsychology techniques to examine the differences by looking at differences in brain activation patterns. Such studies are designed to explain what is happening in the brain when a child expresses language by making movements with a pen or pencil, or typing on a keyboard.

Brain Activation Patterns

A review of the literature by Palmis and colleagues (2017) provides a summary of the neuropsychology behind the motor control of handwriting—one component of a complex process that integrates motor and language abilities. The researchers note that it takes a person several years of practice to advance from first writing their name to writing a sentence fluently. Over time, according to van Galen's (1991) model, the strokes of each letter are learned and stored in long-term memory as "motor programs." It takes time to acquire the motor programs for producing letters, but once they are, the behavior becomes fluent, which allows less attention to be devoted to the task. Decades of observations have led some neuroscientists to identify the left dorsal premotor cortex (Exner's area) as the storage center for "motor images"—or codes for graphic motor patterns (Palmis, et al., 2017). Neuroimaging has suggested this area is more active during linguistic tasks with writing movements than linguistic tasks without writing movements. Palmis and colleagues (2017) describe studies that suggest the dominant superior parietal lobe and cerebellum also play important roles. These areas of the brain appear to be more involved when a person expresses language with a pen and paper than when a person expresses language vocally. The brain also seems to make a distinction between certain symbols. Karimpoor and colleagues (2018) found that certain language-specific portions of the brain were more active when words were written than when numbers were written.

Research has also found particular patterns of brain hemisphere activation (Planton, Longcamp, Péran, Démonet, & Jucla, 2017). Results suggested that the lateralization of brain activity was more pronounced for writing activities than drawing activities. When participants (who were all right-handed) drew, areas within both hemispheres of the brain were active. But when they wrote, activation was stronger in the left hemisphere. The same lateralization seems evident among left-handers—that is, premotor and parietal activations are stronger in the right hemisphere (Palmis et al., 2017). Interestingly, for writers who were forced to switch from their left hand to their right hand in early childhood, the activation is more bilateral (Klöppel, Vongerichten, van Eimeren, Frakowiak, & Siebner, 2007). While regions of the brain associated with language are found largely on the left side (Karimpoor et al., 2018), there does not seem to be any implications for written expression outcomes between left- and right-handers. A study of Greek children between the ages of 7 to 12 found handedness was not related to writing performance or speed (Vlachos & Bonoti, 2004). Another study found no difference between handedness writing skills among Yale freshman (Wittenborn, 1946). Though research in this area is lacking, there does not appear to be an advantage to being left- or right-handed.

There is other evidence of a shift in brain activation when handwriting becomes fluent (Berninger & Winn, 2006). When a person engages in non-fluent copying of orthographic symbols—when he or she is learning new symbols or letters—the left superior parietal lobule, the left inferior prefrontal area, and the primary visual area in the occipital lobe are activated. But when the same person engages in fluent copying (after practice), the left premotor area, the inferior parietal lobule, the left occipital lobe, and the posterior fusiform gyrus are activated. When the integration of orthographic and motor codes is established, cognitive processing shifts, perhaps freeing other cognitive processes for higher-level functions.

Letter Recognition

A fair amount of literature draws more direct connections between handwriting and gains for one specific academic skill: letter learning. The results of multiple studies suggest handwriting serves to link visual processing to motor experience, which strengthens letter recognition skills (James, 2017). When a letter has been formed using a pen, it improves the likelihood the child will recognize that letter later. James (2017) argues that handwriting affects letter learning because it establishes a network of visual and motor brain systems.

Results from a study by Longcamp and colleagues (2008) suggest there is evidence that forming characters by hand, as opposed to typing them, results in stronger facilitation in recognizing those characters later. Longcamp and colleagues' research used fMRI scans to measure neurological activity during recognition of characters. Each adult participant underwent three weekly training sessions to learn new characters, reproducing them either by hand or keyboard. Results suggested that response rates during the recognition tests were higher when the participants had written the characters by hand. In addition, the left Broca's area and bilateral inferior parietal lobules were more active in handwriting participants. The study's findings suggest that the type of motor activity has important implications on how well letters are learned. A similar study of preschool children lends support that these findings (Longcamp et al., 2005). In this experiment, which relied solely on behavioral data, children between the ages of 3 and 5 were trained in either copying letters by hand or by typing them. Tests after three weeks of training found the older children (between 4 1/2 and 5) in the handwriting group responded correctly significantly more often than children in the typing group. Forming individual letters with a pen appears to help build a motor program the brain returns to when the letter is perceived again.

Research by James (2010) also suggests that forming letters with a pen or pencil leads to changes in the visual processing of preschool children. Children participated in two imaging sessions: one before and one after training sessions. During training sessions, an experimenter read a short story with highlighted letters and words. In one group, children copied certain letters and words and were given feedback on writing accuracy. In a second group, children provided only verbal responses to the letters and words. In the imaging sessions, fMRI scans were taken while participants passively viewed presentations of isolated letters, isolated non-letters, and simple shapes. Results suggested that presenting letters that the children had copied activated certain parts of the brain more than other, similar stimuli (non-letters and simple shapes). The motor response of writing the letters was more beneficial than a verbal response. Subsequent research by James and Engelhardt (2012) suggests that 5-year-old children who write letters by hand, as opposed to type or trace them, are better at recognizing those letters. According to fMRI scans, certain "reading circuit" regions of the brain became active when letters that been written were presented, but not when letters that had been typed or traced were presented. Another study found that the motor act of forming letters activates those brain regions more than observing someone else forming the letters (Kersey & James, 2013). These studies suggest a child engages in a certain brain activation patterns only when he or she forms letters by hand.

Purpose of Study

The current study seeks to determine the effects of transcriptional practice, in both handwritten and typed modes, on transcriptional fluency and written product outcomes, in both handwritten and typed products. Research has shown that increased transcriptional fluency leads to better access to internal language abilities, which results in improved written products (Berninger, 1999; Fayol et al., 2012; Christensen, 2004; Abbott & Berninger, 1993; Wicki et al., 2014). Further, the results of the current study should provide information about the differences in transcriptional fluency and written output gains between either mode of transcription. Research has shown that handwriting holds learning advantages over typing, particularly with letter recognition (Longcamp et al., 2005; James, 2010). The purpose of this study is fivefold: to examine the effects of handwriting practice on handwriting fluency, to examine the effects of typing practice on typing fluency, to examine the effects of handwriting practice on written product outcomes, to examine the effects of typing practice on written product outcomes, and to compare expected written product outcome gains between either mode.

Hypotheses

The following hypotheses concerning transcriptional fluency and written product outcomes will be tested.

Transcriptional Fluency

1. Practice is an essential part of advancing from acquisition of a skill to fluency in that skill (Haring & Eaton, 1978). Transcriptional practice in the form of an eight-week handwritten copying exercise is expected to increase handwritten transcriptional fluency, from pretest to posttest, as defined as the rate of letter production per minute on the handwritten alphabet task (H-AT-H) and handwritten sentence copying task (H-ST-H) for participants in the handwriting group.
2. There is expected to be a significant mean difference between groups (handwriting, typing, and control) in both handwritten transcriptional fluency scores: alphabet task fluency (H-AT-H, H-AT-T, H-AT-C) and sentence copying fluency (H-ST-H, H-ST-T, H-ST-C).
3. Transcriptional practice in the form of an eight-week typed copying exercise is expected to increase typed transcriptional fluency, from pretest to posttest, as defined as the rate of letter production per minute on the typed alphabet task (T-AT-T) and typed sentence copying task (T-ST-T) for participants in the typing group.
4. There is expected to be a significant mean difference between groups (handwriting, typing, and control) in both typed transcriptional fluency scores: alphabet task fluency (T-AT-H, T-AT-T, T-AT-C) and sentence copying fluency (T-ST-H, T-ST-T, T-ST-C).

Written Product Outcomes

5. Development of transcription skills allows for a child to focus more attention on the text being generated (Berninger et al., 1992; Berninger et al., 1997). Transcriptional practice in the form of a handwritten copying task is expected to increase all handwritten product outcome variables on the AIMSweb Written Expression probe, from pretest to posttest,

for participants in the handwriting group. Those variables are: word-level language as defined as vocabulary sophistication (H-WL-H), sentence-level language as defined as sentence complexity (H-SL-H), text-level language as defined as text organization (H-TL-H), total words written (H-TWW-H), correct writing sequences (H-CWS-H), words spelled correctly (H-WSC-H), and readability as defined as the score on the Automated Readability Index (H-RI-H).

6. There is expected to be a significant mean difference in all handwritten outcome variable scores from the AIMSweb probe between groups (handwriting, typing, control): word-level language (H-WL-H, H-WL-T, H-WL-C), sentence-level language (H-SL-H, H-SL-T, H-SL-C), text-level language (H-TL-H, H-TL-T, H-TL-C), total words written (H-TWW-H, H-TWW-T, H-TWW-C), correct writing sequences (H-CWS-H, H-CWS-T, H-CWS-C), words spelled correctly (H-WSC-H, H-WSC-T, H-WSC-C), and readability (H-RI-H, H-RI-T, H-RI-C).
7. Transcriptional practice in the form of a typed copying task is expected to increase all typed product outcome variables on the AIMSweb Written Expression probe, from pretest to posttest, for participants in the typed group. Those variables are: word-level language (T-WL-T), sentence-level language (T-SL-T), text-level language (T-TL-T), total words written (T-TWW-T), correct writing sequences (T-CWS-T), words spelled correctly (T-WSC-T), and readability (T-RI-T).
8. There is expected to be a significant mean difference in all typed outcome variable scores from the AIMSweb probe between groups (handwriting, typing, control): word-level language (T-WL-H, T-WL-T, T-WL-C), sentence-level language (T-SL-H, T-SL-T, T-SL-C), text-level language (T-TL-H, T-TL-T, T-TL-C), total words written (T-TWW-H,

T-TWW-T, T-TWW-C), correct writing sequences (T-CWS-H, T-CWS-T, T-CWS-C), words spelled correctly (T-WSC-H, T-WSC-T, T-WSC-C), and readability (T-RI-H, T-RI-T, T-RI-C).

9. Research suggests handwritten texts are longer and of higher quality than typed texts (Connelly et al., 2007; Alves et al., 2016). There is expected to be a significant mean difference in all handwritten outcome variable scores compared to their corresponding typed outcome variable scores: word-level language (H-WL-H, T-WL-T), sentence-level language (H-SL-H, T-SL-T), text-level language (H-TL-H, T-TL-T), total words written (H-TWW-H, T-TWW-T), correct writing sequences (H-CWS-H, T-CWS-T), words spelled correctly (H-WSC-H, T-WSC-T), and readability (H-RI-H, T-RI-T).

CHAPTER III: METHODOLOGY

Participants and Setting

Sixty-six second-graders will be recruited from a Midwestern public elementary school. An email will be sent to classroom teachers (see Appendix A) seeking participation. The students will be enrolled in three different classrooms. Participating students must have the motor capabilities to compose text either by hand or with a computer and keyboard. An assessment of motor functioning is described below. Pretest and posttest assessments will be administered individually. Intervention will be delivered to the full class.

Measures

All participants will be administered pretest and posttest assessments of both transcriptional fluency and written product outcome variables. However, the intervention has been designed to target transcriptional fluency alone. A daily copying task will be introduced to target transcription skills. Past research suggests fluency of transcription allows for more attention to be allocated to other processes involved in writing (Berninger, Whitaker, Feng, Swanson, & Abbott, 1996; Berninger, 1999; Fayol, Christensen, 2004, Alamargot, & Berninger, 2012).

The assessments are as follows: a timed alphabet writing task, a timed sentence copying task, an AIMSweb Written Expression probe, and the Tapley and Bryden dot-filling task (see Appendix B). To ensure consistency between assessments and intervention, all text-based tasks (alphabet, sentence copying, and AIMSweb) will be administered in both modes of composition—once by composing on paper and separately on a computer. Children will compose on a QWERTY keyboard and Microsoft Word on a Microsoft Windows personal computer. In lieu of a Windows computer, any computer using Microsoft Word will be acceptable. However, one group will compose the intervention activity on paper and one group will compose the intervention activity on a computer. All participants in the control group will also be administered the text-based tasks in handwriting and typing modes. The control group will receive no intervention. The Tapley and Bryden dot-filling task, as an assessment of handedness and neuromotor functioning, can only be administered using pencil and paper, and will only be administered during pretest assessments.

Alphabet Writing Task

Each participant will be asked to produce as many letters in the alphabet in order as quickly and accurately as possible for 60 seconds (see Appendix C). Each participant will write letters continuously for 60 seconds—which may involve repeating the alphabet—but the researcher will mark the last letter written at 15 seconds. The number of correct letters obtained from the first 15 seconds correlates higher with other written outcomes than the number of letters obtained from 60 seconds (Berninger et al., 1992). This task has shown to have an interrater reliability score of .97 (Berninger et al., 1997). A letter is considered correct if it can be accurately identified outside of word context and the letter is not a reversal or inversion of another letter. If a letter is written out of alphabetic sequence, it is considered an error. Each participant will earn an alphabet writing task score (AT) for the number of correct letters written per minute, providing a measure of transcriptional fluency:

$$rate = \frac{correct\ letters}{minutes}$$

Sentence Copying Task

Each participant will be asked to copy a pangram as quickly and accurately as possible for 60 seconds (see Appendix D). A pangram is a sentence that includes at least one of every letter of the alphabet. Different pangrams will be used for the handwritten task and the typed task. The pangrams will be chosen from a list of 31-character pangrams (see Appendix E) retrieved from a blog entry (Rutter, 2014). The participant will copy the pangram continuously for 60 seconds, which may involve repeating the pangram. The researcher will record the number of correct letter sequences. A correct letter sequence is an instance in which there are no errors made between a pair of letters. For instance, the pangram "The quick brown fox jumps over the lazy dog." has 44 letter sequences. The example below uses carets to denote correct letter sequences:

^T^h^e^ ^q^u^i^c^k^ ^b^r^o^w^n^ ^f^o^x^ ^j^u^m^p^s^ ^o^v^e^r^ ^t^h^e^ ^l^a^z^y^ ^d^o^g.^

Because of capitalization and spelling errors, the following response has only 41 correct letter sequences:

_t^h^e^ ^q^u^i^c^k^ ^b^r^o_n^ ^f^o^x^ ^j^u^m^p^s^ ^o^v^e^r^ ^t^h^e^ ^l^a^z^y^ ^d^o^g.^

Each participant will earn a sentence copying task score (ST) for the number of correct letter sequences in 60 seconds, providing a per minute rate. This equation provides a measure of transcriptional fluency:

$$rate = \frac{correct\ letter\ sequences}{minutes}$$

AIMSweb Written Expression Probe

Each participant will be administered two AIMSweb Written Expression curriculum-based measures (Power-Smith & Shinn, 2004). The researcher will provide an oral prompt to guide each participant's writing. For example, the prompt might be, "If I were to make a TV show, it would be about …" Each participant will be given one minute to think about what he or she will write and three minutes to write a story based on the prompt. Different writing prompts will be used for the handwritten task and the typed task. Each of the participant's written products will result in seven written product outcome variable scores.

To measure word-level language (WL), a score will be assigned to word choice. To determine this, each word of each sentence will be coded on a 5-point scale. Each word will be assigned a score (1 through 5) based on how advanced the word is:

1 point: First-grade word
2 points: Second-grade word
3 points: Third-grade word
4 points: Fourth-grade word
5 points: Fifth-grade word

A list of vocabulary words outlined by Graham, Harris, and Loynachan (1993) will be used to assign scores (see Appendix F). The total word-level score for the text will be calculated by dividing the total number of points by the number of words in the text, resulting in an average:

$$mean = \frac{total\ points}{number\ of\ words}$$

To measure sentence-level language (SL), a score will be assigned to the complexity of the sentence structure. A coding rubric designed by Whitaker, Berninger, Johnson and Swanson (1994) will be used to assign scores (see Appendix G). The 5-point scale is as follows:

1 point: A sentence fragment, a phrase, or a sentence that does not make sense
2 points: An independent clause (simple sentence)
3 points: The use of a linking word when there is only one independent clause
4 points: The use of a linking word to join two independent clauses (compound sentence)
5 points: The use of a subordinate clause as well as independent clause (complex sentence)

Each sentence completed will be assigned a score, 1 through 5. The total raw score across all sentences will be divided by the number of sentences completed, providing an average to be used as a sentence-level score:

$$mean = \frac{total\ sentence\ score}{number\ of\ sentences}$$

A rubric designed by the same researchers (Whitaker et al., 1994) will be used to measure text-level language (TL). Whitaker and colleagues developed a 5-point scale to quantify the overall organization of a piece of writing (see Appendix G). Primary descriptions are as follows:

1 point: There is an unclear focus.
2 points: Sentences are listed on the topic.
3 points: Sentences are listed on the topic with at least two connectors between sentences.
4 points: There is a use of topic sentences with supporting detail, but no attention to order and/or a lack of transition from topic to topic.
5 points: There is a use of topic sentences with supporting detail, attention to order, and transitions either in the form of a new paragraph or a new topic sentence.

Each written product will yield an organizational score as a measure of text-level language.

The three standard AIMSweb measurements will provide scores for total words written (TWW), correct writing sequences (CWS), and words spelled correctly (WSC). These scoring guidelines provide a measure for general written expression used to compare scores to a normative sample (Power-Smith & Shinn, 2004). Based on research with third-grade participants, reliability scores range from .70 to .73 for TWW, .86 for CWS, and .76 to .78 for WSC (Shinn, 2012). In another study, validity scores were defined by correlation with SAT9 Language scores. In a sample of second-graders, TWW had a correlation of .24, CWS had a correlation of .57, and WSC had a correlation of .38 (Shinn, 2012).

First, the total number of words in the participant's story will be counted to provide a TWW score. Next, CWS will be counted. A correct writing sequence is an instance in which two adjacent writing units (words and punctuation) are correct within the context of the written product. For instance, the excerpt “The sky was blue. It was pretty.” has nine CWSs:

^The^sky^was^blue.^ ^It^was^pretty.^

Because of capitalization and punctuation errors, the following response has six CWSs:

^The^sky^was^blue.^ _it_was^pretty_

Each written product will receive a score for WSC, a measure of spelling.

Readability (RI) of the text will also be measured. The text will be analyzed to compute an Automated Readability Index score. The Automated Readability Index provides a grade-level score based on word difficulty (the average number of characters in each word) and sentence difficulty (the average number of words in each sentence):

$$grade\ level = 4.71(characters\ per\ word) + 0.5(words\ per\ sentence) - 21.43$$

Past research shows the Automated Readability Index has a high (r = .989) test-retest reliability score (Thomas, Hartley, & Kincaid, 1975).

Tapley and Bryden Dot-Filling Task

Each participant will be administered the Tapley and Bryden dot-filling task (Tapley & Bryden, 1985) to provide measures of both handedness and neuromotor function. The task requires the participant to fill in as many dots in a particular pattern as possible within 20 seconds. Each hand is tested. A measure of handedness is calculated by dividing the difference between right- and left-handed scores by the sum of right- and left-handed scores:

$$handedness = \frac{right - left}{right + left}$$

A score of -1.00 reflects a completely left-handed skill and a score of 1.00 reflects a completely right-handed skill. A study by McManus, Van Horn, and Bryden (2016) found a test-retest reliability correlation of 0.83. In terms of validity, the researchers found the Tapley and Bryden task correlates highly (r = 0.75) with a modified Edinburgh Handedness Inventory.

A neuromotor function measure, defined as accuracy in filling out dots, will also be taken. A score for neuromotor function is calculated by dividing the number of circles filled without marks going outside of the line by the total of circles attempted:

$$neuromotor\ function = \frac{dots\ contained\ in\ circles}{total\ circles\ attempted}$$

The measure will be used as a covariate to control for neuromotor function, an important contributor to low-level developmental skills involved in transcription (Berninger et al., 1992; Berninger, 1994).

Measurement Integrity

All pretest and posttest assessments will be administered and scored by a team of graduate clinicians trained by the researcher. Each clinician will demonstrate administration of each task (alphabet writing, sentence copying, AIMSweb probe, and Tapley and Bryden dot-filling task) without error before assessing participants. Appendix H provides a checklist of criteria that must be met. Integrity checks will be performed by the researcher on 20% of each clinician's scoring procedures.

Procedure

Pretest and Posttest Phases

Pretest and posttest assessments will be administered individually in a small, quiet room away from the participant's classroom. A graduate clinician trained in the appropriate procedures will sit across the table from the participant. The clinician will first administer the Tapley and Bryden dot-filling task, but only during the pretest assessment session. Next, the clinician will administer all text-based assessments (alphabet task, sentence copying task, and AIMSweb probe). Each task will be administered once with paper and pencil and separately on a laptop computer. The administration sequence will be counterbalanced. Half of the participants of each group will receive the handwritten battery first and the typed battery second. The other half will receive the typed battery first and the handwritten battery second.

Intervention Phase

For the intervention phase, the participants will be divided into three experimental conditions. One classroom will represent the handwriting group, a second classroom will represent the typing group, and a third classroom will represent the control group. In the handwriting group, the intervention task will be conducted with paper and pencil. In the typing group, the intervention task will be conducted on a computer. The control group will receive no intervention.

The intervention will consist of a daily copying task over eight weeks. Each day, Monday through Friday, the teachers of the handwriting and typing classrooms will project a pangram onto the screen at the front of the class. Teachers will be provided a script to read to their classes (see Appendix I). The participants will be asked to copy the pangram, in their assigned mode of composition, as many times as possible in five minutes. The teacher will time the task, saying "stop" after five minutes. The participants will copy a new pangram each day of the first week. The researcher will provide a new pangram each day for a total of five, 31-character pangrams (see Appendix E). The sequence, involving the same five pangrams, will be repeated each week. For instance, the pangram shown on Monday of the first week will be shown on each Monday throughout the intervention. Each day, each participant will turn in the copied pangrams to his or her teacher. The participants in the typing condition will submit a printed copy while those in the handwriting condition will submit their written product. Submissions will be gathered by the researcher at the end of each week.

To ensure treatment fidelity, each teacher will be trained to administer the pangram copying task. The researcher will provide a protocol, including a script to read to the class (see Appendix I). Training will be completed when the teacher successfully completes all steps on a checklist (see Appendix J) during a simulation. The same checklist will be used to evaluate treatment fidelity during the intervention phase. A member of the research team will observe implementation of the intervention on four different days for each teacher. The researcher will record whether the intervention is implemented properly, as outlined by the five criteria on a checklist. Each observed session will receive a fidelity rating based on the number of criteria met.

For each pangram submitted, a raw score will be recorded as the number of correct letter sequences. Fluency scores will be calculated by dividing the number of correct letter sequences by the number of minutes, providing a per minute rate. Data will be recorded for each participant and the scores will be used to find a mean fluency score for each group each day of the week. This variable will show whether the group, as a whole, is becoming more or less fluent in transcribing pangrams over the course of the week. The daily pangram copying submissions will be scored by trained graduate clinicians. Integrity checks will be performed by the researcher on 20% of each clinician's scoring procedures.

At the conclusion of the study, each teacher will be compensated for their efforts with a $25 Amazon gift card. Each teacher will also be debriefed. The researcher will send an email thanking each teacher and providing a brief explanation of the results. It will be left to the teacher's discretion whether he or she informs his or her students.

Data Analyses

The following analyses will be conducted to evaluate the stated hypotheses. The hypotheses can be categorized by either pertaining to transcriptional fluency or written product outcomes.

Transcriptional Fluency

The hypotheses regarding transcriptional fluency are as follows: handwriting practice will increase handwritten transcriptional fluency within the handwriting group, there will be a significant mean difference in handwritten transcriptional fluency between groups, typing practice will increase typing transcriptional fluency within the typing group, and there will be a significant mean difference in typing transcriptional fluency between groups.

A repeated-measures analysis of covariance (ANCOVA) will be performed to measure within-group differences to determine an effect of timing (between pretest and posttest) and between-group differences to determine an effect of condition (handwriting, typing, or control) for each transcriptional fluency variable: handwritten alphabet task, handwritten sentence task, typed alphabet task, and typed sentence task. Each analysis will also determine an interaction effect involving timing and condition. Scores obtained from the Tapley and Bryden dot filling task will be used as a covariate to control for neuromotor function. With a sample size of 66 participants across groups, an analysis with an alpha level of .05 and power of .80 can expect to detect a medium effect size of .4. Adjustments in alpha level for multiple comparisons will not be made. The number of comparisons made would result in overly conservative estimates (Perneger, 1998). If a significant interaction effect is found, further analysis will be performed.

Fisher's Least Significant Difference post hoc comparisons will be used to determine which group is significantly different than the others.

Written Product Outcomes

The hypotheses regarding written product outcomes are as follows: handwriting practice will increase handwritten product outcomes in the handwriting group, there will be a significant mean difference in handwritten outcome variables between groups, typing practice will increase typed product outcomes in the typing group, there will be a significant mean difference in typed outcome variables between groups, and there will be a significant mean difference in handwritten outcome variables compared to their corresponding typed outcome variables.

A repeated-measures ANCOVA will be performed to measure within-group differences to determine an effect of timing (between pretest and posttest) and between-group differences to determine an effect of condition (handwriting, typing, or control) for each written product outcome: word-level language (WL), sentence-level language (SL), text-level language (TL), total words written (TWW), correct writing sequences (CWS), words spelled correctly (WSC), and readability (RI). Each analysis will also determine an interaction effect between timing and condition. Scores obtained from the Tapley and Bryden dot filling task will be used as a covariate to control for neuromotor function. With a sample size of 66 participants across groups, an analysis with an alpha level of .05 and power of .80 can expect to detect a medium effect size of .4. Adjustments in alpha level for multiple comparisons will not be made. The number of comparisons made would result in overly conservative estimates (Perneger, 1998). If a significant interaction effect is found, further analysis will be performed. Fisher's Least Significant Difference post hoc comparisons will be used to determine which group is significantly different than the others.

A repeated-measures ANCOVA will also be performed to test the hypothesis of an interaction effect on written product outcome variables between handwritten and typed products. Scores obtained from the Tapley and Bryden dot filling task will be used as the covariate to control for neuromotor function. Separate analyses will be performed on seven measures obtained from AIMSweb probe written responses. Each handwritten variable in the handwriting group will be compared to each corresponding typed variable in the typing group. For instance, word-level language mean scores from either mode will be compared between groups (H-WL-H, T-WL-T). The same will follow for sentence-level language (H-SL-H, T-SL-T), text-level language (H-TL-H, T-TL-T), total words written (H-TWW-H, T-TWW-T), correct writing sequences (H-CWS-H, T-CWS-T), words spelled correctly (H-WSC-H, T-WSC-T), and readability (H-RI-H, T-RI-T). With a sample size of 44 participants across groups, an analysis with an alpha level of .05 and power of .80 can expect to detect a medium effect size of .45. Adjustments in alpha level for multiple comparisons will not be made for the reason stated above.

CHAPTER IV: RESULTS

Participants and Setting

The purpose of this study was to explore the effectiveness of handwriting and typing practice on a number of variables measuring transcriptional fluency (alphabet writing and sentence copying), written expression (total words written, correct writing sequences, words spelled correctly, word-level language, sentence-level language, and text-level language) and math computation. Data on handedness and neuromotor functioning were also gathered. All data were collected from three second-grade classrooms at a rural Midwestern elementary school.

Data collection took place on Oct. 4, 2019, (pretest) and Dec. 17, 2019 (posttest). Intervention sessions were held the weeks of Oct. 7 through Dec. 9. One classroom participated in a five-minute daily handwriting intervention for 40 days. A second classroom participated in a five-minute daily typing intervention for 40 days. A third classroom, serving as a control group, received daily instruction as usual. No intervention took place the week of November 25 (the week of Thanksgiving). Each of the two teachers who led the experimental classrooms were trained on implementing their respective interventions. Across four observations for each classroom, intervention integrity checks yielded 100% adherence.

Data were collected in two settings for both the pretest and posttest assessment batteries. In a change approved by the committee, assessment batteries were administered collectively to each class, rather than individually. All students in each class were administered handwritten assessments in their respective classrooms. In addition, all students were administered typed assessments in the school's computer lab. The intended sample size was 66 second-grade students: 22 from each of three classrooms. Due to unforeseen absences, data from 61 participants were collected. Data were collected from 19 participants in handwriting group, 22 participants in the typing group, and 20 participants in the control group. However, given that some students were absent for only one of the four data-collecting settings, the total number of participants from whom handwritten assessments were obtained (both pretest and posttest) equals 60 students. The total number of participants from whom typed assessments were obtained equals 58.

Each participant completed a short demographic survey. Out of the 61 participants, 33 (54.1%) were male and 28 were female (45.9%). At the beginning of the intervention, 43 (70.5%) were 7 years old and 18 (29.5%) were 8 years old. Regarding race, 58 (95.1%) identified as White, 2 (3.3%) identified as Hispanic, and 1 (1.6%) identified as multiracial.

Data Analysis Addenda

As originally outlined, the pretest and posttest data were to be analyzed using a measure of neuromotor function, as obtained from a dot-filling task, to serve as a covariate. A repeated-measures analysis of covariance (ANCOVA) was planned. However, for a variable to be used as a covariate, the variable must meet certain assumptions (Shavelson, 1995). Neuromotor function data, which was gathered from the Tapley and Bryden dot-filling task, violated the assumption of linearity: The regressions between the proposed covariate and dependent variables were not linear. For this reason, it was inappropriate to use neuromotor function as a covariate. As such, repeated-measures analysis of variance (ANOVA) was used in place of repeated-measures ANCOVA. The two factors in the original analysis remain the same. Means of outcome variables were compared within subjects (across time) and between subjects (between conditions). More importantly, the analysis also seeks to determine whether an interaction effect involving time and condition exists.

Assumption checks were performed to determine the appropriateness of the analyses. In general, there are three assumptions to consider when conducting ANOVAs: independence, normality, and sphericity. Each score was independent of the others, which fulfills the first requirement. To address the second assumption, tests of normality of residuals were conducted for each variable. One hundred and two samples were analyzed, which account for eight written scores taken in both the handwriting and typing modes at pretest and posttest. Another variable, math computation skills, was gathered at pretest and posttest, but only in the handwriting mode. Tests in these 34 separate samples were performed across the three experimental groups, resulting in 102 separate samples. Of these 102 samples, statistical significance ($p < .05$) suggesting non-normality was observed among 39 distributions. Given the nature of the overall sample, the lack of normality in these more narrowly defined groups is not overly concerning. A meta-analysis by Harwell, Rubinstein, Hayes, and Olds (1992) found that F tests common in educational and psychological research are relatively insensitive to violations of normality. Lastly, the tests of sphericity that accompany each ANOVA suggest the final condition was met for each variable.

While ANOVAs were used for most analyses, an ANOVA was found to be inappropriate for one analysis. The final hypothesis outlined in the proposal suggested written product outcome gains by the handwriting group on the handwritten assessment would be stronger than the gains by the typing group on the typed assessment. The data analysis to determine a significant difference was revised to an independent samples t-test comparing pretest-to-posttest mean difference scores between groups.

Among written product outcomes, one variable was removed from analysis. To measure readability, defined as a score generated from the Automated Readability Index, a text must comprise of at least 150 words. Analyses showed stories written by participants at pretest averaged 20.5 words when written by hand and 10.78 words when typed. As a result, it was not possible to calculate readability of participants' compositions accurately and the measurement was not analyzed.

Another written product outcome was altered. The original rubric was used to assess the quality of a letter, a type of composition different than that which was asked by the current study. In addition, the original rubric was written to assess the writing of students in middle school, an older sample than the sample in the current study. Based on the inadequacy of the rubric and the developmental level of the participants, the text-level language variable was reconfigured to better assess the overall coherence of a participant's composition. Each composition received a single text-level score on a scale from 0 to 3 (see Appendix K). Primary descriptions are as follows:

0 points: The response is not appropriate to the task.
1 point: The response is appropriate to the task.
2 points: Thoughts within the response share a similar theme.
3 points: Thoughts expressed in the response follow a logical, sequential order.

Lastly, a math computation variable was also analyzed after it was suggested during the study's original proposal. The task required participants to complete as many 1-by-1 addition and subtraction problems as possible in one minute. This variable was used to determine whether the handwriting intervention would result in improved math computation skills between groups from pretest to posttest.

Interrater/Interscorer Reliability

Three independent researchers scored all pretest and posttest assessments, and subsequent interscorer and interrater reliability was calculated for 20 percent of each group's products. After follow-up training and consulting was conducted until 100 percent agreement was found on pretest and posttest scores for all variables: alphabet task, sentence copying task, total words written, correct writing sequences, words spelled correctly, word-level language, sentence-level language, text-level language, math computation, handedness, and neuromotor functioning.

Analysis Results

Transcriptional Fluency

Hypotheses No. 1: There will be a Significant Mean Increase in Transcriptional Fluency as Measured by the Handwritten Alphabet Task Among Students Receiving a Handwriting Intervention Relative to Those Receiving a Typing Intervention or no Additional Instruction

Descriptive statistics of means and standard deviations for the three groups at both pretest and posttest are presented in Table 1. Findings suggest that scores on the alphabet task increased after a five-minute typing intervention over 40 days, but not in a way that was statistically significant between groups.

Table 1.

Means and Standard Deviations of the Handwritten Alphabet Task

Condition		Pretest	Posttest
	n	*M (SD)*	*M (SD)*
Handwriting	19	29.26 (13.6)	39.16 (17.11)
Typing	21	28.19 (9.67)	36.57 (14.44)
Control	20	31.2 (6.82)	41.4 (17.03)

The descriptive statistics for the repeated-measures ANOVA of the handwritten alphabet task are presented in Table 2. The main effect of time was significant, $F(1, 57) = 16.08, p < .01$. This result suggests a significant increase in alphabet writing across groups from pretest to posttest. The main effect of condition was not significant, $F(2, 57) = .78, p = .46$. The interaction effect of time and condition was not significant, $F(2, 57) = .06, p = .94$. A lack of interaction effect between time and condition suggests students who participated in the daily handwriting intervention did not improve their handwritten transcriptional fluency, as defined by scores on the alphabet task, significantly more than other students.

Table 2.

Analysis of Variance of the Handwritten Alphabet Task

Source	SS	df	MS	F	Sig.
Between subjects					
Condition	314.85	2	157.42	.78	.46
Error	11468.62	57	201.204		
Within subjects					
Time	2698.37	1	2698.38	16.08	.000
Time x condition	19.496	2	9.75	.06	.94
Error	9563.97	57	167.79		

Note. Alpha = .05

Hypotheses No. 2: There will be a Significant Mean Increase in Transcriptional Fluency as Measured by the Handwritten Sentence Copying Task Among Students Receiving a Handwriting Intervention Relative to Those Receiving a Typing Intervention or no Additional Instruction

Descriptive statistics of means and standard deviations for the three groups at both pretest and posttest are presented in Table 3. Findings suggest that scores on the sentence copying task increased after a five-minute typing intervention over 40 days, but not in a way that was statistically significant between groups.

Table 3.

Means and Standard Deviations of the Handwritten Sentence Copying Task

Condition		Pretest	Posttest
	n	*M (SD)*	*M (SD)*
Handwriting	19	31.63 (13.26)	48.21 (19.17)
Typing	21	27.33 (9.14)	38.24 (13.31)
Control	20	27.25 (12.35)	44.80 (13.72)

The descriptive statistics for the repeated-measures ANOVA of the handwritten sentence copying task are presented in Table 4. The main effect of time was significant, $F(1, 57) = 107.67$, $p < .01$. This result suggests a significant increase in sentence copying across groups from pretest to posttest. The main effect of condition was not significant, $F(2, 57) = 1.62$, $p = .21$. The interaction effect of time and condition was not significant, $F(2, 57) = 2.11$, $p = .13$. A lack of interaction effect between time and condition suggests students who participated in the daily handwriting intervention did not improve their handwritten transcriptional fluency, as defined by scores on the sentence copying task, significantly more than other students.

Table 4.

Analysis of Variance of the Handwritten Sentence Copying Task

Source	SS	df	MS	F	Sig.
Between subjects					
Condition	1016.32	2	508.16	1.62	.21
Error	17896.31	57	313.97		
Within subjects					
Time	6748.84	1	6748.84	107.67	.000
Time x condition	264.596	2	132.30	2.11	.13
Error	3572.70	57	62.68		

Note. Alpha = .05

Because of insignificant results on both handwritten transcriptional fluency measures, the null hypothesis could not be rejected, leading to the conclusion that a five-minute handwriting intervention over 40 days was not effective in increasing handwritten transcriptional fluency.

Hypotheses No. 3: There will be a Significant Mean Increase in Transcriptional Fluency as Measured by the Typed Alphabet Task Among Students Receiving a Typed Intervention Relative to Those Receiving a Handwriting Intervention or no Additional Instruction

Descriptive statistics of means and standard deviations for the three groups at both pretest and posttest are presented in Table 5. Findings suggest that scores on the alphabet task increased after a five-minute typing intervention over 40 days. In addition, alphabet task scores increased significantly between groups, supporting the hypothesis that the intervention would increase typed transcriptional fluency.

Table 5.

Means and Standard Deviations of the Typed Alphabet Task

Condition		Pretest	Posttest
	n	*M (SD)*	*M (SD)*
Handwriting	19	42.31 (20.88)	41.11 (22.34)
Typing	22	34.18 (17.79)	49.81 (18.13)
Control	17	45.18 (16.17)	42.59 (16.12)

The descriptive statistics for the repeated-measures ANOVA of the typed alphabet task are presented in Table 6. The main effect of time was not significant, $F(1, 55) = 2.19$, $p = .14$. The main effect of condition was not significant, $F(2, 55) = .10$, $p = .91$. The interaction effect of time and condition was significant, $F(2, 55) = 5.15$, $p = .01$. The eta squared effect size value ($\eta^2 = .16$) suggests a small effect. To follow up, a Fisher's LSD post hoc test was conducted, finding a significant mean difference in the typing group (M =15.64, SD = 4.3). The results suggest the improvement shown by the students in the typing group is statistically significantly higher than the improvement found in the other groups. The intervention was effective in increasing students' typed transcriptional fluency as defined by scores on the alphabet task.

Table 6.

Analysis of Variance of the Typed Alphabet Task

Source	SS	df	MS	F	Sig.
Between subjects					
Condition	99.44	2	49.72	.10	.91
Error	26832.38	55	487.86		
Within subjects					
Time	446.53	1	446.53	2.19	.14
Time x condition	2098.86	2	1049.43	5.15	.01
Error	11200.18	55	203.64		

Note. Alpha = .05

Hypotheses No. 4: There will be a Significant Mean Increase in Transcriptional Fluency as Measured by the Typed Sentence Copying Task Among Students Receiving a Typed Intervention Relative to Those Receiving a Handwriting Intervention or no Additional Instruction

Descriptive statistics, including means and standard deviations for the three groups at both pretest and posttest, are presented in Table 7 . Findings suggest that scores on the sentence copying task increased after a five-minute typing intervention over 40 days. In addition, sentence copying task scores increased significantly between groups, supporting the hypothesis that the intervention would increase typed transcriptional fluency.

Table 7.

Means and Standard Deviations of the Typed Sentence Copying Task

Condition		Pretest	Posttest
	n	*M (SD)*	*M (SD)*
Handwriting	19	15.68 (9.26)	19.32 (8.93)
Typing	22	17.05 (9.41)	30.09 (14.41)
Control	17	16.29 (5.13)	23.29 (8.33)

The descriptive statistics for the repeated-measures ANOVA of the typed sentence copying task are presented in Table 8. The main effect of time was significant, $F(1, 55)$ =

41.74, $p < .01$. This result suggests statistically significant improvement in copying skills across groups between pretest and posttest. The main effect of condition was not significant, $F(2, 55) = 2.54$, $p = .09$. The interaction effect of time and condition was significant, $F(2, 55) = 5.48$, $p < .01$. The eta squared effect size value ($\eta^2 = .17$) suggests a small effect. To follow up, a Fisher's LSD post hoc test was conducted. Significant mean differences were observed in the typing group (M =13.05, SD = 1.97) and the control group (M = 7.00, SD = 2.22). The results suggest the improvement shown by the students in the both the typing and control groups is statistically significant. The findings point to the typing intervention's influence in increasing typed transcriptional fluency as defined by scores on the sentence copying task. However, the post hoc analysis also found a significant increase among the students in the control group.

Table 8.

Analysis of Variance of the Typed Sentence Copying Task

Source	SS	df	MS	F	Sig.
Between subjects					
Condition	773.068	2	386.53	2.53	.09
Error	8446.99	55	153.58		
Within subjects					
Time	1786.38	1	1786.38	41.74	.000
Time x condition	468.77	2	234.39	5.48	.01
Error	2353.69	55	42.79		

Note. Alpha = .05

Because of significant results on both typed transcriptional fluency measures, the null hypothesis can be rejected, leading to the conclusion that a five-minute typing intervention over 40 days led to higher typed transcriptional fluency.

Written Product Outcomes

Hypotheses No. 5: There will be a Significant Mean Increase in Product Outcomes as Measured by Handwritten Total Words Written Among Students Receiving a Handwriting Intervention Relative to Those Receiving a Typing Intervention or no Additional Instruction

Descriptive statistics of means and standard deviations for the three groups at both pretest and posttest are presented in Table 9. Findings suggest that the handwriting group's total words written increased after a five-minute typing intervention over 40 days, but not in a way that was statistically significant between groups.

Table 9.

Means and Standard Deviations of Handwritten Total Words Written

Condition		Pretest	Posttest
	n	*M (SD)*	*M (SD)*
Handwriting	19	19.32 (8.80)	27.31 (9.45)
Typing	21	22.48 (13.39)	26.48 (11.52)
Control	20	19.55 (8.59)	31.50 (11.96)

The descriptive statistics for the repeated-measures ANOVA of the handwritten total words written variable are presented in Table 10. The main effect of time was significant, $F(1, 57) = 37.53$, $p < .01$. This result suggests significant improvement in total words written across groups between pretest and posttest. The main effect of condition was not significant, $F(2, 57) = .26$, $p = .77$. The interaction effect of time and condition was not significant, $F(2, 57) = 3.18$, $p = .05$. A lack of interaction effect between time and condition suggests students who participated in a five-minute handwriting intervention over 40 days did not improve the number of total words written on compositions.

Table 10.

Analysis of Variance of Handwritten Total Words Written

Source	SS	df	MS	F	Sig.
Between subjects					
Condition	95.13	2	47.57	.26	.77
Error	10461.16	57	183.53		
Within subjects					
Time	1908.82	1	1908.82	37.53	.000
Time x condition	323.82	2	161.91	3.18	.05
Error	2899.48	57	50.87		

Note. Alpha = .05

Hypotheses No. 6: There will be a Significant Mean Increase in Product Outcomes as Measured by Handwritten Correct Writing Sequences Among Students Receiving a Handwriting Intervention Relative to Those Receiving a Typing Intervention or no Additional Instruction

Descriptive statistics, including means and standard deviations for the three groups at both pretest and posttest, are presented in Table 11. Findings suggest that the handwriting group's correct writing sequences increased after a five-minute typing intervention over 40 days, but not in a way that was statistically significant between groups.

Table 11.

Means and Standard Deviations of Handwritten Correct Writing Sequences

Condition		Pretest	Posttest
	n	*M (SD)*	*M (SD)*
Handwriting	19	10.79 (7.28)	16.79 (9.56)
Typing	21	11.10 (9.80)	15.14 (9.73)
Control	20	10.75 (7.07)	17.85 (10.95)

The descriptive statistics for the repeated-measures ANOVA of the handwritten correct writing sequences variable are presented in Table 12. The main effect of time was significant, $F(1, 57) = 39.89$, $p < .01$. This result suggests significant improvement in correct writing sequences across groups between pretest and posttest. The main effect of condition was not significant, $F(2, 57) = .10$, $p = .91$. The interaction effect of time and condition was not significant, $F(2, 57) = 1.00$, $p = .37$. A lack of interaction effect between time and condition suggests students who participated in a five-minute handwriting intervention over 40 days did not improve the number of correct writing sequences on compositions.

Table 12.

Analysis of Variance of Handwritten Correct Writing Sequences

Source	SS	df	MS	F	Sig.
Between subjects					
Condition	28.80	2	14.40	.10	.91
Error	8240.62	57	144.57		
Within subjects					
Time	978.50	1	978.50	39.89	.000
Time x condition	49.12	2	24.56	1.00	.37
Error	1398.38	57	24.53		

Note. Alpha = .05

Hypotheses No. 7: There will be a Significant Mean Increase in Product Outcomes as Measured by Handwritten Words Spelled Correctly Among Students Receiving a Handwriting Intervention Relative to Those Receiving a Typing Intervention or no Additional Instruction

Descriptive statistics of means and standard deviations for the three groups at both pretest and posttest are presented in Table 13. Findings suggest that the handwriting group's words spelled correctly increased after a five-minute typing intervention over 40 days, but not in a way that was statistically significant between groups.

Table 13.

Means and Standard Deviations of Handwritten Words Spelled Correctly

Condition		Pretest	Posttest
	n	*M (SD)*	*M (SD)*
Handwriting	19	15.16 (8.67)	21.37 (8.67)
Typing	21	18.00 (13.11)	21.95 (10.55)
Control	20	15.05 (8.08)	24.40 (9.79)

The descriptive statistics for the repeated-measures ANOVA of the handwritten words spelled correctly variable are presented in Table 14. The main effect of time was significant, $F(1, 57) = 34.19$, $p < .01$. This result suggests significant improvement in words spelled correctly across groups between pretest and posttest. The main effect of condition was not significant, $F(2, 57) = .21$, $p = .83$. The interaction effect of time and condition was not significant, $F(2, 57) = 2.03$, $p = .14$. A lack of interaction effect between time and condition suggests students who participated in a five-minute handwriting intervention over 40 days did not improve the number of words spelled correctly on compositions.

Table 14.

Analysis of Variance of Handwritten Words Spelled Correctly

Source	SS	df	MS	F	Sig.
Between subjects					
Condition	66.98	2	33.49	.21	.83
Error	9317.32	57	163.46		
Within subjects					
Time	1267.06	1	1267.06	34.19	.000
Time x condition	150.14	2	75.07	2.03	.14
Error	2112.33	57	37.06		

Note. Alpha = .05

Hypotheses No. 8: There will be a Significant Mean Increase in Product Outcomes as Measured by Handwritten Word-Level Language Scores Among Students Receiving a Handwriting Intervention Relative to Those Receiving a Typing Intervention or no Additional Instruction

Descriptive statistics of means and standard deviations for the three groups at both pretest and posttest are presented in Table 15. Findings suggest that the handwriting group's word-level language scores did not increase after a five-minute typing intervention over 40 days.

Table 15.

Means and Standard Deviations of Handwritten Word-Level Language

Condition		Pretest	Posttest
	n	*M (SD)*	*M (SD)*
Handwriting	19	2.13 (.78)	2.05 (.30)
Typing	21	2.03 (.27)	1.98 (.37)
Control	20	1.93 (.33)	2.06 (.32)

The descriptive statistics for the repeated-measures ANOVA of the handwritten word-level language variable are presented in Table 16. The main effect of time was not significant, $F(1, 57) < .01$, $p = .98$. The main effect of condition was not significant, $F(2, 57) = .63$, $p = .54$. The interaction effect of time and condition was not significant, $F(2, 57) = .68$, $p = .51$. A lack of interaction effect between time and condition suggests students who participated in a five-minute handwriting intervention over 40 days did not improve word-level language, as defined as vocabulary sophistication, on compositions.

Table 16.

Analysis of Variance of Handwritten Word-Level Language

Source	SS	df	MS	F	Sig.
Between subjects					
Condition	.22	2	.11	.63	.54
Error	10.08	57	.18		
Within subjects					
Time	<.01	1	<.01	<.01	.98
Time x condition	.25	2	.13	.68	.51
Error	10.56	57	.19		

Note. Alpha = .05

Hypotheses No. 9: There will be a Significant Mean Increase in Product Outcomes as Measured by Handwritten Sentence-Level Language Scores Among Students Receiving a Handwriting Intervention Relative to Those Receiving a Typing Intervention or no Additional Instruction

Descriptive statistics of means and standard deviations for the three groups at both pretest and posttest are presented in Table 17. Findings suggest that the handwriting group's sentence-level language scores did not increase after a five-minute typing intervention over 40 days.

Table 17.

Means and Standard Deviations of Handwritten Sentence-Level Language

Condition		Pretest	Posttest
	n	*M (SD)*	*M (SD)*
Handwriting	19	1.96 (1.36)	1.75 (1.10)
Typing	21	1.75 (1.32)	1.66 (.83)
Control	20	2.05 (1.05)	1.75 (.85)

The descriptive statistics for the repeated-measures ANOVA of the handwritten sentence-level language variable are presented in Table 18. The main effect of time was not significant, $F(1, 57) = 1.10$, $p = .30$. The main effect of condition was not significant, $F(2, 57) = .32$, $p = .73$. The interaction effect of time and condition was not significant, $F(2, 57) = .11$, $p = .89$. A lack of interaction effect between time and condition suggests students who participated in a five-minute handwriting intervention over 40 days did not improve sentence-level language, as defined as sentence complexity, on compositions.

Table 18.

Analysis of Variance of Handwritten Sentence-Level Language

Source	SS	df	MS	F	Sig.
Between subjects					
Condition	.87	2	.44	.32	.73
Error	77.64	57	1.36		
Within subjects					
Time	1.16	1	1.16	1.10	.30
Time x condition	.238	2	.12	.11	.89
Error	60.58	57	1.06		

Note. Alpha = .05

Hypotheses No. 10: There will be a Significant Mean Increase in Product Outcomes as Measured by Handwritten Text-Level Language Scores Among Students Receiving a Handwriting Intervention Relative to Those Receiving a Typing Intervention or no Additional Instruction

Descriptive statistics of means and standard deviations for the three groups at both pretest and posttest are presented in Table 19. Findings suggest that the handwriting group's text-level language scores increased after a five-minute typing intervention over 40 days. In addition, text-language scores increased significantly between groups, partially supporting the hypothesis that the intervention would increase written product outcomes.

Table 19.

Means and Standard Deviations of Handwritten Text-Level Language

Condition		Pretest	Posttest
	n	*M (SD)*	*M (SD)*
Handwriting	19	1.26 (.73)	2.05 (.71)
Typing	21	1.71 (1.01)	1.38 (.80)
Control	20	1.50 (.69)	1.85 (.67)

The descriptive statistics for the repeated-measures ANOVA of the handwritten text-level language variable are presented in Table 20. The main effect of time was significant, $F(1, 57) = 4.22$, $p = .04$. The main effect of condition was not significant, $F(2, 57) = .28$, $p = .76$. The interaction effect of time and condition was significant, $F(2, 57) = 6.29$, $p < .01$. The eta squared effect size value ($\eta^2 = .18$) suggests a small effect. To follow up, a Fisher's LSD post hoc test was conducted, finding a significant mean difference in the handwriting group ($M = .79$, $SD = .23$). The results suggest the improvement shown by the students in the handwriting group is statistically significant, leading to the conclusion that a five-minute handwriting intervention over 40 days increased text-level language, as defined by overall coherence, on compositions.

Table 20.

Analysis of Variance of Handwritten Text-Level Language

Source	SS	df	MS	F	Sig.
Between subjects					
Condition	.39	2	.20	.28	.76
Error	40.23	57	.71		
Within subjects					
Time	2.16	1	2.16	4.22	.04
Time x condition	6.44	2	3.22	6.29	.003
Error	29.19	57	.51		

Note. Alpha = .05

Because of significant results on text-level language, the hypothesis that there would be a mean difference in written product outcomes between groups over time is partially supported. However, the hypothesis that the intervention would improve five other variables of written product outcomes (total words written, correct writing sequences, words spelled correctly, word-level language, and sentence-level language) is not supported. The intervention appears only to have improved the overall coherence of the students' compositions.

Hypotheses No. 11: There Will be a Significant Mean Increase in Product Outcomes as Measured by Typed Total Words Written Among Students Receiving a Typing Intervention Relative to Those Receiving a Handwriting Intervention or no Additional Instruction

Descriptive statistics of means and standard deviations for the three groups at both pretest and posttest are presented in Table 21. Findings suggest that the typing group's total words written increased after a five-minute typing intervention over 40 days, but not in a way that was statistically significant between groups.

Table 21.

Means and Standard Deviations of Typed Total Words Written

Condition		Pretest	Posttest
	n	*M (SD)*	*M (SD)*
Handwriting	19	11.95 (7.00)	14.05 (8.32)
Typing	22	9.68 (6.66)	11.59 (5.97)
Control	17	10.88 (5.71)	11.53 (4.82)

The descriptive statistics for the repeated-measures ANOVA of the typed total words written variable are presented in Table 22. The main effect of time was not significant, $F(1, 55) = 3.40$, $p = .07$. The main effect of condition was not significant, $F(2, 55) = .93$, $p = .40$. The interaction effect of time and condition was not significant, $F(2, 55) = .28$, $p = .76$. A lack of interaction effect between time and condition suggests students who participated in a five-minute typing intervention over 40 days did not improve the number of total words written on compositions.

Table 22.

Analysis of Variance of Typed Total Words Written

Source	SS	df	MS	F	Sig.
Between subjects					
Condition	120.56	2	60.28	.93	.40
Error	3583.24	55	65.15		
Within subjects					
Time	69.24	1	69.24	3.40	.07
Time x condition	11.20	2	5.60	.28	.76
Error	1120.75	55	20.38		

Note. Alpha = .05

Hypotheses No. 12: There will be a Significant Mean Increase in Product Outcomes as Measured by Typed Correct Writing Sequences Among Students Receiving a Typing Intervention Relative to Those Receiving a Handwriting Intervention or no Additional Instruction.

Descriptive statistics of means and standard deviations for the three groups at both pretest and posttest are presented in Table 23. Findings suggest that the typing group's correct writing sequences increased after a five-minute typing intervention over 40 days, but not in a way that was statistically significant between groups.

Table 23.

Means and Standard Deviations of Typed Correct Writing Sequences

Condition		Pretest	Posttest
	n	*M (SD)*	*M (SD)*
Handwriting	19	6.63 (5.89)	9.42 (7.77)
Typing	22	5.50 (5.06)	7.50 (5.76)
Control	17	6.06 (5.17)	5.53 (3.24)

The descriptive statistics for the repeated-measures ANOVA of the typed correct writing sequences variable are presented in Table 24. The main effect of time was not significant, *F*(1, 55) = 3.72, *p* = .06. The main effect of condition was not significant, *F*(2, 55) = .98, *p* = .38. The interaction effect of time and condition was not significant, *F*(2, 55) = 1.72, *p* = .19. A lack of interaction effect between time and condition suggests students who participated in a five-minute typing intervention over 40 days did not improve the number of correct writing sequences on compositions.

Table 24.

Analysis of Variance of Typed Correct Writing Sequences

Source	SS	df	MS	F	Sig.
Between subjects					
Condition	95.50	2	47.75	.98	.38
Error	2686.53	55	48.85		
Within subjects					
Time	57.83	1	57.83	3.72	.06
Time x condition	53.55	2	26.77	1.72	.19
Error	854.70	55	15.54		

Note. Alpha = .05

Hypotheses No. 13: There will be a Significant Mean Increase in Product Outcomes as Measured by Typed Words Spelled Correctly Among Students Receiving a Typing Intervention Relative to Those Receiving a Handwriting Intervention or no Additional Instruction

Descriptive statistics, including means and standard deviations for three groups at both pretest and posttest, are presented in Table 25. Findings suggest that the typing group’s words spelled correctly increased after a five-minute typing intervention over 40 days, but not in a way that was statistically significant between groups.

Table 25.

Means and Standard Deviations of Typed Words Spelled Correctly

Condition		Pretest	Posttest
	n	*M (SD)*	*M (SD)*
Handwriting	19	8.37 (6.38)	11.32 (7.86)
Typing	22	7.32 (6.22)	9.18 (5.59)
Control	17	7.88 (5.01)	8.00 (4.02)

The descriptive statistics for the repeated-measures ANOVA of the typed words spelled correctly variable are presented in Table 26.The main effect of time was significant, $F(1, 55) = 4.84$, $p = .03$. This result suggests significant improvement in words spelled correctly across groups between pretest and posttest. The main effect of condition was not significant, $F(2, 55) = .69$, $p = .50$. The interaction effect of time and condition was not significant, $F(2, 55) = 1.14$, $p = .33$. A lack of interaction effect between time and condition suggests students who participated in a five-minute typing intervention over 40 days did not improve the number of words spelled correctly on compositions.

Table 26.

Analysis of Variance of Typed Words Spelled Correctly

Source	SS	df	MS	F	Sig.
Between subjects					
Condition	78.01	2	39.01	.69	.50
Error	3092.69	55	56.23		
Within subjects					
Time	77.41	1	77.41	4.84	.03
Time x condition	36.36	2	18.18	1.14	.33
Error	879.65	55	15.99		

Note. Alpha = .05

Hypotheses No. 14: There will be a Significant Mean Increase in Product Outcomes as Measured by Typed Word-Level Language Scores Among Students Receiving a Typing Intervention Relative to Those Receiving a Handwriting Intervention or no Additional Instruction

Descriptive statistics of means and standard deviations for the three groups at both pretest and posttest are presented in Table 27. Findings suggest that the typing group's word-level language score did not increase after a five-minute typing intervention over 40 days.

Table 27.

Means and Standard Deviations of Typed Word-Level Language

Condition		Pretest	Posttest
	n	*M (SD)*	*M (SD)*
Handwriting	19	1.94 (.56)	2.25 (.43)
Typing	22	2.17 (.67)	1.99 (.88)
Control	17	2.17 (.36)	2.20 (.59)

The descriptive statistics for the repeated-measures ANOVA of the typed word-level language variable are presented in Table 28. The main effect of time was not significant, $F(1, 55) = .21$, $p = .65$. The main effect of condition was not significant, $F(2, 55) = .29$, $p = .75$. The interaction effect of time and condition was not significant, $F(2, 55) = 1.79$, $p = .18$. A lack of interaction effect between time and condition suggests students who participated in a five-minute typing intervention over 40 days did not improve word-level language, as defined as vocabulary sophistication, on compositions.

Table 28.

Analysis of Variance of Typed Word-Level Language

Source	SS	df	MS	F	Sig.
Between subjects					
Condition	.25	2	.13	.29	.75
Error	23.96	55	.44		
Within subjects					
Time	.07	1	.07	.21	.65
Time x condition	1.19	2	.60	1.79	.18
Error	18.32	55	.33		

Note. Alpha = .05

Hypotheses No. 15: There will be a Significant Mean Increase in Product Outcomes as Measured by Typed Sentence-Level Language Scores Among Students Receiving a Typing Intervention Relative to Those Receiving a Handwriting Intervention or no Additional Instruction

Descriptive statistics of means and standard deviations for the three groups at both pretest and posttest are presented in Table 29. Findings suggest that the typing group's sentence-level language score did not increase after a five-minute typing intervention over 40 days.

Table 29.

Means and Standard Deviations of Typed Sentence-Level Language

Condition		Pretest	Posttest
	n	*M (SD)*	*M (SD)*
Handwriting	19	1.77 (1.23)	1.83 (1.38)
Typing	22	1.68 (1.35)	1.48 (1.23)
Control	17	1.65 (1.04)	1.22 (.41)

The descriptive statistics for the repeated-measures ANOVA of the typed sentence-level language variable are presented in Table 30. The main effect of time was not significant, $F(1, 55) = .84$, $p = .36$. The main effect of condition was not significant, $F(2, 55) = .83$, $p = .44$. The interaction effect of time and condition was not significant, $F(2, 55) = .44$, $p = .65$. A lack of interaction effect between time and condition students who participated in a five-minute typing intervention over 40 days did not improve sentence-level language, as defined as sentence complexity, on compositions.

Table 30.

Analysis of Variance of Typed Sentence-Level Language

Source	SS	df	MS	F	Sig.
Between subjects					
Condition	2.53	2	1.27	.83	.44
Error	83.65	55	1.52		
Within subjects					
Time	1.04	1	1.04	.84	.36
Time x condition	1.09	2	.55	.44	.65
Error	67.95	55	1.24		

Note. Alpha = .05

Hypotheses No. 16: There will be a Significant Mean Increase in Product Outcomes as Measured by Typed Text-Level Language Scores Among Students Receiving a Typing Intervention Relative to Those Receiving a Handwriting Intervention or no Additional Instruction

Descriptive statistics of means and standard deviations for the three groups at both pretest and posttest are presented in Table 31. Findings suggest that the typing group's text-level language score did not increase after a five-minute typing intervention over 40 days.

Table 31.

Means and Standard Deviations of Typed Text-Level Language

Condition		Pretest	Posttest
	n	*M (SD)*	*M (SD)*
Handwriting	19	.84 (.60)	1.32 (.67)
Typing	22	.91 (.75)	1.18 (.59)
Control	17	1.24 (.90)	1.12 (60)

The descriptive statistics for the repeated-measures ANOVA of the typed text-level language variable are presented in Table 32. The main effect of time was not significant, $F(1, 55) = 3.98$, $p = .05$. The main effect of condition was not significant, $F(2, 55) = .27$, $p = .77$. The interaction effect of time and condition was not significant, $F(2, 55) = 2.54$, $p = .09$. A lack of interaction effect between time and condition suggests students who participated in a five-minute typing intervention over 40 days did not improve text-level language, as defined as overall coherence, on compositions.

Table 32.

Analysis of Variance of Typed Text-Level Language

Source	SS	df	MS	F	Sig.
Between subjects					
Condition	.34	2	.17	.27	.77
Error	35.11	55	.64		
Within subjects					
Time	1.26	1	1.26	3.98	.05
Time x condition	1.61	2	.81	2.54	.09
Error	17.43	55	.32		

Note. Alpha = .05

Cross-Modal Comparisons

Hypothesis No. 17: There will be a Significant Mean Increase in Handwritten Total Words Written Among Students Receiving a Handwriting Intervention Relative to Typed Total Words Written Among Students Receiving a Typing Intervention

Descriptive statistics of *t* scores and significance values are presented in Table 33. The results of a planned comparison suggested the gain in total words written on the handwritten assessment of 19 participants in the handwriting group ($M = 8.00$, $SD = 9.82$) was a significant increase over the contemporary gain on the typed assessment of 22 participants in the typing group ($M = 1.91$, $SD = 7.75$), $t(39) = 2.22$, $p = .02$ (one-tailed). Cohen's effect size value (d =

.69) suggests a moderate effect. Students who participated in a five-minute handwriting intervention over 40 days increased their total words written on handwritten compositions more than students who participated in an equivalent typing intervention increased on typed compositions.

Table 33.

T Scores and Significance of Cross-Modal Comparisons

Variable	*t*	*df*	*Sig.*
Total Words Written	2.22	39	.02
Correct Writing Sequences	1.68	39	.05
Words Spelled Correctly	1.92	39	.03
Word-Level Language	.31	39	.40
Sentence-Level Language	-.02*	39	.99
Text-Level Language	1.84	39	.04

Note. *Two-tailed

Hypothesis No. 18: There will be Significant Mean Increase in Handwritten Correct Writing Sequences Among Students Receiving a Handwriting Intervention Relative to Typed Correct Writing Sequences Among Students Receiving a Typing Intervention

The gain in correct writing sequences on the handwritten assessment of 19 participants in the handwriting group (M = 5.47, SD = 6.83) was not significantly different compared to the contemporary gain on the typed assessment of 22 participants in the typing group (M = 2.05, SD = 6.25), $t(39) = 1.68$, $p = .05$ (one-tailed). Students who participated in a handwriting intervention did not increase their correct writing sequences on handwritten compositions more than students who participated in an equivalent typing intervention increased on typed compositions.

Hypothesis No. 19: There Will be Significant Mean Increase in Handwritten Words Spelled Correctly Among Students Receiving a Handwriting Intervention Relative to Typed Words Spelled Correctly Among Students Receiving a Typing Intervention

The gain in words spelled correctly on the handwritten assessment of 19 participants in the handwriting group (M = 6.26, SD = 8.21) was a significant increase over the contemporary gain on the typed assessment of 22 participants in the typing group (M = 1.86, SD = 6.44), t(39) = 1.92, p = .03 (one-tailed). Cohen's effect size value (d = .60) suggests a moderate effect. Students who participated in a handwriting intervention increased their words spelled correctly on handwritten compositions more than students who participated in an equivalent typing intervention increased on typed compositions.

Hypothesis No. 20: There will be Significant Mean Increase in Handwritten Word-Level Language Scores Among Students Receiving a Handwriting Intervention Relative to Typed Word-Level Language Scores Among Students Receiving a Typing Intervention

The change in word-level language scores on the handwritten assessment of 19 participants in the handwriting group (M = -.08, SD = .90) was not significantly different than the contemporary change on the typed assessment of 22 participants in the typing group (M = -.18, SD = 1.15), t(39) = .31, p = .40 (one-tailed). Students who participated in a handwriting intervention did not increase their word-level language on handwritten compositions more than students who participated in an equivalent typing intervention increased on typed compositions.

Hypothesis No. 21: There will be Significant Mean Increase in Handwritten Sentence-Level Language Scores Among Students Receiving a Handwriting Intervention Relative to Typed Sentence-Level Language Scores Among Students Receiving a Typing Intervention

The change in sentence-level language scores on the handwritten assessment of 19 participants in the handwriting group (M = -.21, SD = 1.81) was not significantly different than the contemporary change on the typed assessment of 22 participants in the typing group (M = -.20, SD = 1.58), t(39) = -.02, p = .99 (two-tailed). Students who participated in a handwriting intervention did not increase their sentence-level language on handwritten compositions more than students who participated in an equivalent typing intervention increased on typed compositions.

Hypothesis No. 22: There will be Significant Mean Increase in Handwritten Text-Level Language Scores Among Students Receiving a Handwriting Intervention Relative to Typed Text-Level Language Scores Among Students Receiving a Typing Intervention

The gain in text-level language scores on the handwritten assessment of 19 participants in the handwriting group (M = .79, SD = .98) was a significant increase over the contemporary gain on the typed assessment of 22 participants in the typing group (M = .27, SD = .82), $t(39) = 1.84$, $p = .04$ (one-tailed). Cohen's effect size value (d = .57) suggests a moderate effect. Students who participated in a handwriting intervention increased their text-level language on handwritten compositions more than students who participated in an equivalent typing intervention increased on typed compositions.

Math Computation

Hypotheses No. 23: There will be a Significant Mean Increase in Math Computation as Measured by Math Scores Among Students Receiving a Typing Intervention Relative to Those Receiving a Handwriting Intervention or no Additional Instruction

Descriptive statistics of means and standard deviations for the three groups at both pretest and posttest are presented in Table 34. Findings suggest that the handwriting group's math computation scores increased after a five-minute typing intervention over 40 days, but not in a way that was statistically significant between groups.

Table 34.

Means and Standard Deviations of Math Computation

Condition		Pretest	Posttest
	n	*M (SD)*	*M (SD)*
Handwriting	19	12.95 (5.89)	18.26 (8.17)
Typing	21	10.76 (4.47)	13.19 (5.80)
Control	20	13.00 (5.77)	15.25 (5.00)

The descriptive statistics for the repeated-measures ANOVA of the math computation variable are presented in Table 35. The main effect of time was significant, $F(1, 57) = 30.54$, $p < .01$. This result suggests significant improvement in math skills across groups between pretest and posttest. The main effect of condition was not significant, $F(2, 57) = 2.25$, $p = .12$. The interaction effect of time and condition was not significant, $F(2, 57) = 2.65$, $p = .08$. A lack of interaction effect between time and condition suggests students who participated in a five-minute handwriting intervention over 40 days did not improve math composition scores.

Table 35.

Analysis of Variance of Math Computation

Source	SS	df	MS	F	Sig.
Between subjects					
Condition	267.56	2	133.78	2.25	.12
Error	3386.93	57	58.42		
Within subjects					
Time	332.402	1	332.402	30.54	.000
Time x condition	57.59	2	28.80	2.65	.08
Error	620.50	57	10.89		

Note. Alpha = .05

CHAPTER V: DISCUSSION

The current study sought to determine whether a brief daily intervention would be effective in improving two areas of writing: transcriptional fluency and written product outcomes. The results from a number of previous studies suggest increasing transcriptional fluency leads to greater access to language abilities, which results in improved written products (Berninger, 1999; Fayol et al., 2012; Christensen, 2004; Abbott & Berninger, 1993; Wicki et al., 2014). In addition, the current study sought to illuminate differences in gains between handwritten products and typed products. Previous studies suggest that handwriting holds learning advantages over typing (Longcamp et al., 2005; James, 2010).

Unlike previous research, the current study distilled the intervention to basic mechanical practice. One group of second-graders copied sentences five minutes a day for 40 days with paper and pencil. A second group copied the same sentences five minutes a day for 40 days using a keyboard and word processor. A third group received daily instruction as usual during this 40 day period.

Transcriptional Fluency

Handwritten Transcriptional Fluency Findings

The first two hypotheses posited that a five-minute daily handwriting intervention over 40 days would both increase those students' handwritten transcriptional fluency and do so significantly more than students who practiced typing or students who received no additional instruction. Improvements were observed, but the handwriting group's improvement was not better than that of the other groups. Unexpectedly, the control group improved slightly more than the handwriting group. On the surface, this finding is not consistent with previous research suggesting more practice handwriting increases handwritten transcriptional fluency (Tucha et al., 2008; Graham, Harris, & Fink, 2000; Santangelo & Graham, 2016). To help understand this, more context about the three classrooms is needed. It is possible that differences in the amount of time each classroom spent on handwriting outside of the intervention (especially the control group) may explain why the result was not consistent with previous research.

Before the intervention, each teacher completed a survey asking how much time their classes spent on handwriting, typing, and written expression instruction and practice in a typical week. They were also asked how much time is spent on writing across other classroom activities. Two of the three teachers completed the survey: the teacher of the typing group and the teacher of the control group. The questionnaire also revealed that the control group teacher reported spending more time on each of the categories than the typing group: handwriting (25 minutes a week compared to 15 minutes a week), typing (40 to 15), written expression (225 to 180), and writing in other activities (300 to 150). It is important to note that an absence of similar information from the handwriting group classroom makes any comparison among groups incomplete. Furthermore, there is no way to ensure these amounts of time stayed consistent after the classrooms began the intervention phase of the experiment. However, more time spent on handwriting and writing in other activities in the control group classroom might potentially render this study's results more ambiguous. Five minutes a day of handwriting, even an activity providing practice writing each letter, may not be enough to differentiate that classroom from the others. It is possible that, on average, the students in the control group spent the same amount of time as the handwriting group students—or even more time.

The true amount of time each classroom spent on handwriting throughout the week is unknown. The current results suggest that a five-minute intervention over 40 days was not effective in increasing students' transcriptional fluency beyond that of other second-grade students. However, a lack of consistency with previous research does not nullify those previous findings. More likely, a lack of consistency reveals possible shortcomings in the current study's experimental design. A more robust intervention, which would ensure more time spent handwriting compared to other groups, may produce results consistent with previous research. If fact, while the difference was not significant, there is some evidence that the group that practiced handwriting the most in their classroom (the control group) also increased its transcriptional fluency the most. What the current study adds to the body of research is that an intervention of five minutes a day for 40 days may not be enough.

Typed Transcriptional Fluency Findings

Two more hypotheses concerning transcriptional fluency posited that a five-minute daily typing intervention over 40 days would both increase those students' typed transcriptional fluency and do so significantly more than students who practiced handwriting or students who received no additional instruction. The results of the current study suggest the typing intervention, unlike the handwriting intervention, was effective in increasing transcriptional fluency.

Results clearly suggest that students who practiced typing every day became significantly more fluent at typing compared to their peers. Those students who spent time copying sentences increased their speed in finding the appropriate letter on the keyboard—whether the task was typing the alphabet or copying a sentence. These results are consistent with past research suggesting that practicing typing builds typed transcriptional fluency (Stevenson & Just, 2014), a concept that has more often been applied to handwriting and handwritten transcriptional fluency. It follows the general principle that suggests practicing a skill builds fluency in that skill (Haring & Eaton, 1978). The current research builds upon previous research by suggesting the same process is true for typing—and that a simple, five-minute daily activity is effective among second-graders.

It may be difficult to understand why the typing group showed such clear improvement in typed transcriptional fluency when the handwriting group did not show similar improvement in handwritten transcriptional fluency. The teacher survey results regarding time spent typing were similar to the same survey's results regarding time spent handwriting. The results suggested the control group classroom typically spent more time typing than the typing group classroom (40 minutes a week compared to 15 minutes a week) before the intervention was implemented. Like with handwriting, whether these amounts of time stayed consistent during the intervention phase of the experiment is unknown. What is known is that the typing group engaged in at least 25 minutes a week of typing.

Despite this possible disparity in overall time, the typing group's typed transcriptional fluency increased significantly when compared to the other two classrooms. Gains in typed transcriptional fluency were not found among the control group the same way handwritten transcriptional fluency gains were. One hypothesis to explain this difference is to suggest that the deliberate nature of the intervention made the typing group's typing time more robust than any time spent in the computer lab by the other groups. The process of copying sentences that contain every letter of the alphabet may have provided a structure to typing not otherwise experienced. This could be a more potent practice if students are at an earlier acquisition stage of the typing skill. Haring and Eaton (1978) have suggested that acquisition of a skill (like locating the appropriate keys on a keyboard) necessarily precedes fluent use of that skill. While students of this grade level have experienced a fair amount of writing by hand, especially in the school setting, it appears few had much experience using a keyboard. It is suggested that by second grade, students have acquired the skill of writing each individual letter, but haven't yet acquired the skill of locating each letter on the keyboard. If these two skill sets are at different acquisition levels, the effects of interventions targeting each mode can be expected to be different. An intervention addressing a skill in a lower acquisition phase, the typing intervention, can be expected to have a more powerful effect than an intervention addressing a skill in a higher acquisition phase. As such, nearly any amount of additional time spent typing, particularly an exercise that requires them to find and strike every letter of the alphabet, would be more beneficial to typing skills than the same amount of time spent handwriting would be to handwriting skills.

Written Product Outcomes

The current study also sought to answer whether handwriting and typing practice results in better written expression. Each participant was required to write two stories at pretest (one handwritten and one typed) and two stories at posttest. Story prompts were randomized across groups and tests. No group received the same prompt in any two settings. Data on a number of variables were then analyzed to detect significant effects across time and between groups. Significant interaction effects would indicate a particular intervention's effectiveness. However, larger increases by students who practiced handwriting and those who practiced typing were expected, in part, based on the expectation that those respective interventions would significantly increase those modes of transcriptional fluency.

Importantly, the experiment was designed in a way to measure possible increases in transcriptional fluency after intervention, and then to measure any increases in product outcomes that might follow. Following the hypotheses developed based on previous research, the increases in written product outcomes would be dependent on increases in transcriptional fluency. As explained above, the handwriting intervention was not found to improve handwriting transcriptional fluency compared to other groups. However, the typing intervention was effective in improving typing transcriptional fluency compared to other groups.

Handwritten Product Outcome Findings

A number of hypotheses posited that a five-minute daily handwriting intervention over 40 days would both increase those students' handwritten product outcomes and do so significantly more than students who practiced typing or students who received no additional instruction. Improvements were observed for four of six variables, but only one—text-level language—increased significantly compared to other groups. The intervention only contributed to higher overall coherence of the students' stories. Previous research has suggested an increase of transcriptional fluency results in the greater access to linguistic abilities, which leads to better compositions (Berninger, 1999; Fayol et al., 2012; Christensen, 2004; Abbott & Berninger, 1993; Wicki et al., 2014). The current findings are not consistent with previous research because the intervention did not lead to a statistically significant increase in transcriptional fluency. As a result, no connection between transcriptional fluency and compositional quality could be made. No statistically significant increase of handwritten transcriptional fluency among the handwriting group was observed. Because of this, the finding that the handwriting intervention led to more coherent stories does not directly complement previous research, but it does expand on it by detecting the improvement of compositional quality without the presence of more fluent writing mechanics.

It was unexpected to observe a significant increase in text-level language scores between groups. Each composition was assigned a score on a four-point scale to assess the overall coherence of the piece. Criteria included composing a story with multiple thoughts on the same topic and presenting them in a logical, sequential order. The results suggest the students who practiced handwriting wrote more coherent stories after the intervention. However, based on the lack of a significant increase in transcriptional fluency, it's difficult to understand why. If transcriptional fluency increased at the same rate among students in the handwriting group and the control group, it would be reasonable to expect similar increases in text-level language in both groups. However, that was not observed. The text-level language increase was only observed among the handwriting group.

As a result, it is plausible that other, unidentified variables influenced the handwriting group's growth in text-level language. The students in that group may have received more instruction from their teacher about writing a coherent story. It is possible that the teacher of that classroom spent more instructional time discussing how to express thoughts in a logical, sequential order when telling a story. It could be that the students in that class had more experience practicing this skill, resulting in more developed story-telling. It is also possible that the group's posttest writing prompt lent itself more to an orderly, coherent story. If the prompt elicits a more relatable circumstance, it is possible the students are more capable of generating a more coherent story.

Whatever the case may be, it is difficult to assign too much credit to the handwriting intervention because similar transcriptional fluency increases between groups did not result in similar text-level language increases between groups. If any credit can be given to the intervention, it must be given to some other, unexpected quality of the daily routine—and not its impact on transcriptional fluency. For instance, the practice of copying pangrams every day may have made the translation process more efficient without making the transcription piece more efficient. Berninger and colleagues (1992) suggest translation is at least a two-part process.

When language is formed in working memory, it is called text generation. When that language is transformed into graphic symbols of letters and words, it is called transcription. Past research acknowledges three constraints that hinder a person's potential written product (Berninger, 1994). The first type, neurodevelopmental constraint, refers to skills particularly essential to transcription: orthographic coding, neuromotor function, and visual-motor integration. The second type, linguistic constraint, refers to a person's capacity for language at the word, sentence, and text levels. The third constraint, cognitive constraint, refers to how attention and memory impact the planning and revision stages of writing. Past research has suggested that these cognitive processes do not appear to factor into the written products of early elementary school children (Berninger et al., 1991; Abbott & Berninger, 1993). The results of the current study may raise questions about the role of cognitive processes at this age. It could be possible that the intervention had an effect on loosening constraints on students' cognitive processes that inform planning and revision, thereby allowing for more coherent stories. There is evidence that the control group increased its handwritten transcriptional fluency more than the handwriting group. However, the students in the control group did not participate in the routine practice of copying specific sentences with every letter of the alphabet. Perhaps the daily task of writing specific sentences by hand lifted cognitive constraints, rather than neurodevelopmental constraints, toward higher quality stories.

None of the rest of the product outcomes among the handwriting group increased statistically significantly more than among other groups. AIMSweb variables of total words written, correct writing sequences, and words spelled correctly all increased, but not significantly compared to other groups. Word-level and sentence-level language scores decreased slightly. Presumably, these measures of written expression did not increase significantly between groups because the students' transcriptional fluency didn't increase significantly between groups. A lack of significant increases among these variables is not surprising, given the lack of increase in transcriptional fluency.

Typed Product Outcome Findings

A number of hypotheses posited that a five-minute daily typing intervention over 40 days would both increase those students' typed product outcomes and do so significantly more than students who practiced handwriting or students who received no additional instruction. Unlike the effects of the handwriting intervention on handwritten transcriptional fluency, results suggest the typing intervention significantly increased students' typed transcriptional fluency. Despite this, significant improvement in typed product outcomes was not observed.

The current study sought to examine whether the benefit of increased handwritten transcriptional fluency on handwritten product outcomes translated to typing and typed composition. The theory that greater transcriptional fluency results in the greater access to linguistic abilities, which lead to better compositions was applied (Berninger, 1999; Fayol et al., 2012; Christensen, 2004; Abbott & Berninger, 1993; Wicki et al., 2014). However, this benefit was not observed in any of the typed product outcomes. As a result, the current findings are not consistent with this principle of previous research, which would suggest such a benefit. The fact that increased typed transcriptional fluency was observed, but an increase to typed product outcomes was not, adds important information to the literature. In this study, more fluent typing did not result in higher quality compositions.

When reviewing AIMSweb variables, the handwriting group students, who did not practice typing, increased their total words written, correct writing sequences, and words spelled correctly more than either the typing or control groups. Importantly, the difference in gain was not statistically significant. The results suggest the typing intervention was not an effective treatment in increasing performance on AIMSweb probes.

The same trend was observed for the language-based measures. The handwriting group students increased their word-, sentence-, and text-level language scores more than either the typing or control group. This may make the result of the handwriting intervention on the handwriting group (a statistically significant improvement) more remarkable. This improvement by the handwriting group over the typing group suggests an advantage to additional handwriting practice, at least when students compose by hand. The same increase in story coherence on the students' compositions was not observed on typed stories.

Cross-Modal Comparisons

Another round of analyses sought to examine differences in written product outcomes across modes of composition. The gains among the handwriting group on the handwritten assessment were compared to the gains among the typing group on the typed assessment. Assuming both groups would increase in their respective modes, this analysis provides another way of comparing those improvements.

Six hypotheses posited that a five-minute daily handwriting intervention over 40 days would return greater gains on product outcomes on handwritten stories than a daily typing intervention would on typed stories. Significant differences were found when comparing total words written, words spelled correctly, and text-level language. For each variable, handwritten gains were statistically significantly higher than typed gains. Past research has suggested that handwriting, because of the neural pathways involved, holds learning advantages over typing (Longcamp et al., 2005; James, 2010). These studies examined early literacy skills, particularly letter learning. For instance, children who formed letters by hand more often recognized those letters later than children who typed the letters (Longcamp et al., 2008). The findings of the current study add to the literature by looking at more advanced literary skills. The statistical results suggest greater improvements in handwritten compositions than were observed in typed compositions.

An important caveat should be made. This hypothesis was developed with the expectation that the handwriting group would improve its handwritten transcriptional fluency significantly more than the other groups. This increase was not observed. There was no statistically significant increase between groups. The highest increase was observed in the control group, which also produced the highest gains in some product outcomes. Because this increase was higher than the increase of the handwriting group, there would also be a significant difference between the control group gain in handwritten variables and the typing group gain in typed variables. But that analysis is outside the scope of the outlined hypotheses. More importantly, the gains seen by the handwriting group on some handwritten product outcomes (total words written, words spelled correctly, text-level language) were stronger than the same gains by the typing group on typed product outcomes, despite the handwritten increase not being statistically significant between groups. This may suggest value to handwriting separate from the transcriptional fluency metric.

Regarding AIMSweb variables, increases to both total words written and words spelled correctly among those who practiced handwriting were significantly higher than increases by their typing counterparts. Gains in correct writing sequences were also stronger, but the difference was not significant. Overall, the findings suggest more potent results from the handwriting intervention. When making cross-modal comparisons, it is important to note that, across groups, students wrote more words on handwritten assessments than they did on typed assessments. Across groups, participants wrote an average of 20.5 words in their pretest handwritten stories. On their pretest typed stories, those same participants wrote an average of 10.78 words. However, not only were the total gains among the handwriting group higher, but the percent increases were stronger. Among students who practiced handwriting, a 41% increase was observed in total words written, a 56% increase was observed in correct writing sequences, and a 41% increase was observed in words spelled correctly. Among students who practiced typing, those increases were 20%, 36%, and 25%, respectively. The differences in gains by the handwriting group on handwritten assessments over the typing group on typed assessments is clear.

Examining language-based variables, changes in word-level language scores (vocabulary sophistication) and sentence-level language scores (sentence complexity) were not significantly different between groups. However, increases in the text-level language scores (story coherence) of handwritten compositions were stronger for students who practiced handwriting than increases in coherence of typed composition for students who practiced typing. This difference in improvement suggests more powerful results from the handwriting intervention. The text-level coherence scores were dependent on three criteria: appropriately responding to the prompt; including more than one thought with a similar theme; and expressing those thoughts in a logical, sequential order. The handwriting group improved this aspect of written expression more than the typing group. Even while handwriting transcriptional fluency didn't increase statistically significantly more than typing transcriptional fluency, the handwriting group witnessed greater whole-text improvement. This result suggests value to handwriting practice that isn't observed for typing practice.

Math Computation

At the proposal of this study, an assessment of math computation was added to the battery. As was suggested, if transcriptional fluency increases access to language ability, it may also increase access to computational ability. All participants were administered an assessment with 1-by-1 math problems, a mix of both addition and subtraction. These assessments were completed at pretest and posttest. Results show that scores across all groups increased, with the handwriting group showing the largest improvement. While the handwriting group's improvement was strongest, it was not statistically significantly different than the other groups. No intervention had a significant effect on math computation scores. Before the current study, no known research had examined the effects of handwritten (or typed) transcription on math computation skills. However, the results of this study offer little in the way of adding to the literature. Ultimately, without a significant increase in handwritten transcriptional fluency by the handwriting group, it is not surprising that a significant increase in math computation skills was not observed. It is possible that if a significant increase of transcriptional fluency is achieved, a significant increase in math computation skills would follow.

General Considerations

Limitations and Future Direction

The experimental design of the current study was developed to both measure potential effects of an intervention on transcriptional fluency and the following effects those increases in transcriptional fluency might have on written product outcomes. The second set of hypotheses were somewhat dependent on the success of first set of hypotheses. Unfortunately, the handwriting intervention was not found to have a statistically significant effect on handwritten transcriptional fluency. The typing intervention did, however, have a statistically significant effect on typed transcriptional fluency. Therefore, the most notable limitations of the current study may be associated with the handwriting intervention. Future research in this area would benefit from considering ways to strengthen the handwriting intervention.

Lessening Classroom Differences

The current study was designed to closely approximate how an intervention would be delivered in a school setting. It compared the effects of separate interventions for separate pre-determined populations—three second-grade classrooms, each with its own teacher. However, this design could not control for individual teachers' approaches to handwriting and typing outside of the intervention. One teacher may ask more handwritten products from his or her students. Another may require more typing. Another may spend more time on spelling or grammar. An alternate experimental design would find a way to assure more uniform instruction among participants. One option would be to use a random sample, in which all students across three classrooms where randomly assigned to one of three conditions. Although this would help guard against variance as a result of different instructional approaches by teachers, this design would pose more logistic complications, such as how to administer the intervention when each group is spread across multiple locations.

The strong increases in handwritten transcriptional fluency in the control group in the current study, along with results from a teacher survey, raise some questions about the disparity of classroom experiences. The improvement among students who received no additional instruction may indicate a difference in classroom attention to handwriting. Interestingly, if the control group classroom indeed spent more time practicing handwriting throughout the week, as the teacher survey results suggest, the general principle behind the original hypothesis would be supported. Mean increases among control group students were slightly higher than handwriting group mean increases. While it is impossible to support with the current data, that difference in time spent handwriting could account for the greater improvement in handwritten transcriptional fluency.

More Robust Intervention

One of the strengths of the current research is that is closely approximates how an intervention would be delivered in a school setting. Accordingly, the study was intentionally designed to test a simple intervention that could be easily implemented in a school. Participants were asked to copy a pangram as many times as they could for five minutes. One classroom completed the task with pencil and paper. Another classroom used a computer and keyboard. No other instructions were introduced. This simplicity may have come at a cost. The interventions may not have been potent enough to establish the expected effects. One way to make the intervention more robust, yet keep the focus on motor mechanics, would be to include demonstration of how to form the strokes of each letter. The corresponding typing intervention could include demonstration of where to find letters on a keyboard. Among the written products gathered from this study, there were plenty of examples of reversed or unidentifiable letters, which potentially affect the scores in a number of domains. Skinner (1998) noted the importance of frequency of responding across acquisition, fluency, maintenance, and generalization stages of learning. Proper demonstration of forming the letter and reinforcement of the correct letter should ensure more accurate transcription, and, in theory, faster responses. Before the copying intervention, participants could be instructed on the correct strokes for each letter—perhaps supplied with dotted-line traces of each letter. At least one study has shown that targeted instruction of how to write each letter improves handwriting fluency (Graham et al., 2000).

Participants could also be rewarded for more accurate completion of either task, as a way to reinforce the correct response.

More Time Engaged in Intervention

There are other ways to make the intervention more robust. One option is to add more time to the intervention. Instead of five minutes a day, the intervention could be doubled by including a second session elsewhere in the day. This may or may not be feasible based on a number of factors, including teachers' schedules and the accessibility of computers. In addition to increasing session length, another possibility would be to increase the number of intervention sessions. That is, the intervention could be continued for longer than 40 days while ensuring consistent implementation over the course of those days. One schedule-related limitation of the current study was the variability of the elementary school calendar. The intervention was scheduled from October to December and the participating school was not in session for four days the week of November 25 (the week of Thanksgiving). The students were only in school for a half-day on the Monday of that week. As a result, there was a full week in which the intervention was not implemented. On some other weeks, the teachers were not able to implement the intervention each of the five days. For instance, the typing group was not able to access the computer lab on more than one early-dismissal day. In addition, the teacher of the handwriting group reported not being able to find time—or simply forgetting—to implement the intervention.

Measuring Neuromotor Function

Other aspects of the current study could be adjusted or refined. Originally, the current study planned on using neuromotor function as a covariate, an approach that could have lent power to the data analysis. This dimension, which refers to the brain's ability to communicate with the hand toward using motor movements to form letters on a page, has been found to contribute to handwriting fluency (Berninger, 1999). However, neuromotor function has more often been measured by finger-tapping tasks. The reason for using the Tapley and Bryden dot-filling task was to find an assessment that could measure the same variable by using a movement more related to writing. Ultimately, the assessment did not yield results with a linear relationship to dependent variables, which violates the assumptions of a covariate. The data from the dot-filling task was not normally distributed, perhaps because the task was too difficult for second-graders. Going forward, in order to isolate neuromotor function, a more valid measure for this age group would need to be used.

Implications

This study provides valuable information about the effects of simple handwriting and typing practice. Three findings stand out among the others. First is the improvement of the coherence of handwritten stories found among those students who practiced handwriting. However, those students did not become more fluent in handwriting compared to their peers. This finding may suggest value to the handwriting intervention that is independent of transcriptional fluency. In addition, this finding, coupled with the null result of a measure among students who practiced typing on typed compositions, suggests language-based composition improvements exclusive to those who practice handwriting.

The second finding of particular interest is the strong improvement of typing fluency found among students who practiced typing. The results seem to confirm the effectiveness of simple, rote practice of typing when that skill is in the early acquisition phase. While the intervention improved transcriptional fluency of typing, this improvement in fluency did not translate into statistically significant increases in product outcomes. The implication of this finding is that more fluent typing does not result in higher quality typed compositions, which seemingly refutes an idea borrowed from the literature on handwriting transcriptional fluency and composition quality. Had the handwriting intervention in the current study yielded statistically significantly higher handwritten transcriptional fluency, the potential results could have been all the more informative.

Finally, the current study found gains on some variables (total words written, words spelled correctly, and text-level language) to be stronger within handwritten compositions by students who practiced handwriting compared to typed compositions by students who practiced typing. Even while increases in handwritten transcriptional fluency were not statistically significantly different between groups, significantly higher gains in these variables were observed in the handwriting group compared to the typing group—within compositions in their respective modes. The handwriting group wrote more words, spelled more words correctly, and wrote more coherent stories. Writing by hand resulted in better outcomes than writing by typing.

Overall, the current study provides a foundation in which to further explore simple school-based writing interventions for early elementary school students. It serves as a model in which to examine the effects of such interventions on both transcriptional fluency and a range of written product outcomes. In addition, the study compares writing in two modes, handwriting and typing, in ways novel to previous research. As a result, the current study's findings provide direction for how to refine research that might ultimately help students improve their writing.

REFERENCES

Abbott, R. D., & Berninger, V. W. (1993). Structural equation modeling of relationships among developmental skills and writing skills in primary-and intermediate-grade writers. *Journal of Educational Psychology*, *85*(3), 478.

Achieve, Inc. (2005). *Rising to the Challenge: Are High School Graduates Prepared for College and Work?* Washington, DC: Author.

Alves, R. A., Limpo, T., Fidalgo, R., Carvalhais, L., Pereira, L. Á., & Castro, S. L. (2016). The impact of promoting transcription on early text production: Effects on bursts and pauses, levels of written language, and writing performance. *Journal of Educational Psychology*, *108*(5), 665.

Berninger, V. W. (1999). Coordinating transcription and text generation in working memory during composing: Automatic and constructive processes. *Learning Disability Quarterly*, *22*(2), 99-112.

Berninger, V. W. (1994) *Reading and Writing Acquisition: A Developmental Neuropsychological Perspective.* Dubuque, IA: WCB Brown & Benchmark.

Berninger, V. W., Abbott, R. D., Swanson, H. L., Lovitt, D., Trivedi, P., Lin, S. J. C., ... & Amtmann, D. (2010). Relationship of word-and sentence-level working memory to reading and writing in second, fourth, and sixth grade. *Language, Speech, and Hearing Services in Schools*, *41*(2), 179-193.

Berninger, V. W., Fuller, F., & Whitaker, D. (1996). A process model of writing development across the life span. *Educational Psychology Review*, *8*(3), 193-218.

Berninger, V. W., Mizokawa, D. T., & Bragg, R. (1991). Scientific practitioner: Theory-based diagnosis and remediation of writing disabilities. *Journal of school psychology*, *29*(1), 57-79.

Berninger, V. W., Vaughan, K. B., Abbott, R. D., Abbott, S. P., Rogan, L. W., Brooks, A., Reed, E., & Graham, S. (1997). Treatment of handwriting problems in beginning writers: Transfer from handwriting to composition. *Journal of Educational Psychology*, *89*(4), 652.

Berninger, V. W., Vaughan, K., Abbott, R. D., Begay, K., Coleman, K. B., Curtin, G., ... & Graham, S. (2002). Teaching spelling and composition alone and together: Implications for the simple view of writing. *Journal of Educational Psychology*, *94*(2), 291.

Berninger, V. W., & Whitaker, D. (1994). Theory-based assessment and remediation of writing disabilities: An update. *Canadian Journal of School Psychology*, *9*(2), 150-156.

Berninger, V. W., Whitaker, D., Feng, Y., Swanson, H. L., & Abbott, R. D. (1996). Assessment of planning, translating, and revising in junior high writers. *Journal of School Psychology*, *34*(1), 23-52.

Berninger, V. W., & Winn, W. (2006). Implications of advancements in brain research and technology for writing development, writing instruction, and educational evolution. *Handbook of Writing Research*, 96-114.

Berninger, V. W., Yates, C., Cartwright, A., Rutberg, J., Remy, E., & Abbott, R. (1992). Lower-level developmental skills in beginning writing. *Reading and Writing*, *4*(3), 257-280.

Bingham, G. E., Quinn, M. F., & Gerde, H. K. (2017). Examining early childhood teachers' writing practices: Associations between pedagogical supports and children's writing skills. *Early Childhood Research Quarterly*, *39*, 35-46.

Brooks, A., Vaughan, K., & Berninger, V. (1999). Tutorial interventions for writing disabilities: Comparison of transcription and text generation processes. *Learning Disability Quarterly*, *22*(3), 183-190.

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

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

Cunningham, A. E., & Stanovich, K. E. (1990). Early spelling acquisition: Writing beats the computer. *Journal of Educational Psychology*, *82*(1), 159.

Cutler, L., & Graham, S. (2008). Primary grade writing instruction: A national survey. *Journal of educational Psychology*, *100*(4), 907.

Diamond, K. E., Gerde, H. K., & Powell, D. R. (2008). Development in early literacy skills during the pre-kindergarten year in head start: Relations between growth in children's writing and understanding of letters. Early Childhood Research Quarterly, 23, 467–478.

Espin, C. A., Weissenburger, J. W., & Benson, B. J. (2004). Assessing the writing performance of students in special education. *Exceptionality*, *12*(1), 55-66.

Fayol, M., Alamargot, M. D., & Berninger, V. (2012). *Translation of thought to written text while composing: Advancing theory, knowledge, research methods, tools, and applications*. Psychology Press.

Gerde, H. K., Bingham, G. E., & Wasik, B. A. (2012). Writing in early childhood classrooms: Guidance for best practices. *Early Childhood Education Journal*, *40*(6), 351-359.

Gerde, H. K., & Bingham, G. E. (2012, July). An examination of materials and interaction supports for children's writing in preschool classrooms. Paper presented at the Annual meeting of the Society for the Scientific Study of Reading. Montréal, Quebec.

Graham, S., Berninger, V. W., Abbott, R. D., Abbott, S. P., & Whitaker, D. (1997). Role of mechanics in composing of elementary school students: A new methodological approach. *Journal of educational psychology*, *89*(1), 170.

Graham, S., Harris, K. R., & Fink, B. (2000). Is handwriting causally related to learning to write? Treatment of handwriting problems in beginning writers. *Journal of educational psychology*, *92*(4), 620.

Graham, S., Harris, K.R. and Loynachan, C. (1993). The Basic Spelling Vocabulary List. *Journal of Educational Research, 86*(6) 363-368.

Haring, N. G., & Eaton, M. D. (1978). Systematic instructional procedures: An instructional hierarchy. *The fourth R: Research in the classroom*, 23-40.

Harwell, M. R., Rubinstein, E. N., Hayes, W. S., & Olds, C. C. (1992). Summarizing Monte Carlo results in methodological research: The one-and two-factor fixed effects ANOVA cases. *Journal of Educational Statistics*, 17(4), 315-339.

Hayes, J. R., & Flower, L. S. (1980). Identifying the organization of writing processes. In L. W. Gregg & E. R. Steinberg (Eds.), *Cognitive processes in writing*. Hillsdale, NJ: Erlbaum.

Hooper, S. R., Costa, L. J., McBee, M., Anderson, K. L., Yerby, D. C., Knuth, S. B., & Childress, A. (2011). Concurrent and longitudinal neuropsychological contributors to written language expression in first and second grade students. *Reading and Writing*, *24*(2), 221-252.

James K. H. (2010). Sensori-motor experience leads to changes in visual processing in the developing brain. *Developmental Science, 13*(2), 279-288.

James, K. H. (2017). The importance of handwriting experience on the development of the literate brain. *Current Directions in Psychological Science*, *26*(6), 502-508.

James, K. H., & Engelhardt, L. (2012). The effects of handwriting experience on functional brain development in pre-literate children. *Trends in neuroscience and education*, *1*(1), 32-42.

Jones, D., & Christensen, C. A. (1999). Relationship between automaticity in handwriting and students' ability to generate written text. *Journal of educational psychology*, *91*(1), 44.

Karimpoor, M., Churchill, N. W., Tam, F., Fischer, C. E., Schweizer, T. A., & Graham, S. J. (2018). Functional MRI of handwriting tasks: A study of healthy young adults interacting with a novel touch-sensitive tablet. *Frontiers in Human Neuroscience, 12*(30).

Kersey, A. J., & James, K. H. (2013). Brain activation patterns resulting from learning letter forms through active self-production and passive observation in young children. *Frontiers in Psychology*, *4*, 567.

Kiefer, M., Schuler, S., Mayer, C., Trumpp, N. M., Hille, K., & Sachse, S. (2015). Handwriting or typewriting? The influence of pen-or keyboard-based writing training on reading and writing performance in preschool children. *Advances in cognitive psychology*, *11*(4), 136.

Kim, Y. S. G., Gatlin, B., Al Otaiba, S., & Wanzek, J. (2018). Theorization and an empirical investigation of the component-based and developmental text writing fluency construct. *Journal of learning disabilities*, *51*(4), 320-335.

Kim, Y. S., Al Otaiba, S., Puranik, C., Folsom, J. S., Greulich, L., & Wagner, R. K. (2011). Componential skills of beginning writing: An exploratory study. *Learning and individual differences*, *21*(5), 517-525.

Klöppel, S., Vongerichten, A., van Eimeren, T., Frackowiak, R. S., & Siebner, H. R. (2007). Can left-handedness be switched? Insights from an early switch of handwriting. *Journal of Neuroscience*, *27*(29), 7847-7853.

Limpo, T., Alves, R. A., & Connelly, V. (2017). Examining the transcription-writing link: Effects of handwriting fluency and spelling accuracy on writing performance via planning and translating in middle grades. *Learning and Individual Differences*, *53*, 26-36.

Limpo, T., & Alves, R. A. (2013). Modeling writing development: Contribution of transcription and self-regulation to Portuguese students' text generation quality. *Journal of Educational Psychology*, *105*(2), 401.

Limpo, T., & Alves, R. A. (2018). Tailoring multicomponent writing interventions: Effects of coupling self-regulation and transcription training. *Journal of learning disabilities*, *51*(4), 381-398.

Longcamp, M., Boucard, C., Gilhodes, J., Anton, J., Roth, M., Nazarian, B., & Velay, J. (2008). Learning through hand- or typewriting influences visual recognition of new graphic shapes: Behavioral and functional imaging evidence. *Journal of Cognitive Neuroscience, 20*(5), 802-815.

Longcamp, M., Zerbato-Poudou, M. T., & Velay, J. L. (2005). The influence of writing practice on letter recognition in preschool children: A comparison between handwriting and typing. *Acta psychologica*, *119*(1), 67-79.

Malecki, C. K., & Jewell, J. (2003). Developmental, gender, and practical considerations in scoring curriculum-based measurement writing probes. *Psychology in the Schools*, *40*(4), 379-390.

McManus, I. C., Van Horn, J. D., & Bryden, P. J. (2016). The Tapley and Bryden test of performance differences between the hands: The original data, newer data, and the relation to pegboard and other tasks. *Laterality: Asymmetries of Body, Brain and Cognition*, *21*(4-6), 371-396.

Medwell, J., & Wray, D. (2008). Handwriting–A forgotten language skill? *Language and education*, *22*(1), 34-47.

Medwell, J., & Wray, D. (2014). Handwriting automaticity: the search for performance thresholds. *Language and Education*, *28*(1), 34-51.

National Center for Education Statistics. (2012). *The nation's report card: Writing 2011* (NCES 2012-470). Washington, DC: Institute of Education Sciences, U.S. Department of Education.

National Commission on Writing. (2003, April). *The neglected "R": The need for a writing revolution*. Retrieved April 23, 2008, from http://www.writingcommission.org/prod_downloads/writingcom/neglectedr.pdf

National Early Literacy Panel (NELP). (2008). *Developing early literacy: Report of the National Early Literacy Panel*. Washington, DC: National Institute for Literacy.

O'Mahony, P., Dempsey, M., & Killeen, H. (2008). Handwriting speed: duration of testing period and relation to socio-economic disadvantage and handedness. *Occupational Therapy International*, *15*(3), 165-177.

Palmis, S., Danna, J., Velay, J. L., & Longcamp, M. (2017). Motor control of handwriting in the developing brain: A review. *Cognitive neuropsychology*, *34*(3-4), 187-204.

Perneger, T. V. (1998). What's wrong with Bonferroni adjustments. *Bmj*, *316*(7139), 1236-1238.

Peverly, S. T. (2006). The importance of handwriting speed in adult writing. *Developmental Neuropsychology*, *29*(1), 197-216.

Phillips, J. G., Gallucci, R. M., & Bradshaw, J. L. (1999). Functional asymmetries in the quality of handwriting movements: A kinematic analysis. *Neuropsychology*, *13*(2), 291.

Planton, S., Longcamp, M., Péran, P., Démonet, J.-F., & Jucla, M. (2017). How specialized are writing-specific brain regions? An fMRI study of writing, drawing and oral spelling. *Cortex*, 88, 66–80.

Power-Smith, K. A., and Shinn, M. R. (2004). *Administration and Scoring of Written Expression Curriculum-Based Measurement (WE-CBM) for Use in General Outcome Measurement.* Retrieved from https://aimsweb.pearson.com

Santangelo, T., & Graham, S. (2016). A comprehensive meta-analysis of handwriting instruction. *Educational Psychology Review*, *28*(2), 225-265.

Schrank, F. A., Mather, N., & McGrew, K. S. (2014). *Woodcock-Johnson IV Tests of Achievement*. Rolling Meadows, IL: Riverside.

Shatil, E., Share, D. L., & Levin, I. (2000). On the contribution of kindergarten spelling to Grade 1 literacy: A longitudinal study in Hebrew. *Applied Psycholinguistics*, 21, 1–21.

Shavelson, R. J. (1995). *Statistical Reasoning for the Behavioral Sciences, Third Edition.* Neeham Heights, Massachusetts: Allyn & Bacon.

Shinn, M. R. (2012). *AIMSweb Technical Manual.* Retrieved from https://aimsweb.pearson.com

Skinner, C. H. (1998). Preventing Academic Skills Deficits. In T. S. Watson, F. M. Gresham (Eds.), *Handbook of Child Behavior Therapy.* (pp. 61-82).

Stevenson, N. C., & Just, C. (2014). In early education, why teach handwriting before keyboarding?. *Early Childhood Education Journal*, *42*(1), 49-56.

Stievano, P., Michetti, S., McClintock, S. M., Levi, G., & Scalisi, T. G. (2016). Handwriting fluency and visuospatial generativity at primary school. *Reading and Writing*, *29*(7), 1497-1510.

Thomas, G., Hartley, R. D., & Kincaid, J. P. (1975). Test-retest and inter-analyst reliability of the automated readability index, Flesch reading ease score, and the fog count. *Journal of Reading Behavior*, *7*(2), 149-154.

Tucha, O., Tucha, L., & Lange, K. W. (2008). Graphonomics, automaticity and handwriting assessment. *Literacy*, *42*(3), 145-155.

Ritchey, K. D., & Coker Jr, D. L. (2013). An investigation of the validity and utility of two curriculum-based measurement writing tasks. *Reading & Writing Quarterly*, *29*(1), 89-119.

Rutter, R. (2014, October 30). List of pangrams [Web log post]. Retrieved from http://clagnut.com/blog/2380

Van Galen, G. P. (1991). Handwriting: Issues for a psychomotor theory. *Human movement science*, *10*(2-3), 165-191.

Vlachos, F., & Bonoti, F. (2004). Handedness and writing performance. *Perceptual and motor skills*, *98*(3), 815-824.

Whitaker, D., Berninger, V., Johnston, J., & Swanson, H. L. (1994). Intraindividual differences in levels of language in intermediate grade writers: Implications for the translating process. *Learning and Individual differences*, *6*(1), 107-130.

Wicki, W., Lichtsteiner, S. H., Geiger, A. S., & Müller, M. (2014). Handwriting fluency in children. *Swiss journal of psychology*.

Wittenborn, J. R. (1946). Correlates of handedness among college freshmen. *Journal of Educational Psychology*, *37*(3), 161.

APPENDIX A: RECRUITMENT EMAIL

Classrooms will be recruited by emailing the teacher. The following email will be sent to second-grade teachers:

(Name of teacher),

I'm emailing you to see if you're interested in participating in a research study examining students' writing skills.

The study would involve a short, daily, classroom-wide intervention designed to increase students' transcriptional fluency—or how fast they can form letters and words.

If you'd like to hear more, I'd be happy to meet to explain the study further.

Thank you,

Brian Klein
Graduate clinician
Illinois State University

APPENDIX B: PRETEST AND POSTTEST ASSESSMENT BATTERY

Assessment	What it measures	How it's measured
Alphabet Task	1. Transcriptional fluency (Timed letter production)	Rate = (correct letters)/(minutes)
Sentence Copying Task	1. Transcriptional fluency (Timed correct letter sequence production)	Rate = (correct letter sequences)/(minutes)
AIMSweb Written Expression Probe	1. General outcome measures a.) Total words written b.) Correct writing sequences c.) Words spelled correctly	1. a.) Score = total words b.) Score = total correct writing sequences c.) Score = total words spelled correctly
	2. Text generation a.) Word level b.) Sentence level c.) Text level	2. a.) Mean = (total vocabulary score)/(total words written) b.) Mean = (total sentence complexity score)/(total sentences written) c.) Score = organizational score
	3. Readability	3. Score = Automated Readability Index score
Tapley and Bryden Dot-Filling Task	1. Handedness 2. Neuromotor functioning	1. Score = (right score − left score)/(right score + left score) 2. Score = (contained dots)/(total circles attempted)

APPENDIX C: ALPHABET WRITING TASK PROTOCOL

Handwriting condition

Materials:
Lined handwriting paper
Pencil
Stopwatch

Procedure:
Provide the child with the paper and pencil. Say “I want you to write as many letters of the alphabet as you can in one minute. Make sure to write them in order. Write them as quickly as you can without making mistakes. Are you ready? Go.” Mark the last letter completed at 15 seconds but let the participant continue until 60 seconds have passed. Say “stop” at 60 seconds.

Typing condition

Materials:
Computer with Microsoft Word
Stopwatch

Procedure:
Make sure a new Microsoft Word document is open. Say “I want you to type as many letters of the alphabet as you can in one minute. Make sure to type them in order. Type them as quickly as you can without making mistakes. Are you ready? Go.” Record the last letter completed at 15 seconds but let the participant continue until 60 seconds have passed. Highlight the last letter completed at 15 seconds and save the file.

APPENDIX D: SENTENCE COPYING TASK PROTOCOL

Handwriting condition

Materials:
Lined handwriting paper
Pencil
Stopwatch
Printed pangram

Procedure:
Provide the child with the paper and pencil. Say "I want you to copy this sentence as many times as you can in one minute. Write it as quickly as you can without making mistakes. If you finish the sentence before I say 'stop,' write it again. Are you ready? Go." Say "stop" at 60 seconds.

Typing condition

Materials:
Computer with Microsoft Word
Stopwatch
Printed pangram

Procedure:
Make sure a new Microsoft Word document is open. Say "I want you to copy this sentence as many times as you can in one minute. Type it as quickly as you can without making mistakes. If you finish the sentence before I say 'stop,' write it again. Are you ready? Go." Say "stop" at 60 seconds. Save the file.

APPENDIX E: LIST OF PANGRAMS

The following list of pangrams were obtained from a blog entry (http://clagnut.com/blog/2380). Each pangram is 31 characters long.

- Do wafting zephyrs quickly vex Jumbo?
- Fickle jinx bog dwarves spy math quiz.
- Public junk dwarves hug my quartz fox.
- Jumping hay dwarves flock quartz box.
- Five hexing wizard bots jump quickly.
- Quick fox jumps nightly above wizard.
- Vamp fox held quartz duck just by wing.
- Five quacking zephyrs jolt my wax bed.
- The five boxing wizards jump quickly.
- Jackdaws love my big sphinx of quartz.

APPENDIX F: WORD-LEVEL WRITTEN OUTCOMES VOCABULARY LIST

The following words will be used to score word-level written outcomes. The list was developed by Graham, Harris, and Loynachan (1993). A word will receive one point if it's in the first-grade list, two points if it's in the second-grade list, three points if it's in the third-grade list, four points if it's in the fourth-grade list, and five points if it's in the fifth-grade list. An unlisted word will receive five points.

First grade

a	fun	me	stop	cat	in	rat	box	him	out
all	get	mom	sun	come	into	red	boy	his	pan
am	go	my	ten	cow	is	ride	but	home	ran
and	good	no	the	dad	it	run	came	hot	pig
at	got	not	this	day	its	sat	can	I	so
ball	had	of	to	did	let	see	car	if	may
be	hat	oh	top	do	like	she	out	play	for
bed	he	old	toy	dog	look	sit	pan	up	one
big	hen	on	two	fat	man	six	pet	book	here

Second grade

about	bring	dress	foot	hit	looking	nine	room	still	want
add	brother	drive	four	hold	lost	north	said	store	warm
after	brown	drop	fox	hole	lot	now	same	story	wash
ago	bus	dry	from	hop	love	nut	sang	take	way
an	buy	duck	full	hope	mad	off	saw	talk	week
any	by	each	funny	horse	made	only	say	tall	well
apple	cake	eat	game	house	make	open	school	teach	went
are	call	eating	gas	how	many	or	sea	tell	were
as	candy	egg	gave	ice	meat	other	seat	than	wet
ask	change	end	girl	inch	men	our	seem	thank	what
ate	child	fall	give	inside	met	outside	seen	that	when
away	city	far	glad	job	mile	over	send	them	while
baby	clean	farm	goat	jump	milk	page	set	then	white
back	club	fast	goes	just	mine	park	seven	there	who
bad	coat	father	going	keep	miss	part	sheep	they	why
bag	cold	feed	gold	king	moon	pay	ship	thing	wind
base	coming	feel	gone	know	more	pick	shoe	think	wish
bat	corn	feet	grade	lake	most	plant	show	three	with
bee	could	fell	grass	land	mother	playing	sick	time	woke
been	cry	find	green	last	move	pony	side	today	wood
before	cup	fine	grow	late	much	post	sing	told	work

being	cut	fire	hand	lay	must	pull	sky	too	yellow
best	daddy	first	happy	left	myself	put	sleep	took	yet
bike	dear	fish	hard	leg	nail	rabbit	small	train	your
bill	deep	five	has	light	name	rain	snow	tree	zoo
bird	deer	fix	have	line	need	read	some	truck	
black	doing	flag	hear	little	new	rest	soon	try	
blue	doll	floor	help	live	next	riding	spell	use	
boat	door	fly	here	lives	nice	road	start	very	
both	down	food	hill	long	night	rock	stay	walk	

Third grade

able	believe	cover	flying	hurt	mean	pass	sew	stove	twelve
above	below	dark	follow	I'd	merry	past	shall	street	twenty
afraid	belt	desert	forest	I'll	might	penny	short	strong	uncle
afternoon	better	didn't	forgot	I'm	mind	people	shot	study	under
again	birthday	dinner	form	inches	money	person	should	such	upon
age	body	dishes	found	isn't	month	picture	sight	sugar	wagon
air	bones	does	fourth	it's	morning	place	sister	summer	wait
airplane	born	done	free	I've	mouse	plan	sitting	Sunday	walking
almost	bought	don't	Friday	kept	mouth	plane	sixth	supper	wasn't
alone	bread	dragon	friend	kids	Mr.	please	sled	table	watch
along	bright	draw	front	kind	Mrs.	pocket	smoke	taken	water
already	broke	dream	getting	kitten	Ms.	point	soap	taking	weather
also	brought	drink	given	knew	music	poor	someone	talking	we're
always	busy	early	grandmother	knife	near	race	something	teacher	west
animal	cabin	earth	great	lady	nearly	reach	sometime	team	wheat
another	cage	east	grew	large	never	reading	song	teeth	where
anything	camp	eight	ground	largest	news	ready	sorry	tenth	which
around	can't	even	guess	later	noise	real	sound	that's	wife
art	care	ever	hair	learn	nothing	rich	south	their	wild
aunt	carry	every	half	leave	number	right	space	these	win
balloon	catch	everyone	having	let's	o'clock	river	spelling	thinking	window
bark	cattle	everything	head	letter	often	rocket	spent	third	winter
barn	cave	eyes	heard	life	oil	rode	sport	those	without
basket	children	face	he's	list	once	round	spring	thought	woman
beach	class	family	heat	living	orange	rule	stairs	throw	won
bear	close	feeling	hello	lovely	order	running	stand	tonight	won't
because	cloth	felt	high	loving	own	salt	state	trade	wool
become	coal	few	himself	lunch	pair	says	step	trick	word
began	color	fight	hour	mail	paint	sending	stick	trip	working

begin	corner	fishing	hundred	making	paper	sent	stood	trying	world
behind	cotton	flower	hurry	maybe	party	seventh	stopped	turn	would
write	wrong	yard	yesterday	year	you’re				

Fourth grade

across	building	company	enjoy	good-by	known	pencil	remember	suit	trouble
against	built	couldn't	enough	group	laugh	picnic	return	sure	truly
answer	captain	country	everybody	happened	middle	police	Saturday	swimming	turtle
awhile	carried	discover	example	harden	minute	pretty	scare	though	until
between	caught	doctor	except	haven't	mountain	prize	second	threw	village
board	charge	doesn't	excuse	heavy	ninth	quite	since	tired	visit
bottom	chicken	dollar	field	held	ocean	radio	slowly	together	wear
breakfast	circus	during	fifth	hospital	office	raise	stories	tomorrow	we'll
broken	cities	eighth	finish	idea	parent	really	student	toward	whole
build	clothes	else	following	instead	peanut	reason	sudden	tried	whose
women	wouldn’t	writing	written	wrote	yell	young			

Fifth grade

although	attention	cousin	favorite	happiness	planet	probably	several
America	beautiful	decide	finally	important	present	problem	special
among	countries	different	future	interest	president	receive	suddenly
arrive	course	evening	happiest	piece	principal	sentence	suppose
surely	surprise	they’re	through	usually			

APPENDIX G: SENTENCE- AND TEXT-LEVEL WRITTEN OUTCOMES RUBRIC

The following rubric, developed by Whitaker and colleagues (1994), outlines point values for different sentence- and text-level criteria.

Sentence level

1 point: A sentence fragment, a phrase, or a sentence that does not make sense
2 points: An independent clause (simple sentence)
3 points: The use of a linking word when there is only one independent clause
4 points: The use of a linking word to join two independent clauses (compound sentence)
5 points: The use of a subordinate clause as well as independent clause (complex sentence)

Text level

1 point: There is an unclear focus.
The text is rambling.
The sentence structure may be complex, but thoughts wander.
There may be no resemblance to letter genre.

2 points: Sentences are listed on the topic.
There may be poor order.
There are few connectors or subordinate clauses used.

3 points: Sentences are listed on the topic with at least two connectors between sentences.
The order may be poor or there may be good chronological order, but no use of topic sentences.

4 points: There is a use of topic sentences with supporting detail, but no attention to order and/or a lack of transition from topic to topic.
There must be a letter format.

5 points: There is a use of topic sentences with supporting detail, attention to order, and transitions either in the form of a new paragraph or a new topic sentence.
The paragraphs are well elaborated.
There must be a letter format.

APPENDIX H: GRADUATE CLINICIAN TRAINING CHECKLIST

Proficiency of task administration is assessed based on meeting the criteria outlined below. A graduate clinician has mastered the administration of a task when he or she has met all criteria during a practice administration.

Clinician name: ____ Date: __________________

Observed task: ____

Proper task administered	Y / N
Instructions clearly provided	Y / N
Task timed correctly	Y / N
Task administered in correct mode of composition	Y / N

APPENDIX I: TEACHER INTERVENTION PROTOCOL

Handwriting condition

Materials:

Pangram
Projection screen or Smartboard
Stopwatch
Lined handwriting paper
Pencils

Procedure:

Each teacher will project the designated pangram onto the screen in front of the class. Pangrams will be named by the day in which they should be shown (Monday, Tuesday, Wednesday, Thursday, Friday).

Step 1:
The teacher will start by saying "I am going to show you a sentence. When I do, you are to begin copying the sentence. You are to copy the sentence as many times as you can in five minutes. If you finish with the sentence before I tell you to stop, write the sentence again. Write as quickly as you can without making mistakes. Are you ready?"

Step 2:
Once the pangram is projected on the screen, the teacher will say the following: "OK, begin." The teacher will begin timing.

Step 3:
The teacher will say "stop" at five minutes. The participants will turn their copies into the teacher.

Typing condition

Materials:
Pangram
Projection screen or Smartboard
Stopwatch
Laptop computers with Microsoft Word

Procedure:
Each teacher will project the designated pangram onto the screen in front of the class. Pangrams will be named by the day in which they should be shown (Monday, Tuesday, Wednesday, Thursday, Friday).

Step 1:
The teacher will start by saying “I am going to show you a sentence. When I do, you are to begin copying the sentence. You are to copy the sentence as many times as you can in five minutes. If you finish with the sentence before I tell you to stop, type the sentence again. Type it as quickly as you can without making mistakes. Are you ready?”

Step 2:
Once the pangram is projected on the screen, the teacher will say the following: “OK, begin.”

Step 3:
The teacher will say “stop” at five minutes. The participants will save or print their copies and turn them into the teacher.

APPENDIX J: INTERVENTION FIDELITY CHECKLIST

Intervention fidelity is assessed based on meeting the criteria outlined below. Observance of each criterion is worth 1 point. A fidelity score is calculated by dividing the number of points received by the number of total possible points.

The correct pangram is displayed on the screen.	0 / 1
The teacher reads the copying instructions.	0 / 1
The teacher begins timing the task.	0 / 1
The teacher stops the task at five minutes.	0 / 1
The teacher collects all submissions.	0 / 1
Total	

APPENDIX K: TEXT-LEVEL WRITTEN OUTCOME RUBRIC

Each composition will be assigned a text-level language score based on evidence of coherence. A scale from 0 to 3 will be used to determine the level of coherence. Ask the following questions when assessing each composition.

This assessment measures coherence of structure, not clarity of meaning. Issues of clarity affected by misspellings, syntactical errors, and semantic errors are not relevant. However, if no part of the composition past that which is provided by the prompt is understandable, the composition receives a zero.

0 points: Response is not appropriate to the task.

1 point: The response is appropriate to the task.

- Composition must reasonably connect to prompt.

2 points: Thoughts within the response share a similar theme.

- Composition must express more than one thought.
- Thoughts must share a similar theme.

3 points: Thoughts expressed in the response follow a logical order.

- Composition must express more than one thought.
- Thoughts must share a similar theme.
- Writing must have some semblance of sequence.