Impact of Language Complexity on Typing Speeds of School-Aged Children: A Pilot Study

by

Emily Staffiere

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Graduate Department of Applied Psychology and Human Development
University of Toronto

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Abstract

The present pilot study explored the impact of language complexity on students' typing speeds, measured in net characters per minute (CPM), and the relationship of typing speed to other academic skills. Students (N =28) in grades two through four were shown three standardized passages in succession and were given two minutes to copy each passage accurately. Each student was shown a passage at the grade one level, their previous grade level, and their current grade level. Passage difficulty only impacted net CPM produced by grade two students such that they typed more characters within the time limit when copying the grade one passage relative to the higher grades. A hierarchical regression demonstrated that typing performance was largely dependent on age, such that older students typed more than younger students. These findings will aid in the selection of appropriate text passages to include in a standardized measurement tool for typing fluency.

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Table of Contents

List of Tables

List of Figures

List of Appendices

Chapter 1
Writing Literature Review

1 The Process of Writing

Generating well-written text is a hallmark skill of everyday life. Not only does writing allow communication between people, but it is considered a foundational literacy skill that is essential for school, employment and daily living (Graham & Perin, 2007). When students are asked to complete a writing task, often the goal is for them to produce legible written communication in order to share their knowledge (Rogers & Case-Smith, 2002; Graham & Hebert, 2011). An area of focus in the writing literature is on low-level transcription skills that enable the physical production of written words (Hayes, 2012), a fundamental skill in a student's ability to produce text in written compositions.

1.1 Simple View of Writing

The current writing literature emphasizes the process of composing text, specifically how high-quality written text is produced and influenced by various cognitive and motor processes like fluency and revision (Berninger et al., 1996). The 'simple view of writing' (Berninger, 2000; Berninger & Graham, 1998; Berninger et al., 2002) describes a functional model of the writing process, in which writing is represented as a triangle within an environment of short-term, working and long-term memory. Transcription skills (the process of dictating language with written symbols) and executive functions (e.g. self-regulation) are the vertices of the triangle base that enable the overall goal of text generation (the process of idea conversion into language) at the top vertex (Berninger & Amtmann, 2003). This model supports the notion that text generation at the word, sentence, and discourse levels is influenced by lower level, less complex cognitive skills. It stipulates that the key instructional components for developing writing ability are transcription and self-regulation working together to enable text generation (Berninger et al., 2002). Text generation draws on both idea generation and translation, conceptualized as the active process of translating ideas into language representations in working memory including composing words, sentences, and passages (Berninger et al., 1992; Berninger & Graham, 1998). It encompasses fluency, quality, and discourse structures of written text (Berninger, 2000). Executive functions and self-regulation skills are understood as higher order processes that increasingly play a role in text generation and management of the writing process as they include planning, translating, reviewing and revising (Berninger & Amtmann, 2003). They enable strategic writing by allowing the writer to coordinate working memory, attention, inhibition, and attention shifting resources (Berninger et al., 2002; Berninger & Winn, 2006; McCutchen, 2000) in order to stay on task and logically denote their thoughts during the writing process (Berninger & Winn, 2006). Transcription skills provide the foundation for writing as they enable writers to translate their language representations into orthographic symbols using pencil, pen, or keyboard (Berninger et al., 1992; Berninger, 1999). This stage encompasses the student's ability to fluently and accurately produce letters and words via handwriting or keyboarding, as well as using appropriate and correct spelling conventions to translate language representations of ideas into written words on paper (Berninger & Graham, 1998; Berninger & Winn, 2006). Handwriting fluency, or the ability to write in an automatic way without thinking about the mechanics of how to form individual letters or how to join hand movements of frequently used letter combinations or syllables (Lichtsteiner et al., 2018), is one means of measuring transcription skill.

A student's handwriting or transcription fluency, often measured in the number of letters a student can write in thirty or sixty seconds (e.g. Puranik et al., 2017; Peverly et al., 2007), has been shown to relate to how well a student can write (Berninger, 2000; Jones & Christensen, 1999; Feng et al., 2019). Handwriting fluency predicts both writing quality and production even after controlling for gender and initial word-reading skills of students in kindergarten through grade one (Malpique et al., 2020). Together with spelling, transcription fluency predicts writing quality in elementary school-aged students (Graham et al., 1997). Fluency of alphabet writing has also been shown to predict whether a student will have difficulty with transcription skills (Berninger, 1999). In a recent meta-analysis, Kent and Wanzek (2016) confirmed significant, moderate correlations between individual component skills (handwriting fluency, spelling, reading and oral language) and students' writing quality, with the correlation between transcription skill and a student's quality of writing having an effect size of 0.49. Together with spelling, transcription fluency accounts for approximately 25% of the variance in student writing quality on standardized writing assessment measures (Kent & Wanzek, 2016).

1.1.1 Transcription Skills

Transcription skills are fundamental to a beginner writer's ability to convert ideas into written words on paper (Berninger & Amtmann, 2003). Various researchers have postulated that novice writers are limited in their overall writing skill due to a lack of automaticity in transcription skills (McCutchen, 2000; Berninger, 1999; Graham & Harris, 2000). Automaticity refers to a student's ability to execute cognitive tasks like writing quickly, accurately, efficiently, and without the need for allocated attention to the task (La Berge & Samuels, 1974). Automaticity implies that the execution of tasks or skills can occur without conscious thought so that other aspects of a task that demand more thought and effort can be undertaken. Cognitive Load Theory dictates that automaticity of skills is essential, as learners are only capable of attending to a limited number of cognitive tasks at one time and have limited capacity to process additional information (Paas & Ayres, 2014; Paas et al., 2004).

All components in the simple view of writing draw on a student's limited capacity of cognitive resources as they write (Connelly et al., 2007). An increase in effort required for one component will subsequently result in fewer resources available for other writing components (Berninger & Winn, 2006; Graham et al., 2017) as dictated by the Cognitive Load Theory (Paas & Ayres, 2014). In the framework of Berninger and Winn (2006), increased cognitive load toward transcription will subsequently weaken the student's ability to appropriately engage executive functions when writing. Additionally, when students struggle with transcription skills or have difficulty producing orthographic symbols, their development of text-generation is limited as the individual must allocate greater cognitive effort to physically producing letters and words due to a lack of handwriting automaticity (Lichtsteiner et al., 2018). Students with learning disabilities who experience difficulties acquiring basic writing skills typically produce work that contains many spelling, grammar and usage errors (Graham et al., 1993). Subsequently, they often experience subsequently poorer self-efficacy about their performance, which negatively affects their motivation to write and use writing as a means of expression. A lack of transcription fluency taxes a student's short-term working memory and overwhelms their processing demands for the writing task, resulting in poor text production (Berninger & Swanson, 1994; Jones & Christensen, 1999; Graham, 1990). Students will write simpler text and do not engage in as much planning or revision (Feng et al., 2019) when they are having to allocate more cognitive resources toward transcription processes. As low-level handwriting skills become fluent, they have less impact on cognitive load and thereby less impact on the student's expression of ideas in written text (Christensen & Jones, 2000). With automaticity students can focus working memory resources on idea generation, planning, monitoring and revisions (Bisschop et al., 2017).

Research has shown that explicit instruction of transcription skills enhances writing quality for students in grades one to three with an effect size (ES) of .55 (Graham et al., 2012), a relationship that holds true for students with and without learning disabilities. Transcription skills demonstrate moderate correlations with both the amount of writing produced by a student ($r = .48$; Graham et al., 2012) as well as the quality of their written narrative (Summer et al., 2013). By improving students' handwriting and spelling abilities, educators enable students to better allocate capacity-limited working memory resources toward higher-level writing skills to create higher-quality compositions (McCutchen, 2011; Berninger et al., 2002; Berninger & Winn, 2006; Berninger, 1999). They are subsequently able to engage in higher-order writing processes such as idea generation, vocabulary selection, composition and revision (Grabowski, 2010; Graham et al., 1997; Freeman et al., 2005). Students with poor handwriting skills often have overwhelming difficulty completing assignments and may avoid academic tasks all together, thus decreasing their overall school performance (Freeman et al., 2005). For these students who lack automaticity in their handwriting, word processors and keyboarding have been suggested as alternative means of producing written work by compensating for poor transcription fluency.

1.2 Keyboarding as a Means of Transcription

Keyboarding is becoming more available to students as a means to produce work through word processors (Rogers & Case-Smith, 2002; Donica et al., 2018). In the modern classroom, students are asked to produce both handwritten and computer-generated work making it increasingly important for students to develop keyboarding competency to complete tests and assignments successfully. With the increasing use of computers in the classroom, word processing has become a prevalent use of computers in schools across all grade levels and subject areas (Goldberg et al., 2003). In order to optimize student use of word processors there must be an understanding of the developmental trajectory of typing skill to facilitate instruction.

Keyboarding, or typing, is a learned skill that involves the integration of visual and kinesthetic feedback to locate and press keys on a keyboard to produce written work (Freeman et al., 2005).

This skill requires the individual to internalize motor sequences to build efficiency since keyboarding requires simultaneous fine control of fingers and the production of highly coordinated rapid movement sequences (Schmidt & Lee, 2011). Novice keyboarders spend a great deal of time focusing on key location rather than text composition (Connelly et al., 2007; Johansson et al., 2010; Ouellette & Tims, 2014) as they often employ the 'hunt and peck' method of visually locating keys and using one finger on one hand to press the keys (Hoot, 1986). They are "keyboard grazers" as they search for the right keys to press rather than placing their hands and fingers in a fixed position (Yechiam et al., 2003). Masterson and Apel (2006) argue that this grazing strategy sacrifices spelling accuracy in written work. A touch-typing method is thought to be a more efficient means of keyboarding as hands are placed in a fixed position on the keyboard as a starting point and the student then presses keys by utilizing all fingers without looking at the keyboard (Johansson et al., 2010). This method requires bimanual finger placement on home row keys and reliance on kinesthetic feedback rather than visually searching for keys (Freeman et al., 2005). Touch-typing enables the writer to read and type simultaneously as the need to visually look at key location is eliminated, allowing them to focus more on the content rather than the mechanics of writing. Consequently, their written output may be of better quality due to this automaticity (Alves et al., 2008; Christensen, 2004; Freeman et al., 2005; Johansson et al., 2010; Donica et al., 2018). Specifically, students may produce text that is more creative, includes more originality of ideas, is more organized and structured, has accurate spelling and grammar, incorporates elaboration of ideas, and is sensitive to the reading audience. The reduced reliance on visual cues in favor of muscle memory (Stevenson & Just, 2014; Gordon et al., 1994) enables students to dedicate cognitive resources toward content-related aspects of writing rather than the mechanics of pressing keys, as outlined by the Cognitive Load Theory (Paas & Ayres, 2014; Paas et al., 2004).

1.3 Similarities Between Means of Transcription

Both means of transcription, handwriting and keyboarding, produce written language by enabling motor mechanics that produce specific orthographic codes (Preminger et al., 2004). Handwriting involves the integration of visual-perceptual and fine motor skills to produce written letters and words (Exner, 1989), whereas keyboarding requires linear finger movements to press specific keys rather than letter strokes (Chwirka et al., 2002). Both means initially require visual feedback, for guidance of the pencil and for locating keys on the keyboard, respectively, but require the development of motor competence and motor learning to build skill proficiency (Connelly et al., 2007; Freeman et al., 2005; Rogers & Case-Smith, 2002; Preminger et al., 2004). They involve a sensory feedback system whereby students receive immediate feedback from touch, kinesthesia and motor memory, and vision (Stevenson & Just, 2014). As students build proficiency in handwriting and keyboarding motor memory takes over the role of vision, as fingers begin to print letters and locate commonly used keys automatically (Freeman et al., 2005; see Stevenson & Just, 2014 for a detailed explanation of the stages of motor learning for handwriting and keyboarding).

Handwriting speed is highly corelated with typing speed (Connelly et al., 2007), implying that strong handwriting skills can facilitate optimal typing speeds. A significant, low to moderate relationship has also been found between keyboarding speed and handwriting speed of upper-elementary school students (Kameda & Freeman, 2004; Preminger et al., 2004; Rogers & Case-Smith, 2002), as well as between keyboarding speed and handwriting legibility (Rogers & Case-Smith, 2002). Students who are good at handwriting often have greater speed when keyboarding. Freeman et al. (2005) reported a fair to moderate correlation between keyboarding speed acquisition and handwriting speed, suggesting good fine motor skills in handwriting promote the acquisition of keyboarding skills. Handwriting and keyboarding utilize similar underlying linguistic processes in the content of producing written work, such as planning, generating words, retrieving knowledge from long-term memory, orthographic coding and rapid automatized naming (Berninger et al., 2006). This is reflected in the strong relationship between orthographic-motor integration and the length and quality of young students' compositions written by hand and by typing (Christensen, 2004).

1.4 Advantages of Keyboarding

Some authors have argued that handwriting is advantageous to students' learning as writing movements have been shown to increase a student's letter recognition and memorization of letter forms (Longcamp et al., 2005) by linking visual processing with motor experience (James, 2017). Keyboarding changes the writing process from forming letters by hand to finding and selecting the right key on a keyboard (Berninger & Amtmann, 2003). This change in motor movements could subsequently reduce letter recognition since the trajectory in typing each word no longer depends on the specific relationship between a visual letter form and a movement to produce the letter (e.g. Gentner, 1983; Logan, 1999). The student must utilize spatial learning to build a cognitive map of the keyboard before they can build this proficiency.

On the other hand, several authors have suggested that keyboarding, or typing, is easier than handwriting as it does not require the student to utilize precise or complex motor planning skills to produce each individual letter (MacArthur, 1999; Preminger et al., 2004). The reduced physical demands of keyboarding at the level of each letter may allow a student to better concentrate on the content and quality of their work as a result of this simplified means of text production (MacArthur, 2000). Bisschop et al. (2017) found that for students with specific handwriting difficulties, keyboarding increased the rate of their alphabet production on a fluency task. Typing may subsequently enable the production of written work that is neater and more legible (Klein et al., 2003; MacArthur, 2000). Word processors also facilitate easier text revisions as students can add, modify, delete, or move ideas within their composition (Graham, 2008; MacArthur, 2006; Morphy & Graham, 2012) without needing to rewrite unedited text (Christensen, 2004). MacArthur, Graham and Schwartz (1991) found that when students with learning disabilities were asked to make handwritten drafts of their reports, they introduced additional errors in their writing that were accidental results of transcribing subsequent drafts. The authors postulated that difficulties with copying and handwriting mechanics introduce new errors that make students resistant to recopying their work. Written compositions have also been shown to be judged more harshly, regardless of content, when legibility is poor and there are frequent spelling errors (Graham & Hebert, 2011), which could have a further negative effect on students' outlook of writing and increase their resistance toward revising their work. Word processors may combat this resistance as they eliminate the potential for additional errors produced in the process of making handwritten drafts due to poor transcription skills, in addition to facilitating higher-order revisions such as moving content, deleting material and including additional pieces of story content (MacArthur et al., 1991). Only when keyboarded compositions contain a large number of errors will the overall legibility of a typed piece be impacted (Freeman et al., 2005), increasing the student's likelihood of producing legible written work. Consequently, the student who has poor transcription skills may feel more confident and motivated to complete written work by typing as they experience success (Freeman et al., 2005; Morphy & Graham, 2012). Students also consider word processors as preferred writing as the motor requirements for typing are less demanding than intricate handwriting skills (Christensen, 2004).

Meta-analyses of writing instruction have found moderately positive effects of word processors on the quality of written work, with larger effects for low-achieving and struggling students (MacArthur, 2009). Results generally demonstrate advantages for word processors over handwriting with regard to number of words written, number of edits made and quality of writing (Goldberg et al., 2003; Hunter et al., 1990). Bangert-Drowns (1993) reported that word processing, when compared to handwriting, had a statistically significant and positive effect on both writing output (ES = 0.52) and writing quality (ES = 0.27) for students in elementary school through college. Goldberg, Russell and Cook (2003) found similar results for students in kindergarten to grade 12, such that word processors significantly improved writing output (ES = 0.50) and writing quality (ES = 0.41) over writing by hand. Students wrote longer texts that were of greater quality using a word processor. Graham and Perin (2007) reported that for students in grades 4 through 12, word processors had a significantly greater impact on writing quality (ES = 0.55) than writing by hand. This effect held true for students who experience difficulty learning to write (Morphy & Graham, 2012), such that word processing had significant positive effects on their writing in terms of improved length, development and organization, quality of text and reduced number of mechanical errors. The ES for writers in general was found to be at roughly 0.51 but increased to 0.70 for low-achieving students (Graham & Perin, 2007). Most recently, a meta-analysis by Graham et al. (2012) found positive effects for the use of a word-processor on the quality of typed compositions for students in elementary school. However, several authors have stated that keyboarding training and instruction is necessary in order for students to develop computer literacy and utilize word processing to its fullest potential (Margalit & Roth, 1989).

1.5 Keyboarding Instruction

Research indicates that the hinderance to writing quality resulting from poor automaticity in generating letters and words, holds true for both handwriting and keyboarding as modes of transcription (Berninger, 2000; Bourdin & Fayol, 1994; Connelly et al., 2007; Hayes & Chenoweth, 2006). Twenty-five percent of the variance in writing quality for students in primary grades and forty-two percent of the variance for intermediate grades can be explained by lower-order skill fluency (e.g. handwriting and spelling; Berninger, 1999; Graham, 1990). To reduce the constraints on cognitive load due to poor transcription skills, it is imperative that students first develop keyboarding fluency (Connelly et al., 2007). The literature has shown that direct instruction for handwriting and keyboarding, aimed at improving writing fluency and the physical mechanics of producing text, increases a student's quality of written work (Berninger, 1999; Graham et al., 1997; Hayes & Chenoweth, 2006; Puranik & Al Otaiba, 2012). Some consider the possibility that writers could input text without formal typing instruction and develop a system that results in keyboard efficiency (Grabowski, 2008). However, systematic instructional processes are considered more effective in helping students develop automaticity earlier in their educational careers so that they may reap the benefits to their written work from a young age (Poole & Preciado, 2016). There is little evidence amongst the literature in support of specific, outlined approaches that effectively help students develop tying skills (Donica et al., 2018). This is complicated by the fact that comparisons between keyboarding instruction methods is difficult due to the wide variety of age groups and methods of instruction that are examined across studies (Freeman et al., 2005).

The general consensus throughout the literature maintains that students are less likely to attain proficient typing speeds unless they receive instruction and utilize the touch-typing technique to facilitate keyboarding competency (Freeman et al., 2005; Connelly et al., 2007). Without instruction students produce fewer typed characters and subsequently poorer essays when keyboarding then handwriting (Connelly et al., 2007). There is support for the use of a developmentally based, comprehensive keyboarding curriculum to build keyboarding skill proficiency in students (Ashburner et al., 2012; Preminger et al., 2004; Donica et al., 2018). For instance, students in grades three through five who participated in Keyboarding without Tears® (KWT), a developmental based curriculum for keyboarding skills, for one full school year demonstrated increases of six keyboarded net word per minute (WPM) pre-test to post-test (Donica et al., 2018). This increase was significantly larger than the improvement seen in net WPM for the control students who used free web-based activities to learn keyboarding skills (Donica et al., 2018). The touch-typing technique taught in programs like KWT® integrates cognitive, affective, and psychomotor skills, a combination likely optimized by participating in formal instruction on typing skill (Fleming, 2002; Posnick-Goodwin, 2016). Van Weerdenburg et al. (2018) also examined the effect of a touch-typing intervention on typing, spelling, and narrative-writing skills among students in grades four to six. They found positive correlations between typing skill and students' spelling and narrative-writing skills for keyboarded pieces after receiving instruction. However, there are several foundational inconsistencies within the literature for typing instruction. The number of hours of keyboarding instruction across the literature ranges from five to thirty hours ($M = 12.8$), the frequency of instruction ranges from two to five sessions per week ($M = 4.1$) and the recommended length of each instruction session ranges from twenty to forty-five minutes ($M = 30.2$; Freeman et al., 2005). In the discussions of recent keyboarding publications between 25 to 30 hours of total instruction were typically recommended, although these claims were made with limited research support (McLean, 1995).

1.5.1 Gaps in the Literature on Keyboarding Instruction

It is critical to determine the specific components of instruction programs that effectively teach keyboarding skills given the increasing use of computers in the classroom for assignments, note-taking, and assessments (Poole & Preciado, 2016; Donica et al., 2018). Doing so directly relates to the feasibility of typing skill acquisition, with implications for the grade level at which to provide instruction (Freeman et al., 2005). Poole and Preciado (2016) found that teachers reported several barriers to the instruction of touch-typing skills in the curriculum, highlighting the need to develop and optimize keyboarding instruction. These barriers included limited available classroom time for instruction, insufficient student access to technology, and lack of knowledge of touch-typing instruction. Unfortunately, the considerable range of keyboarding instruction programs that rely on the assumption that touch-typing is the most effective method of achieving typing speed proficiency are each inconsistently supported by research (Freeman et al., 2005), making any general conclusions difficult. Authors have agreed though that keyboarding instruction must be incorporated with sufficient practice opportunities to facilitate the development of proficiency for students struggling with handwriting skills (Freeman et al., 2005; MacArthur, 2009).

It is difficult to anticipate whether skills associated with keyboarding and handwriting individually also allow students to attain similar keyboarding and handwriting speeds due to a lack of studies that examine correlations between typing skill and other academic skills (Freeman et al., 2005). There has been evidence to show that a relationship between handwriting and letter recognition exists, such that the motor learning of handwriting helps students memorize and learn letter forms (Longcamp et al., 2005) and facilitates handwriting automaticity when letter recognition is fluent (Fears & Lockman, 2018). Subsequently, there have been implications for reading ability in that handwriting letters facilitates the recruitment of letter processing neural networks (James, 2017) such that handwriting automaticity can predict reading performance (Malpique et al., 2020). With explicit handwriting training, both writing and reading improves with regards to faster written letter rates, more correctly written words, and increased ability to read and understand text (Semeraro et al., 2019). Learning through typing has shown not to recruit the letter processing neural network to the same extent (James, 2010; James & Engelhardt, 2012), but research examining the relationship between typing and reading ability is lacking due to unstandardized methods of assessing typing skill.

A major point of contention is the grade at which to introduce typing instruction. Some have stated that early elementary students have the potential to develop higher-level keyboarding style (Chwirka et al., 2002; MacArthur, 2009) and should be introduced to typing as early as possible to eliminate the habituation of hunt and peck methods (Berninger & Amtmann, 2003). Others suggest that younger students require more time and supervision to build proficiency, making instruction less practical (Pisha, 1993; Nichols, 1995). Chwirka et al. (2002) found that at seven years old, students are able to follow a touch-typing course as they have sufficient fine-motor control, letter recognition, and word identification skills. Chwirka et al. (2002) also found that students at the grade two level were able to reach average typing speeds that approached handwriting speeds after receiving instruction. Other authors have argued that a touch-typing course might be more effective for students between 10 and 12 years old because they have a shorter learning curve to proficiency (Freeman et al., 2005; Rogers & Case-Smith, 2002; Stevenson & Just, 2014). Poole and Preciado (2016) reported that 48.5% of elementary teachers specify grades one and two as the best time to begin teaching, and 43.5% suggest grades three to four. Freeman et al. (2005) consolidated the literature on typing speed norms and ultimately concluded that keyboarding practice should be introduced prior to the grade level for which computers are used to complete academic work. They also suggested that authors generally conclude that upper elementary might be a more practical age at which to introduce instruction in light of feasibility and optimal learning curves.

1.6 Keyboarding Speed

Previous studies have each varied in their measurement and definition of keyboarding performance, although most authors report keyboarding speed as an indicator of typing skill proficiency (Freeman et al., 2005). As students practice and begin to rely on kinesthetic feedback to type accurately, students learn trajectories required to access keys and the sequencing to type words, which allows them to increase their typing speed (Freeman et al., 2005). Finger movements become serial and rapid in succession, which allows students to increase the complexity of the motor task (Freeman et al., 2005). Torkildsen et al. (2016) found that children who transcribe faster produce longer text with fewer spelling errors and higher narrative composition quality. This positive relationship between typing speed and writing quality (MacArthur, 2009) is due to the allocation of cognitive efforts on content rather than mechanics of written work production as a result of reduced cognitive load for transcription (Freeman et al., 2005). Students are able to pay more attention to spelling rules (Van Weerdenburg et al., 2018; Connelly et al., 2007; Johansson et al., 2010) and producing better-quality narrative texts (Van Weerdenburg et al., 2018; Christensen, 2004).

Several authors agree that typing can only be an effective alternative to handwriting when proficiency is achieved (MacArthur & Graham, 1987; Preminger et al., 2004; Connelly et al., 2007; Alves et al., 2008; MacArthur et al., 1993). Simply providing access to word processing software without instruction has no effect on students' writing (Berninger & Amtmann, 2003; MacArthur & Graham, 1987; Bangert-Drowns, 1993; Hunter et al., 1990; Christensen, 2004). When typing speeds are not proficient, writing by hand results in better-quality text generation (Berninger et al., 1997). Dunn and Reay (1989) concluded that students whose keyboarding speed equaled or exceeded their handwriting speed produced higher quality narrative writing using a word processor as opposed to handwriting. Conversely, when their keyboarding speed was less than handwriting speed, their typed written narratives were of lesser quality than handwritten text. Christensen (2004) found a that by improving the keyboarding speed of slow keyboarders, the quality of their keyboarded compositions improved. This positive relationship between keyboarding fluency and writing quality existed with fluent keyboarding skills but resulted in diminished writing quality if the students were not fluent keyboarders. Thus students' writing quality can only be improved when typing skills are automatic (Goldberg et al., 2003; Graham et al., 2012) and they are able to keyboard at least as fast as they can handwrite (Dunn &

Reay, 1989; Freeman et al., 2005; Christensen, 2004; MacArthur, 2009; MacArthur et al., 1993). They subsequently free up cognitive resources to put toward idea generation and content development, as outlined in the Cognitive Load Theory (Paas & Ayres, 2014; Paas et al., 2004).

There appears to be an overall trend emerging that typing speed increases with grade level (Freeman et al., 2005; Berninger et al., 2009). Chwirka et al. (2002) suggested that second grade students were able to learn keyboarding over a six-month instruction period and demonstrated average rates of five words per minute (WPM). A meta-analysis by Freeman et al. (2005) reported broad ranges of attained keyboarding speeds in the keyboarding literature, a consequence of not having standard measurement of typing skill and the subsequent variability in study methodologies. Studies have reported average keyboarding speeds for students in grades one through three to be approximately 9 WPM, with some reaching speeds of up to 30 WPM (Freeman et al., 2005). The range for students in the junior grades are more variable, with grade fours demonstrating speeds between 7.1 to 30 WPM, and fifth grade students producing anywhere between 4.7 to 70 WPM (Freeman et al., 2005). Russell (1999) found that typing speeds of twenty WPM in grade eight students resulted in better writing quality of open-ended test responses compared to handwritten responses but typing speeds less than twenty WPM had negative performance effects. Ultimately, keyboarding speed norms are difficult determine as there is no standardized measurement tool for keyboarding skill and the variability of instruction methods is too great (Freeman et al., 2005), highlighting the need for a consistent and reliable tool to measure typing speed to enable cross-study comparisons. Freeman et al. (2005) summarized the difficulties preventing comparisons between studies to be consequences of: (1) keyboarding speeds not often being reported exclusively for any one age or grade level; (2) grade levels across studies not necessarily including students of the same chronological age; (3) an inability to compare modern computer keyboarding speeds to the speeds produced with older research using typewriters; (4) a considerable range of objectives being examined across studies; and (5) different metrics for reporting keyboarding speeds. With respect to typing metrices, the literature reports three predominant metrics: Gross Words Per Minute (GWPM), Words Per Minute (WPM), and Characters Per Minute (CPM). Researchers do not have a unified coding scheme or procedure, so it is not necessarily the case that the same metrices are identically calculated across studies. GWPM and WPM are generally comparable, although not ideal, as several authors describe these calculations as divisions of the number of characters typed in one minute by five (Dunn & Reay, 1989; Hall, 1985; Pisha, 1993; Rogers & Case-Smith, 2002). Some studies have factored keyboarding errors into measures of keyboard speed (e.g. Dunn & Reay, 1989), but what constitutes an error is not uniformly operationalized. Others instead separately note the keyboard error rates (e.g. Preminger et al., 2004) and still others make no mention of errors. The case made for not including error rate into the speed calculations is that overall legibility of typed work is likely to be influenced by accuracy only when there is an extremely high number of errors, as opposed to handwriting and the influence of poor letter legibility (Freeman et al., 2005).

1.7 Limitations of the Current Research

Without proper keyboarding instruction, word processors are considered a hinderance to student performance (Freeman et al., 2005). Keyboarding instruction ultimately enables students to maximize the use of word processors as it facilitates proficiency in typing and lessons reallocates the cognitive load needed for the physical act of writing to higher-order processes (Christensen, 2004; Connelly et al., 2007). With automaticity in typing skill, cognitive load shifts from transcription to text content and improves overall text quality. Research over the previous two decades has notable gaps and limitations as mentioned above, but most prominent is the lack of a unified and consistent method to measure and record typing speed and proficiency.

Before keyboarding speed norms can be established or the effectiveness of keyboarding instruction can be evaluated, there must exist a consistent, reliable measurement tool for typing speed that can be incorporated into different studies. A standard measure would enable easier conclusions across various studies and allow the literature to converge on establishing developmental trajectories of typing skill acquisition. The current literature is limited by the extreme variability in assessment measures of typing proficiency which hinders cross-study comparisons and conclusions. Previous studies have measured typing speed by employing either sentence or essay composing tasks (e.g. Berninger et al., 2009; Christensen, 2004), copy paradigms (e.g. Van Weerdenburg et al., 2018; Donica et al., 2018), dictation tasks (e.g. Morken & Helland, 2013), or picture elicitation tasks (e.g. Torkildsen et al., 2016). Copy paradigms are considered to have stronger support as they allow for the least amount interference from individual differences in spelling and expression abilities (Grabowski, 2008; Weigelt Marom & Weintraub, 2015; Donica et al., 2018). Although dictation tasks bypass planning and text generation processes so that students can focus on transcription and revision (Morken & Helland, 2013), a student's spelling ability may influence their ability to write down the dictated words or sentences legibly.

Copy paradigms used in previous studies have also varied in their length and content of passages to be copied. A major limitation of the current literature is that previous studies often have not included details about, or samples of the passages used in their measures. This makes result replication challenging as subsequent authors are not able to utilize the same content in the typing paradigm and therefore end up creating or using unique content passages in their study design. Due to the nature of pressing individual keyboard keys based on letter and letter sequences in words, typing speed is likely influenced by the type of words and difficulty of language included in the presented passage that students copy-type. This study was therefore conducted to explore the impact of language complexity on typing speeds of students in early elementary grades by exposing students to passages at different reading-based levels and evaluating the differences in their respective typing output.

Chapter 2
The Present Study

2 Rationale and Hypotheses

In order to accurately replicate and extend previous research on typing skill development, a standardized research paradigm to test typing fluency must be developed. A reliable tool used to assess typing speed would allow consistent measurements and indications of typing proficiency between studies. It is no easy feat to develop any one tool, as there are several dimensions to consider when creating a measurement tool. The present study aimed to examine one aspect of a potential standardized tool by exploring the impact of language complexity and passage difficulty in a novel keyboarding copy-paradigm for school-aged children. This study's measure of typing speed, operationalized as net word and characters per minute, utilized a digital typing software whereby students copied standard passages normed on curriculum grade-levels using a keyboard. The current study employed a copy-typing paradigm in order to reduce the influence of individual student differences in literacy skills. A potential implication of this research is that it will aid in the development of a standardized tool to measure typing fluency as an outcome measure of typing proficiency. By understanding how language complexity in various passages impacts typing speed performance for students, the researchers can begin to effectively select and incorporate appropriate text materials into the copy-paradigm.

This study aimed to answer two main research questions. The first question was does passage difficulty impact a student's typing performance? Specifically, would a student's typing speed in the novel copy paradigm differ between the different grade-level passages they were exposed to? It was predicted that there would be a main effect of passage complexity, such that students will have greater WPM, characters per minute (CPM), and accuracy percentages for the early developmental passage rather than a passage at either the grade prior or current grade level. The researchers also hypothesized that there would be notable differences in the above typing outcome measures between different grades two through four such that older students would type more than younger students, in line with the emerging trend in the literature that typing speed increases with age (Freeman et al., 2005; Berninger et al., 2009).

The second research question centered around the relationship between different academic skills and typing speed. We asked, "Can a student's typing performance be predicted by their reading ability, handwriting fluency, spelling ability and/or fine motor skill?" The researchers anticipated that there would be some predictive ability of related academic skills on typing performance, specifically that handwriting fluency and spelling ability would have a positive impact on students' typing speeds across passages. Handwriting fluency, measured via the motor coordination task outlined below, was theorized to positively impact typing speed as students rely on kinesthetic feedback to press the keys accurately (Freeman et al., 2005) and in in rapid succession to produce words quickly (Schmidt & Lee, 2011). Fears and Lockman (2018) found that for young students, familiarity with letters affected their visual processing and subsequent automaticity when copying letters by handwriting such that they are more automaticity when copying familiar letter stimuli. The current researchers anticipated that this finding, in addition to the fair to moderate correlation between handwriting speed and keyboarding speed acquisition (Freeman et al., 2005), would result in students with faster handwriting speeds performing better on the novel typing paradigm of this study. Spelling ability itself was theorized to have a positive influence on typing fluency as it may enable the student to copy the passage at the word level rather than each letter-by-letter. Grabowski et al. (2010) found that students in the second and fourth grade performed better on copy tasks when copying symbols that formed pronounceable segments, particularly meaningful text and numerical strings. The number of copied characters in the time limit decreased from meaningful text to arbitrary graphical objects. Work by Rieben and her colleagues (e.g. Rieben et al., 1991; Grabowski et al., 2010) investigated how primary school students copy portions of text written on a classroom blackboard. They showed that students' copying strategies develop from copying single letters to copying larger, linguistically relevant units, such that their reproducing progressing from copying letters to syllables, to morphemes and then to words. Good spelling skills might allow students to utilize their knowledge of spelling conventions to anticipate the spelling of the whole word and subsequently the next letter key to press, reducing the cognitive effort needed to spell out each word.

Chapter 3
Methodology

3 Methods

3.1 Participants

Participants from this study were current students at an independent university-affiliated laboratory school for students in kindergarten through grade six Institute in Toronto, Ontario. In collaboration with the administrators of the school, the vice-principal emailed the detailed consent form and an endorsement letter to all parents of students in grades two through six. The parents who consented for their child to participate returned signed paper copies of the form to the primary investigator. A total of seventy-six signed consent forms were received with uneven distribution across grades. The primary investigator then worked with each teacher prior to student involvement to discuss appropriate times for each student to be withdrawn from classroom instruction. A maximum of twelve students per grade were to be included in the study, in no particular order. Students were accordingly withdrawn from class in accordance with the teacher's guidance and researcher availability.

Student consent to participate was obtained from forty-one students across the grades. Four students did not consent to their participation and were removed from the student list. Due to unexpected school closures amidst the pandemic, full data was available for a subset of the students involved. Participants included in the proceeding analyses were 28 (12 male) 7- to 11-year-old students (M = 8.8 years, SD = 0.98). There were eight students in each of grades two (4 male) and three (3 male), and twelve students in grade four (5 male). Participants were not compensated. This research study was approved by the Social Sciences, Humanities and Education Research Ethics Board of the University of Toronto and by the Laboratory School Child Research Committee prior to its commencement.

3.2 Measures

Screening measures for handwriting ability and reading skills were included in this battery of assessments to examine potential correlates or covariates between typing performance and other academic skills. Each measure's protocol was scored by the primary investigator and double scored by a qualified research assistant.

3.2.1 Demographic Questionnaires

After participants confirmed their interest and consented to taking part of the study, the primary investigator emailed a Qualtrics Survey Link to their parent. This survey collected information on family demographics, as well as technology access and familiarity within their household. Parents were asked if their child had access to a computer in their household, and how often their child used it for different activities including typing and homework. Students completed a similar survey during their first participation session with a researcher to ascertain their own perception of computer use, access, and familiarity with typing.

3.2.2 Handwriting Ability

Previous research demonstrates that handwriting fluency is a strong predictor for transcription skills, in addition to explaining one's quality and fluency of text composition (Graham et al., 1997; Jones & Christensen, 1999). Practice in writing letters significantly improves students' ability to produce high quality written text (Jones & Christensen, 1999). For this reason, the current research battery included measures of orthographic motor integration and fine motor skills to examine potential correlations between lower order writing skills and typing performance.

Alphabet Writing Fluency. Orthographic motor integration (OMI) is known as the ability to integrate the retrieval of letter forms from memory with the ability to plan and execute fine-motor movements to create such letters (Berninger, 1999). Christensen (2004) demonstrated that OMI in handwriting and keyboarding are correlated, with OMI in keyboarding being more related to quality and length of composed text. The current study measured each participant's handwriting fluency based on a task developed by Peverly et al. (2007). Participants were asked to print as many of the letters of the alphabet as possible within thirty seconds on a sheet of paper with widely spaced lines. Participants completed this measure by pencil as significant correlations have been found between keyboard and pencil speeds of automaticity of letter production (Berninger et al., 2006). The lowercase letter a was already printed on the sheet as an example. They were told to write the proceeding letters in order, first in lowercase, and then in uppercase if time permitted. Each letter that was distinguishable as a unique letter was given credit as a score of 1. Participants were not penalized for writing the letters out of order, or for writing each letter in both of its case forms interchangeably. Points were summated and the total number of letters written correctly within the time limit was the raw score total used in the proceeding analyses.

Motor Coordination. Visual-motor integration (VMI) skills have proved to be associated with writing legibility (Tseng & Murray, 1994; Volman et al., 2006). There is some evidence that VMI is related to academic performance in reading and writing (Kulp, 1999; Sortor & Kulp, 2003), although some research has not found an association with handwriting difficulties in younger (Marr & Cermak, 2002) or older children (Goyen & Duff, 2005). To assess fine motor skills, the supplemental Motor Coordination (MC) task of the *Beery Developmental Test of Visual-Motor Integration* (6th ed.; Beery & Beery, 2010) was administered. The first three items are based on observational data by the researcher, including the ability of the participant to hold a pencil with a thumb and at least one finger. The participant is then provided with three practice items that teach them to connect dots and draw lines within provided borders of various shapes. When they successfully complete the demonstration items, the participant is then instructed to continue drawing within increasingly complex shape borders, at which point the timer begins. The participant is given a five-minute time limit to complete as many items as possible. If they finish prior to the allotted time limit, the completion time is recorded. One point is awarded for each item for which pencil marks are present between all dots and within the borders, for a possible range between 0 and 30. A standard score was used in the analyses for this study according to norm tables. The MC task demonstrates good psychometric properties with Cronbach's coefficient alpha values ranging between .71 to .89 (Beery & Beery, 2010; McCrimmon et al., 2012).

3.2.3 Reading Skills

Reading proficiency has been shown to account for approximately 25% of the variance in the quality of written work produced by students (Kent & Wanzek, 2016). Williams and Larkin (2013) also found that reading fluency is significantly related to the amount of text that students can produce. Although the typing measure in this study is a copy-paradigm, one’s reading ability was theorized to influence typing performance as the students could have used word or sentence level reading to guide their typing, rather than a letter-by-letter typing method.

Reading Ability. The *Gray Oral Reading Test - Fifth Edition* (GORT-5; Wiederholt & Bryant, 2012) was administered to assess oral reading skills in four key areas: rate, accuracy, fluency and comprehension. The test requires an individual protocol for each participant, as well as a separate student booklet containing sixteen passages of increasing difficulty. There are two parallel forms of a student booklet (A and B), but for this study Form A was used with every participant. The passages are written on the protocol for the researcher to reference, in addition to five comprehension questions per passage. Each participant is shown one reading passage at a time and told to read the passage orally as "carefully and quickly as you can" (Wiederholt & Bryant, 2012). The researcher begins the timer when the student starts reading, denoting each deviation from print onto the protocol as they read. Once the student completes the passage, the researcher notes the total reading time and removes the student book from the participant's view. The researcher calculates a total score for Rate, Accuracy and Fluency for each passage. The Rate score is the number of seconds it took the student to read the passage aloud while the Accuracy score is denoted as the total number of deviations from print the participant read. The Rate and Accuracy scores are summated to calculate a Fluency score. The researcher then asks each comprehension question to the student, who must answer them without being able to reference the text. Each correctly answered question is given a score of 1, and the total is summated for the Comprehension score. The participants continue to read increasingly challenging passages until they reach a ceiling of two consecutive Fluency scores less than or equal to a value of two. This assessment measure has strong evidence of reliability and validity, with Cronbach's coefficient alpha's exceeding .90 (Wiederholt & Bryant, 2012; Hall & Tannebaum, 2013).

Spelling. As reading involves knowledge of word patterns and sound combinations, the *Wechsler Individual Achievement Test – Third Edition* (WIAT-III; Wechsler, 2009) Spelling subtest was given to assess each participant's written spelling of single sounds and works from dictation. It was hypothesized that spelling knowledge might mitigate the amount of letter by letter correspondence the participant had to make when copying each passage key. In this task, the student listens to a target word said by the researcher, followed by the word used in the context of a sentence, and then they write the word down on a lined and numbered sheet of paper using a pencil without an eraser. They begin with a word at their current grade level and must get three consecutive words correct to establish a basal level of skill. If they spell any of the first three words incorrectly, they reverse to complete items prior to the grade start point until they complete three consecutive items correctly. Each correctly spelled word is awarded 1 point, and the total points are summated for a raw score. The participants continue to spell word items until they four consecutive words are written incorrectly. This subtest on the WIAT-III demonstrates sound psychometric properties with coefficient values greater than .90 (Wechsler, 2009).

3.2.4 Typing Speed

Participant's typing speeds were measured in a novel typing paradigm developed by the researchers based on methodology used in previous studies. Russell (1999) measured typing speed using a computer-based keyboarding test containing two passages that students were asked to copy verbatim within a two-minute time constraint. Donica et al. (2018) employed a similar method whereby a computer program was programmed to include three times passages for students to copy via the keyboard within a one or two-minute time limit.

In the current study, the computer program UltraKey for Home (V.6; described below), was programmed to include grade-leveled, timed passages for the students to copy via keyboard. Each passage was displayed on the top half of the computer screen and copied into a blank text box below the passage. They were instructed to copy the text from the passages into the text box by typing them as quickly and accurately as possible (Barkaoui, 2014) until the timer box stopped their typing after two-minutes. This time limit was included to reduce stress and task demands on the students. The passages that were programmed into the software were excerpts of passages from the Acadience Reading Assessment (Good & Kaminski, 2011), a criterion-referenced Oral Reading Fluency measure empirically leveled by curriculum grade. The Lexile measure of each passage was also examined to verify differences in language complexity (see Appendix A and Table 1). The Lexile Framework measures text complexity by examining text characteristics of word frequency and sentence length, using the familiarity of semantic units and complexity of syntactic structures within a text passage (see Smith et al., 2015 for a full review of the Lexile Framework). Two passages at the grade one level, and one passage from each subsequent grade level, were uploaded into UltraKey for Home (V.6) and programmed as novel typing test content to be used in this study. Each student was asked to complete one practice passage and three timed passages according to their current grade level. Students in grade two only completed two subsequent passages after the practice passage.

Each student received a practice passage at grade one level in order for them to become accustomed to the platform and computer device. During this practice passage, the students were instructed on the features of the software and given an overview of how the task would progress, as they practiced copying the passage they were presented with. They were told that UltraKey for Home (V.6) had the backspace key disabled within it so they should just go on to the next letter or word if they made a mistake. The backspace key has been disabled in prior research to allow researchers to collect a more precise accuracy and WPM calculation (Barkaoui, 2014). This program also had auto-correct and autocapitalization disabled within it. Following the practice passage, all students completed a second passage at the grade one level that was used as a universal baseline measurement of typing skill for all students. This ensured that all students completed a passage at an early developmental level independent of their current grade level. Again, they were told to type as quickly and as accurately as they could until the program prompted them to stop. Students in grade two then completed one final passage at the grade two level to mirror their current curriculum grade. All other students completed two additional passages, one at a curriculum level below their current grade, and one passage at their same curriculum grade level. See Table 1 for a breakdown of stimulus passages exposed to each student based on their grade level at the time of the study.

Table 1.

Breakdown of Stimulus Passages Completed by Students

	Grade Two Students	Grade Three Students	Grade Four Students
Grade One Level	Grade One	Grade One	Grade One
Previous Grade Level	N/A	Grade Two	Grade Three
Current Grade Level	Grade Two	Grade Three	Grade Four

Note. See Appendix A for full text transcripts of each passage. The Lexile ranges for the passages were as followed: *Grade One* = 410 – 600L; *Grade Two* = 410 – 600L; *Grade Three* = 610 – 800L; *Grade Four* = 810 – 1000L.

The primary investigator of this study then transcribed and coded all typed passages for each student. Each error was coded according to its error type: additional space key, additional letter key, additional punctuation key, additional capitalization, omitted space key, omitted letter key, omitted punctuation key, omitted capitalization, incorrect letter key. The units of measurement used for analysis included net words per minute (WPM; excluding capitalization errors), gross characters per minute (CPM), net CPM, and accuracy percentages for both WPM and CPM measures. The net WPM represented the number of keyed WPM that were typed accurately and without any errors. Gross CPM was the number of characters keyed per minute regardless of errors, whereas net CPM was the number of correctly typed characters keyed per minute. Accuracy percentage was the percentage of either words or characters keyed correctly out of all the words or characters typed, respectively. The primary investigator also observed and noted students' typing method and hand placement: hunt and peck or touch-typing methods.

3.3 Materials

3.3.1 Computer

A Lenovo ThinkPad with a monitor size of 17 inches was used to complete the typing measure described above. The model number of the device was ThinkPad E580; CPU *Intel Core i5-8250U, ram GB DDR4, 2400 MHz.*

3.3.2 Typing Software

The typing software license used for the aforementioned typing paradigm was UltraKey for Home – Bytes of Learning (Version 6). The program can be found at this link: https://www.bytesoflearning.com/products-item/UltraKey_for_Home. The software license was downloaded to the Lenovo ThinkPad described above and the data server hosted on the local machine. The program's data was encoded anonymously according to unique participant identification numbers and backed up to the university system each night. As each participant typed, UltraKey - 6 identified specific typing errors and displayed them graphically at the end of the test. These errors were noted by the primary investigator but not used in analyses.

3.4 Procedure

Students were individually withdrawn from classes at the predetermined times and brought to the research room by one of four researchers, including the primary investigator. Each student's participation consisted of two individual sessions, each approximately twenty minutes in length.

Informed consent from each individual student was obtained at the start of the first session. The students were told that they could withdraw themselves and their data from the study at any point. Three of the students who did not consent did so at this early stage and were subsequently brought back to their classrooms. Students who agreed to participate went on to complete the demographic questionnaire and the GORT-5 reading measure. Once these measures were completed, they were reminded that there would be a second session another day and were returned to their classroom.

The second session began with confirmation of consent to participate. The student then proceeded to complete the alphabet writing fluency task, the motor coordination activity, and the spelling measure, respectively. All these tasks are described above. Each student then completed the typing speed paradigm and returned to their classroom. The order of the testing sessions remained constant for all participants to maintain student interest and motivation by completing the screener measures before the typing paradigm.

3.5 Data Analysis Plan

General descriptive statistics for typing speed measures (CPM and WPM) were calculated to explore trends in typing performance for students in each grade. Spearman correlation coefficients were then computed to examine associations among the variables, particularly the relationships between the typing outcome measures (CPM and WPM) as well as associations between all academic skills that were measured. General statistics of literacy skills ((handwriting fluency, fine motor control, spelling ability and reading level) were also examined.

To explore whether passage difficulty influences typing speed, several independent repeated measures analyses of variance (RM ANOVA) were conducted. These analyses were conducted for each grade independently to allow the researchers to examine the effect of passage complexity on typing performance (net CPM) while controlling for age as a covariate or influencing variable. The small overall sample size also constricted the statistical power of these analyses overall, so breaking the analyses down by grade made this a true pilot study in nature.

Regression analyses were then conducted to examine what additional literacy skills (handwriting fluency, fine motor control, spelling ability and reading level) influence typing speed performance over and above a student’s age. Net CPM for the grade one-leveled passage was used as the outcome variable in these analyses as the results of the above-mentioned ANOVAs showed nonsignificant differences in net CPM between the increasingly difficult passages for grades three and four students.

Chapter 4
Results

4 Data Analysis

4.1 Descriptive Statistics of Typing Speed Measures

Means and standard deviations of net characters per minute (CPM) and net words per minute (WPM) typed by students in each grade are presented in Table 2. Note that grade two students only completed two passages, as outlined in the typing paradigm description above. The measures of CPM and WPM incorporated indices of accuracy as well, as they were both calculated as correct characters and words typed each minute, respectively. Generally, students of all grades typed more correct characters on the easier, grade one leveled passage relative to the passage at their current grade level. Both grade two and three students did the poorest on the grade two-leveled passage (see Table 1 for passage breakdown). Notably, the grade four students performed the best on the previous grade passage, reflected in the largest CPM and WPM counts for those students. The older students also showed large standard deviations, highlighting wide individual differences in typing speeds and correct keystrokes on this task. There was a strong positive linear change in net CPM and student age, as shown in Figure 1. Means and standard deviations of other study variables are shown in Table 4.

Table 2.

Means (Standard Deviations) for Typed CPM and WPM by Students in Each Grade

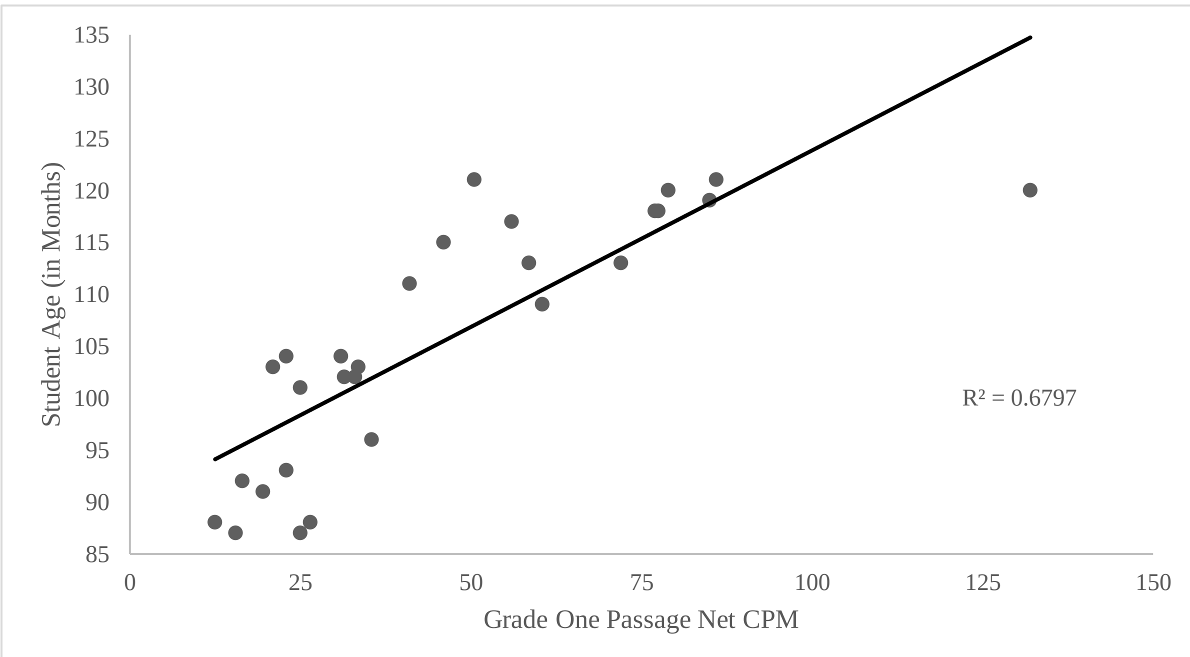
		Passage		
		Grade One	Previous Grade	Current Grade
Grade Two Students	WPM	3.44 (1.35)	-	3.00 (1.31)
	CPM	21.75 (7.38)	-	20.56 (6.71)
Grade Three Students	WPM	5.44 (2.54)	3.63 (2.70)	5.94 (2.53)
	CPM	32.31 (12.35)	26.94 (13.38)	30.19 (13.47)
Grade Four Students	WPM	12.46 (4.66)	13.46 (4.64)	11.46 (4.43)

CPM	71.71 (24.51)	75.46 (28.11)	73.38 (29.12)

Note. Grade Two, *N* = 8; Grade Three, *N* = 8; Grade Four, *N* = 12. *Net Characters per Minute* (CPM) were calculated as total correct number of keystrokes produced within the two-minute time limit, divided by two. *Net Words per Minute* (WPM) calculated as the number of correct proper words produced within the two-minute time limit, divided by two.

Figure 1.

Linear Relationship Between Student Age and Typing Speed on the Grade One Passage



4.2 Associations Between Study Variables

4.2.1 Associations Between Typing Measures

As can be seen in Table 3, CPM and WPM outcome measures of each passage are very highly correlated with each other. Due to there being a strong bivariate Spearman rank-order correlation between the CPM and WPM for each passage in this study (rs(26) = 0.97, $p < .001$; rs(26) = 0.93, $p < .001$; rs(26) = 0.96, $p < .001$; respectively), net CPM was emphasized as the main outcome variable in the proceeding analyses.

Table 3.

Spearman's rho Correlations between Typing Performance Outcome Measures (WPM, CPM)

	Net WPM Grade One Passage	Net WPM Previous Grade Passage	Net WPM Current Grade Passage
Net CPM Grade One Passage	0.971 ***		
Net CPM Previous Grade Passage		0.929 ***	
Net CPM Current Grade Passage			0.961***

Note. * $p < .05$, ** $p < .01$, *** $p < .001$

4.2.2 Associations Between Academic Skills

Spearman rho correlations between the various screener variables and the typing outcome measure of net CPM are included in Table 4. Importantly, the strongest correlation exists between the student's age in months and their net CPM typed in the grade one leveled passage. Notable significant correlations also include the strong association between spelling and reading ability, as well as between spelling and handwriting fluency.

Table 4.

Descriptive Statistics and Spearman's rho Correlations for Study Variables

Variable	*N*	*M*	*SD*	1.	2.	3.	4.	5.	6.
1.Net CPM Grade One Passage [a]	28	46.18	28.67	-					
2. Age in Months	28	105.57	11.82	.875***	-				

3. Handwriting Fluency [a]	28	12.39	5.78	.475*	.414*	-			
4. Motor Coordination [b]	28	88.07	8.85	-.273	-.223	.268	-		
5. Spelling [b]	28	106.68	12.31	.280	.205	.540**	.210	-	
6. Reading Index [b]	28	102.86	11.08	.140	.060	.179	.250	.621***	-

[a] Raw Score

[b] Standard Score

* $p < .05$; ** $p < .01$; *** $p < .001$.

4.3 Does Passage Difficulty Influence Typing Speed?

Initial data exploration demonstrated that there was a significant difference in net CPM based on passage difficulty for students as a whole group. However, upon the inclusion of age as a covariate, that analysis was no longer significant. Therefore, the researchers suspected that this passage effect was largely contingent on age and was a reflection of a developmental aspect. To note, the passages that students were exposed to in the paradigm varied for each grade, such that they all typed the same grade one leveled passage but were exposed to different leveled passages based on their respective previous and current grade. Therefore, the typing paradigm was unique for the students based on their grade level, which further prompted the researchers to separate each analysis by grade.

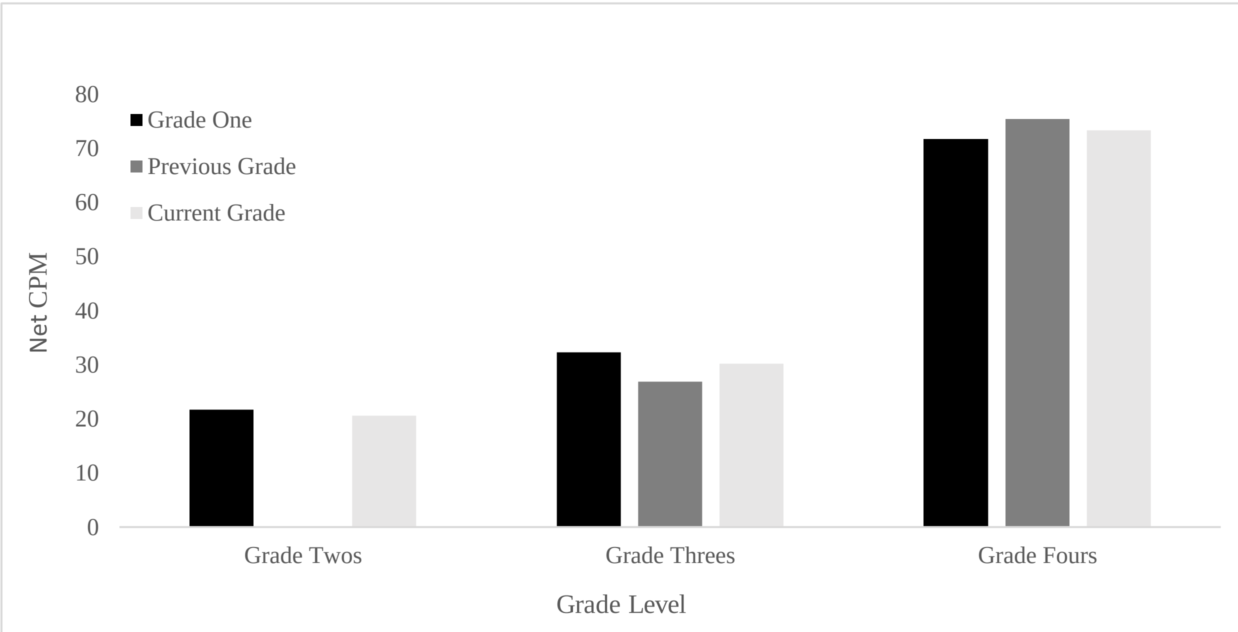
4.3.1 Does passage difficulty affect net CPM in grade two?

A paired-samples t-test was used to determine whether there was a statistically significant mean difference for grade two students between the net number of CPM typed on the grade one reading-leveled passage and the grade two reading-leveled passage. No outliers were detected in the data, as assessed by inspection of a boxplot. The assumption of normality was not violated, as assessed by Shapiro-Wilk’s test ($p = .631$). Grade two students typed more correct CPMs with the grade one passage ($M = 21.750$, $SD = 7.377$) than the grade two passage ($M = 20.563$, $SD =$

6.711), a statistically significant mean increase of 1.188 CPM, 95% CI [0.165, 2.210], $t(7) = 2.747$, $p = .029$, $d = 0.971$. See Figure 2 for a graphical representation of this result.

Figure 2

Net CPM Typed by Students in Grades 2 Through 4 on Passages of Increasing Complexity



Note. Grade two students only completed two passages, as the grade one passage fulfilled the requirements of completing a passage leveled at the grade before.

4.3.2 Does passage difficulty affect net CPM in grade three?

A one-way repeated measures ANOVA was conducted to determine whether there was a statistically significant difference in net CPM typed between three different leveled passages for grade 3 students. There was one outlier student whose data across the three passages was greater than their peers, according to inspection of boxplots. The inclusion of this student also resulted in data that was not normally distributed, thereby violating this assumption as indicated by significant Shapiro-Wilk tests ($p < 0.05$). The RM ANOVA was run both without and including this outlier student, which resulted in no difference in final results. Therefore, the outlier was included in the reported analysis. The assumption of sphericity was not met, as assessed by Mauchly's test of sphericity, $\chi^2(2) = 0.03$, $p = 0.01$. In practice, the assumption of sphericity is considered difficult not to violate (e.g. Weinfurt, 2000). Epsilon (ε) was 0.562, as calculated according to Greenhouse and Geisser (1959) and was used to correct the one-way repeated measures ANOVA. Maxwell and Delaney (2004) suggest using the Greenhouse-Geisser correction, especially if estimated epsilon (ε) is less than 0.75. The passage difficulty did not result in any statistically significant differences in net CPM typed by grade three students between the passages (see Figure 1), $F(1.125, 7.874) = 4.583$, $p = 0.062$. Net CPM increased from the grade before passage ($M = 26.938$, $SD = 13.380$), to the current grade passage ($M = 30.188$, $SD = 13.467$), to the grade one leveled passage ($M = 32.313$, $SD = 12.346$).

4.3.3 Does passage difficulty affect net CPM in grade four?

A one-way repeated measures ANOVA was conducted to determine whether there was a statistically significant difference in net CPM typed between three different leveled passages for grade four students. There was one outlier indicated by inspection of a boxplot for the grade one leveled passage data, but this score was included due to a lack of sufficient reasons to remove it. The assumption of normality was met, indicated by nonsignificant Shapiro-Wilk tests ($p > 0.05$). The assumption of sphericity was also met, as assessed by Mauchly’s test of sphericity, $\chi^2(2) = 1.619$, $p = 0.445$. The passage difficulty did not result in statistically significant differences in net CPM typed by grade four students between the passages (see Figure 1), $F(2, 22) = 0.802$, $p = 0.461$, although net CPM increased from the grade one passage ($M = 71.708$, $SD = 24.506$), to the current grade passage ($M = 73.375$, $SD = 29.124$), to the grade before passage ($M = 75.458$, $SD = 28.113$).

4.4 What Additional Factors Influence Typing Speed?

A hierarchical multiple regression was run to determine if the addition of handwriting fluency, motor coordination, spelling and reading skills improved the prediction of net CPM typed for the grade one leveled passage over and above students’ age alone. Preliminary analyses with age entered into the first block of the regression, and all predictor variables entered in the second block, indicated that spelling and reading ability as independent variables did not add any significant unique variance, as can be seen in Table 5. The correlations in Table 5 also demonstrate that, not surprisingly, greater handwriting fluency is associated with better spelling skills, which are in turn associated with better reading skills. By this logic, handwriting fluency shares variance with reading and spelling abilities, further contributing to their non-significant variance in the initial regression model. Subsequently, spelling and reading as independent predictor variables were removed from further analyses. The final regression model included age as the predictor variable in the first block followed by handwriting fluency and fine motor control together in the second block, shown in Table 6.

Table 5.

Hierarchical Multiple Regression Predicting Net CPM From All Screener Variables

	Net CPM			
	Model 1		Model 2	
Variable	B	β	B	β
Constant	-164.95		-97.88	
Age	2.00**	0.82	1.50**	0.62
Handwriting Fluency			1.43	0.29
Motor Coordination			-1.04*	-0.32
Reading Index			0.49	0.19
Spelling			0.09	0.04
R^2	0.680		0.821	
F	55.18**		4.33*	
ΔR^2	0.680		0.141	
ΔF	55.18**		4.33*	

Note. $N = 28$. * $p < .05$, ** $p < .001$.

4.4.1 Assumptions

There was linearity as assessed by partial regression plots and a plot of studentized residuals against the predicted values. There was independence of residuals, as assessed by a Durbin-Watson statistic of 1.521. There was homoscedasticity, as assessed by visual inspection of a plot of studentized residuals versus unstandardized predicted values. There was no evidence of multicollinearity, as assessed by tolerance values greater than 0.1. There were one studentized deleted residual greater than +3 standard deviations, but there were no leverage values greater than 0.28 nor values for Cook's distance above 1. The assumption of normality was met, as assessed by a P-P Plot.

4.4.2 Final Regression Model of Typing Performance

The full final model of gender, age, handwriting fluency and motor coordination to predict net CPM for the grade one leveled passage (Model 2) was statistically significant, $R^2 = .780$, $F(3, 24) = 28.325$, $p < .001$; adjusted $R^2 = .752$. The addition of handwriting fluency and motor coordination to the prediction of net CPM (Model 2) led to a statistically significant increase of R^2 of .100, $F(2, 24) = 5.451$, $p = .011$. This model can be seen in Table 6.

Table 6.

Hierarchical Multiple Regression Predicting Net CPM From Age, Handwriting Fluency and Motor Coordination

	Net CPM			
	Model 1		Model 2	
Variable	B	β	B	β
Constant	-164.95		-52.30	
Age	2.00**	0.82	1.51**	0.62
Handwriting Fluency			1.70*	0.34
Motor Coordination			-0.93*	-0.29

R^2	0.680	0.780
F	55.18**	5.45*
ΔR^2	0.680	0.100
ΔF	55.18**	28.33**

Note. $N = 28$. * $p < .05$, ** $p < .001$.

Chapter 5
Discussion

5 The Current Study

The current study was conducted as a preliminary analysis of the effects of passage complexity on typing performance in school aged students. The results of this study will be used to inform the development of a standardized typing measure by prompting the inclusion of appropriate passages for students to type. Specifically, the first research question of this study aimed to answer whether students' typing speed in a novel copy paradigm, as measured in net characters per minute (CPM), would differ between three grade-leveled reading passages of increasing reading difficulty and subsequent language complexity, as indicated by increasing Lexile counts (see Table 1). The researchers were interested in how many individual keystrokes students would correctly type per minute in the novel typing paradigm, rather than how many proper words they produced. The analyses did show differences in net WPM produced by students between the different passages, however there were very strong correlations (> 0.90) for the net CPM and WPM typed for each passage. This high correlation enabled the researchers to focus on net CPM as the outcome variable for this study. Strikingly, the results of this study showed that there were no significant differences in net CPM produced by grade three and four students for the different leveled passages, indicating that passage difficulty did not impact their ability to type correct CPM. There was a significant difference in net CPM typed for grade two students, such that they produced more correct CPMs when copy-typing the grade one-leveled passage rather than the passage at their current second grade level. The researchers hypothesize that this difference could, in part, reflect a notably more challenging grade two passage. The first sentence of the grade two-level passage contains two proper nouns, which are unfamiliar words (see Appendix A) to young students. These unfamiliar and uncommon words contain letter sequences that students are exposed to infrequently, which may have influenced students unfairly such that they spent more time than usual trying to figure out the spelling and key sequences of these words. This added time would have resulted in fewer words produced as they occupied more cognitive resources and more time.

Spearman's correlational analyses demonstrated that handwriting fluency was significantly ($p < .05$), positively associated with both net CPM in the grade one-leveled passage and students age.

There was also a significant ($p < .001$) correlation between a student's age and their net CPM produced on the easier grade one passage. These results suggest that students have greater transcription abilities as a function of age. As students get older, they not only write more letters quicker, but they also produce more correct CPM on the typing task.

The second research question aimed to discern whether typing speed could be predicted by other academic skills including reading ability, handwriting fluency, spelling ability, and/or fine motor skill. Due to the nonsignificant differences in net CPM between the typing passages for grades three and four students, the regression analyses to answer this question utilized the net CPM for the grade one leveled passage as the outcome variable. In the initial analysis model, neither reading nor spelling ability added and significant, unique variance to the prediction of net CPM, suggesting that a student's typing ability is not contingent on the development of reading or spelling skills. Not surprisingly, Spearman's correlations demonstrated that greater handwriting fluency is associated with better spelling skills, which are in turn associated with better reading skills. By this logic, handwriting fluency likely shares variance with reading and spelling abilities, which could be contributing to their non-significant variance in the initial regression model. It might also the case that likely this grade one leveled passage was within the reading ability of all students in this study and thus less likely to have a significant impact in this analysis. The analysis did demonstrate that 68 percent of the variance in net CPM is accounted for by a student's age alone, pointing to a developmental aspect in typing speeds that aligns with previous research showing an overall trend of increasing typing speed with grade level (Freeman et al., 2005; Berninger et al., 2009). Handwriting fluency and fine motor coordination added an additional 10 percent of variance to the model prediction with age, raising the amount of variance in net CPM predicted by these variables to 78 percent. This result from the final reported regression model suggests that typing performance is largely dependent on a student's age, such that older students type more than younger students. This is important to note in the consideration of typing instruction. It appears that the developmental trajectory of typing skill is that as students get older and, theoretically, are exposed to computers more so as a means of completing schoolwork, their typing skills increase. It suggests that there is a sort of practice effect to typing; the more students use computers to type out their work as they get into each successive grade level, the better their typing skills become. Interestingly, the students in this study had notable difficulty with the fine motor coordination task. There was a sizable number of students in the sample who obtained standardized scores on this measure that were below average, indicating that generally, this sample size had poor fine motor coordination. The nature of these low scores might have had a disproportionate effect on the final output, potentially elevating a relationship between motor coordination and typing speed. There are a multitude of factors that could have influenced students' scores on this measure, including but not limited to; students' motivation, a desire or misconception of the students that speed trumped accuracy, misunderstanding of the standardized instructions, and/or true difficulty with the task. It is challenging to discern the exact reason, but forty-three percent of the students scored below average on this standardized measure.

The researchers anticipate that reading and spelling did not add unique variance to the regression analysis because of the general lack of experience using keyboarding among the students in the same. The students in this sample were in the primary grades and had not received formalized keyboarding instruction in school prior to this study. The students in grade four had received some instruction throughout the school year, prior to this study, but this instruction was based on an exploratory and inquiry-based approach to learning rather than formal instruction sessions on hand-key placement. This could indicate that, due to the novelty of typing text, reading and spelling ability could not influence performance as the students allocated more cognitive resources to typing individual letters and were not focused on text at the word or sentence level. In the framework of the simple view of writing and the cognitive load theory (Berninger & Winn, 2006; Paas & Ayres, 2014; Paas et al., 2004), the difficult nature of visually referring back to the text to type each letter at a time, the students may not have had enough cognitive resources available to utilize reading or spelling skills as potential strategies to make the task easier. This relationship could potentially differ for older students who have more familiarity with keyboard key placement, as they might use less visual searching and be able to utilize related skills like reading and spelling to help them type more quickly. The fact that typing performance was not predicted or influenced by the academic skills of spelling or reading, suggests that typing is predominately a motor task that is facilitated by practice and familiarity with keyboard exposure. This has implications for current teachers, as it supports the inclusion of specific touch-typing instruction when students are being asked to use keyboarding as a means to produce assignments or complete schoolwork. Regardless of their levels of reading or spelling skills, students need practice and more exposure to keyboarding as an individual academic skill, as indicated by the predominant positive relationship found in this study between age and typing speed. This finding is also in-line with previous research that states that simply providing access to word processing software without instruction has no effect on students' writing (Berninger & Amtmann, 2003; MacArthur & Graham, 1987; Bangert-Drowns, 1993; Hunter et al., 1990; Christensen, 2004). This finding also supports the argument that keyboarding is a possible alternative means of producing written work for students with handwriting difficulties, as it suggests the students can be taught this motor task irrespective of their existing skill levels in related academic domains like reading. However, it does imply that instruction is therefore required for these students especially if they are to reach a level of typing proficiency that supports typing as an alternative to handwriting (MacArthur & Graham, 1987; Preminger et al., 2004; Connelly et al., 2007; Alves et al., 2008; MacArthur et al., 1993). For those who have not attained keyboarding proficiency, typing may still require the use of extensive cognitive resources and result in poorer text quality produced, as per the cognitive load framework (Paas & Ayres, 2014; Paas et al., 2004). These students may benefit from the use of voice recognition, or speech-to-text, software as it removes the physical component of writing completely.

5.1 Limitations

With this being a pilot study, there are several limitations that affect the generalizability of these results. Predominantly, the small sample size included in this study limits our ability to generalize these results to the greater population of students in grades two through four. There was a notable discrepancy between the number of students in each grade, with a larger amount of older grade fours included in the analyses. Also, I did not record the handedness of the students, which prevents me from examining any potential effects of handedness on typing performance. Due to the placement of keys on a keyboard and the type of words they were prompted to copy, a student might have been disadvantaged if they were mainly prompted to type letter keys that were on the side of their non-dominant hand. For instance, a right-handed student who was exposed to more letters on the left side of the keyboard, may have experienced a disadvantage in typing using their non-dominant hand. There is an area of research examining whether typing performance is connected to the demographic features (such as handedness) of the typist (e.g. Brizan et al., 2015). This work into keystroke dynamics biometrics has suggested that the handedness of typists can be recognized based on their typing behaviour (Brizan et al., 2015; The et al., 2013). An unavoidable limitation in typing research generally, is that the device used by participants is often novel. For instance, the laptop used in this study was a Microsoft personal computer running Windows 10 instead of the MacBooks that the laboratory school normally uses with their students. This is an important limitation as each device has a unique keyboard and sizing between keys, which could impact a student's ability to type proficiently when using novel devices.

5.2 Future Directions

The current study was a preliminary analysis of one factor to consider in the development of a standardized typing test, language complexity in the narratives presented to students as stimuli to copy-type in a novel typing skill paradigm. The main finding in this study is that the universal passage leveled at a grade one reading level, was a good indicator of typing skill, particularly net characters per minute produced in a two-minute copy typing paradigm. Next steps would be to replicate the current study and build a larger sample size of students in order to increase statistical power in our results. Future research should also expand the scope of included grades, to examine any differences in the early, middle and late elementary grade levels. Long term goals in the development of a standardized typing skill measurement tool is to build novel copy passages that are unique to this copy typing paradigm but still contain identical word usage and Lexile counts, as well as characters per passage as the universal passage in this study. I hope to build a new passage for students to type that would still be at a grade one reading level, but one that is unique to this task and not taken from an existing reading measure.

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Appendix A: Typing Passages

Universal Passage – Grade One Level

Parts of a Tree

Trees are very tall plants. They come in different shapes and sizes. Yet all trees have the same parts. The leaves are the green parts of the tree. Some leaves are big and flat. Others look just like thin needles. No matter their size or shape, leaves take in air and sunlight. Trees need air and light to live and grow.

Lexile Range: 410 – 600L

Grade Two Leveled Passage

Roller Skating Fun

Every Saturday Dad and Craig did something together. This morning Dad had a surprise. They were going to go roller skating. Craig was excited. He had never been roller skating. Dad said it was a lot of fun, so Craig got dressed and put on his coat. They walked to the bus and rode to the skating rink.

Lexile Range: 410 – 600L

Grade Three Leveled Passage

Skimboarding

As the waves rolled onto the shore, a group of teens ran into the surf with funny round boards under their arms. Allie looked up from reading her book and watched them. When they reached the wet sand, they tossed their boards toward the incoming waves. Then, they quickly jumped onto them. Some of them fell flat into the water.

Lexile Range: 610 – 800L

Grade Four Leveled Passage

Rainbows

Since long ago, people around the world have been amazed by the rainbow. This natural light show has inspired everything from movies to songs. A close look at the science behind the rainbow shows that there is more to the rainbow than what meets the eye. The first thing most people notice about a rainbow is the bright colours.

These colours are created by the sunlight passing through raindrops. Different colors reflect back at slightly different angles, splitting the light into the rainbow. What may surprise you is that the colors you see are not the only colors in a rainbow. Rainbows are actually made up of every color in the light spectrum, from red to violet.

Lexile Range: 810 – 1000