HOW DOES CHILDREN'S SPELLING SUPPORT THEIR LITERACY?

by

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DEDICATION

This thesis is dedicated to my grandfather, who showed me what it means to always have someone in your corner.

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ABSTRACT

Ample research suggests that spelling accuracy, measured using a binary correct-incorrect or on a continuum of correctness, is a primary way to predict future reading and spelling ability. Recent theory has proposed an additional predictor of literacy development: spelling fluency, or the speed of accurate spelling. In the current study, we investigated whether spelling fluency was a significant predictor of current and future reading and spelling ability, beyond what was accounted for by known predictors and various measures of spelling accuracy. Participants were 124 students in Grade 1 and 82 students followed longitudinally from Grade 1 to Grade 2. Hierarchical linear regressions revealed that although spelling fluency was not a significant predictor of current or future reading or spelling ability, some measures of spelling accuracy were, particularly when letter-pattern knowledge was the basis of measurement. Implications for teaching and evaluating literacy skills and considerations for future research are discussed herein.

LIST OF ABBREVIATIONS

BAS3: British Ability Scales – Third Edition

CELF-5: Clinical Evaluation of Language Fundamentals – Fifth Edition

CTOPP-2: Comprehensive Test of Phonological Awareness – Second Edition

DASH: Detailed Assessment of Speed of Handwriting

TOSREC: Test of Silent Reading Efficiency

TOWL-4: Test of Written Language – Fourth Edition

TOWRE-2: Test of Word Reading Efficiency – Second Edition

WIAT-III: Weschler Individual Achievement Test – Third Edition

WRMT-III: Woodcock Reading Mastery Test – Third Edition

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CHAPTER 1: LITERATURE REVIEW

On the surface, spelling seems as simple as regurgitating rote memorization, but it is much more complicated than that. There are many cognitive skills that children use when spelling, such as letter-sound mapping and motor coordination, that make up the process of spelling and writing (e.g., Bonin, Méot, Lagarrigue, & Roux, 2015). However, most of the research to date has focused on spelling accuracy, or the product of spelling (e.g., Clemens, Oslund, Simmons, & Simmons, 2014; Sénéchal, 2017; Treiman, Kessler, Pollo, Byrne, & Olson, 2016). In doing so, important information about how children think about spelling has been neglected. Only recently have studies started measuring handwriting fluency, defined as the speed of accurate copying or spelling, to better understand spelling processes and the relations between these processes and the final product. In this chapter, we review available evidence and theoretical predictions as to whether there is a relation between handwriting fluency and spelling accuracy in early childhood and what this might tell us about how typically developing children think about spelling. Investigating the role of handwriting fluency in literacy development may provide more insight into theories of spelling development and processes as well as assist us in developing effective literacy teaching and interventions for children.

It is important to note that the research in the area of handwriting fluency and spelling accuracy is small and methodologically varied. Some studies have used copying tasks while others use spelling to measure handwriting fluency, even though they potentially tap different cognitive processes. Furthermore, the types of copying or spelling tasks used vary from writing letters of the alphabet to writing whole words or whole texts. Because of the differences in results between alphabet writing tasks, word writing, and text writing tasks, they will be discussed separately.

First, it is necessary to provide a brief description of handwriting fluency, which serves as its definition for the remainder of this chapter. Currently, there is no agreed upon definition of handwriting fluency in the literature. For this reason, we turn to the parallel literature on reading fluency for our definition of handwriting fluency. Although definitions of reading fluency are also debated, it is often thought to represent how quickly an individual is able to think about and accurately process not only whole words, but individual letters, sentences, and passages. "Processing" in the case of reading fluency refers to the ways in which children are thinking about the words; that is, how they make sense of their component phonological, orthographic, and morphological parts (Fuchs, Fuchs, Hosp, & Jenkins, 2001; Wolf & Katzir-Cohen, 2001). We use this as the foundation for our working definition of handwriting fluency, which here refers to the speed of accurately writing letters, words, or texts. As with reading fluency, this construct is intended to provide information on the speed and ease of accurately producing written language.

Theoretical Context

Before drawing connections between handwriting fluency and spelling accuracy, it is important to discuss theory related to how they develop throughout childhood; we begin with a brief review of theories of how accurate spelling is achieved in alphabetic languages. There are several models that describe the development of skilled spelling as occurring in stages over the course of childhood (see Deacon & Sparks, 2014 for a review). Some emphasize a child's growing ability to understand phonological rules, or the sounds that letters make when they are alone and together. Phase theory is one such example, which proposes that spelling development goes through three stages – pre-alphabetic, partial alphabetic, and full alphabetic – before reaching the final consolidated alphabetic stage, or fully accurate spelling (see Ehri, 2015 for a review). Transitions between stages are characterized by a deepening understanding of letter-sound relations in spelling. Models based in phonological rules suggest that accurate spellings occur when an individual fully understands the relations between letters and the sounds they make regularly and irregularly.

Other models, called constructivist in reference to a child's ability to construct their spelling from their knowledge of written language patterns, incorporate multiple skills into the process of achieving skilled spelling (see Deacon & Sparks, 2014 for a review). One example is the Integration of Multiple Patterns framework (IMP; Treiman & Kessler, 2014). IMP suggests that accurate spelling is achieved through combining units of language, particularly phonemes (letter-sound correspondences), graphemes (letter patterns), and morphemes (the smallest meaningful parts of words), which are statistically learned over the course of early childhood through gradual exposure to written words. These models propose that a child is able to spell words accurately after moving through multiple stages of integrating known rules with more complex rules that they learn throughout development.

Of note in both theories reviewed as well as most models of the development of accurate spelling is the absence of handwriting fluency. Although handwriting is necessary to produce a spelling on paper, its potential contribution is not considered in these models to date. Furthermore, there is no discussion of how handwriting skills may develop over time and what this might tell us about shifts in a child's understanding of written language; theoretically, it could indicate faster integration of the patterns that contribute to IMP, or rapid mapping of letters to sounds. Especially given models of reading development, which emphasize fluent reading in addition to accurate reading (see Ehri, 2015 for a review), this omission is notable in the theories of spelling development.

In an attempt to fill these gaps, we turn instead to models of *how* accurate spellings are produced, which offer more insight into the development of handwriting fluency, the relation between handwriting fluency and spelling, and what children may think about while spelling. A model of writing by Bonin and colleagues (2015) has proposed three broad stages in which these processes occur: input identification, central processing, and peripheral processing.

The first stage is the input identification stage. Here, the target word is presented and identified by the writer. When spelling, this is hearing and deciding which word is supposed to be written. Skilled writers who already have the word in their lexicon, or mental word bank, will also process it through the semantic system by identifying the meaning of the word before moving directly to the next stage. Those who do not have prior knowledge of the word skip the semantic processing step entirely (Bonin et al., 2015; Ellis, 1982).

Next is the central processing stage, wherein the identified target word is mentally translated into the letters needed to write it, also known as its orthographic representation. The process used to do this is best understood in the context of the dual-route hypothesis, which suggests that there are two potential routes that can be used to accurately produce a spelling depending on an individual's knowledge of the word (e.g., Ellis, 1982; Rapp, Epstein, & Tainturier, 2002; Sheriston, Critten, & Jones, 2016). When words are familiar, what is known as the lexical route is activated. Words are retrieved from an individual's lexicon, or mental word bank, as a whole and translated into letters before being written down (Ellis, 1982). If the word is a homophone (e.g., blue and blew), the semantic representation of the word established in the input identification stage is now used to help the writer decide which spelling is most appropriate (Bonin et al., 2015; Ellis, 1982; Olive, 2014). When words are unfamiliar, the whole word cannot be accessed in its full form as it does not exist in the lexicon, and therefore the sub-lexical route is used instead. This bypasses the lexicon completely and involves converting the sounds in the word into letters to piece together a potential spelling. These letters are held in the working memory until writing begins (Bonin et al., 2015; Ellis, 1982).

The final stage is peripheral processing, which is when handwriting occurs. Multiple decisions regarding letter writing must be made here, including the size of the letters, whether they are capitalized or lower-case, the position of the letters in the word (especially if letters are joined, as in cursive writing), and how neat the text should be, among others (Ellis, 1982). Motor patterns are then identified to produce the target letters. This involves deciding the order of motor activation, which way we are writing (e.g., left to right, right to left, etc.), and how large the movements need to be to produce the correctly sized letter. The motor movements are then activated, and handwriting can finally begin (Bonin et al., 2015; Ellis, 1982).

To illustrate how these processes would occur for novice and skilled spellers, consider again the homophones *blue* and *blew*. A novice speller would first hear the sounds in the word they are supposed to write and may recognize the word, but not know how to spell it. They would then use the sub-lexical route to begin translating the sounds into letters. Because they are potentially unaware of the differences in meaning between the two spellings, or even that there are two spellings of the word that could be correct, it is highly likely that they will use the more common representation of the sounds, or the word *blue*. Once the decision on which letters to write is complete, they would then begin writing the word using appropriate letter sizing and spacing. On the other hand, a skilled speller would hear and recognize the word quickly, using the context provided or inferred to develop a semantic representation of the word as either *blue* or *blew*. They would then access the word in their lexicon and begin writing the letters required to spell it.

The movement through the multiple stages of spelling is predicted to be rapid but differs slightly depending on the skill of the writer. Spelling is thought to be *sequential* in novice writers such that one stage must be finished before the next stage can begin. For instance, the full representation of the word needs to be established during central processing before motor movements can begin in the peripheral processing stage. Sequential processing is thought to occur in beginner writers because they have not yet mastered many writing skills; each one requires focus, and they are unable to do all of them at once. However, as writers develop and each stage becomes more automatic, the stages of spelling begin to happen *concurrently*. Automaticity of handwriting is thought to be achieved around age nine (Thibon, Gerber, & Kandel, 2018). Writers can then access word representations, select letters, and activate motor movements at the same time (Olive, 2014). It stands to reason, then, that a highly skilled speller should be able to begin writing faster than a novice writer, resulting in faster handwriting fluency and more accurate spelling.

There have been multiple theories that focus specifically on the relation between handwriting speed and spelling accuracy, each taking a slightly different approach. McCutchen (1996) proposed Capacity Theory, which suggests that the minimal resources available for our working memory and attention limit our ability to focus on more than one task at a time until that task becomes so automatic that working memory is bypassed (Sweller, 1988; Sweller & Chandler, 1994). To overcome this, working memory devotes resources to lower-order or more basic skills such as handwriting before resources can be allocated to higher-order or complex skills like spelling accuracy, ideation, and composition (Hayes & Flower, 1980). In this case, Capacity Theory posits that attention cannot be devoted to both handwriting and spelling when neither are automatic, which tends to be the case in novice spellers. To achieve accurate spelling, an individual who has not yet developed a lexicon of spellings in their long-term memory will need to rely on using the sub-lexical route to integrate the phonological, orthographic, and morphological components of the word. Because the sub-lexical route is slower and occurs sequentially rather than concurrently, and because it requires significantly more cognitive resources to use, it is theorized that it will result in slower handwriting fluency than if these processes were automatic.

While Capacity Theory provides insight into *why* handwriting speed might be slower, it does not provide much nuance as to *when* this might occur, which would be when the link between handwriting fluency and spelling is most obvious. Van Galen (1991)'s proposed the Cascade Theory, which allows us to answer the question of when these processes are occurring. According to this model and that of Bonin and colleagues (2015), spelling using the lexical or sub-lexical pathway comes before handwriting; we must know at least part of what we are going to write before we begin translating the word into print. Even without the addition of spelling, handwriting is a complicated psychomotor process requiring attention to case, letter form, letter size, and writing speed. A delay in the processing of constructing a spelling would cascade into handwriting and subsequently serve to delay that as well, suggesting that we may see a pause before handwriting begins or longer handwriting duration in novice spellers.

Taken together, these theories point to the possibility of using handwriting fluency as a tool to gauge an individual's spelling development and predict later spelling accuracy. More fluent handwriting suggests use of the lexical pathway to construct accurate spellings, which in turn might indicate that a child is more advanced in their spelling skills (Bonin et al., 2015; Ellis, 1982). The relation may also operate in the reverse; following McCutchen (1996)'s Capacity Theory, it is predicted that fluent handwriting frees cognitive resources that a child can dedicate to the more complex task of constructing an accurate spelling. Although no single theory yet exists to unify our understanding of the potential relation between handwriting fluency and spelling accuracy, empirical studies have started to investigate this further.

Empirical Evidence to Date

In recent years, the theoretical predictions of the relation between handwriting fluency and spelling accuracy have been empirically investigated. Various methods have been used to measure handwriting fluency, including alphabet writing, word writing, and sentence or passage writing fluency. Each of the methods of measuring handwriting fluency are evaluated individually due to differences in their results as well as in the potential underlying skills used – for instance, alphabet writing may not require letter-sound mapping in the way that spelling might. Studies of typically developing, school-aged children are discussed here; although there is a growing body of evidence examining the relation between spelling accuracy and typing fluency (see Feng, Lindner, Ji, & Joshi, 2019 for a review), its inclusion is beyond the scope of this review. Because of the sparse literature on handwriting fluency and its relation with spelling accuracy as a whole, studies in any language type (e.g., alphabetic, monosyllabic) are included with discussion of how different languages may account for varying findings.

Alphabet Writing

Alphabet writing fluency is one way of measuring handwriting fluency that investigates the automaticity of peripheral processes when writing (Bonin et al., 2015). It is one of the most common ways of measuring handwriting fluency to date and, with some exceptions, has been linked to spelling accuracy (Abbott, Berninger, & Fayol, 2010; Jiménez & Hernádez-Cabrera, 2019; Kent et al., 2014; Kim et al., 2014; Morin, Lavoie, & Montesinos, 2012; Olinghouse, 2008; Pontart et al., 2013; Puranik & Al Otaiba, 2012; Puranik et al., 2017; Rodríquez &

Villarroel, 2017; Salas & Silvente, 2020). The score is the total number of alphabet letters correctly written in order within a given timeframe; this has varied from one minute (Jiménez & Hernández-Cabrera, 2019; Morin, Lavoie, & Montesinos, 2012; Rodríquez & Villarroel, 2017; Puranik & Al Otaiba, 2012) to the first 15 seconds (Abbott, Berninger, & Fayol, 2010; Fayol & Miret, 2005; Kent, Wanzek, Petscher, Al Otaiba, & Kim, 2014; Kim, Al Otaiba, Puranik, Folsom, & Gruelich, 2014; Olinghouse, 2008; Salas & Silvente, 2020), or overall without a time limit imposed (Pontart, Bidet-Illdei, Lambert, Morisset, Flouret, & Alamargot, 2013; Puranik, Patchan, Sears, & McMaster, 2017). Some studies ask participants to copy alphabet letters, with an argument that this focuses measurement exclusively on the peripheral motor aspects of handwriting while limiting the influence of central processes such as letter-sound mapping or orthographic letter patterns (Jiménez & Hernández-Cabrera, 2019; Rodríquez & Villarroel, 2017). Although it deviates slightly from our definition of handwriting fluency, which emphasizes the speed of movement through all the processes of handwriting, copying alphabet letters is beneficial to approximate a pure measurement of the peripheral processes of spelling and handwriting. As such, copying-based alphabet writing tasks will still be reviewed here, but separately from memory-based alphabet writing tasks.

Most of the studies to date have found a significant relation between alphabet writing fluency and spelling accuracy. Small to moderate positive correlations have been found between concurrent measures of alphabet writing fluency and spelling accuracy in 11 studies of students in kindergarten through Grade 5 (Jiménez & Hernádez-Cabrera, 2019; Kent et al., 2014; Kim et al., 2014; Morin, Lavoie, & Montesinos, 2012; Olinghouse, 2008; Pontart et al., 2013; Puranik & Al Otaiba, 2012; Rodríquez & Villarroel, 2017; Salas & Silvente, 2020) and in multiple alphabetic languages including English, French, and Spanish. A small body of studies have replicated these findings longitudinally for Spanish-speaking students between Grades 1 to 2 (Jiménez & Hernádez-Cabrera, 2019), and Grades 1 to 3 (Rodríquez & Villarroel, 2017), French-speaking students in Grades 2 to 5 (Pontart et al., 2013), and English-speaking students in Grades 3 to 4 (Abbott, Berninger, & Fayol, 2010). Furthermore, two studies have shown this relation to withstand controls including earlier alphabet writing fluency as an autoregressor, oral letter naming fluency and knowledge, verbal- and non-verbal intelligence, age, gender, and race (Fayol & Miret, 2005; Puranik et al., 2017). One of those studies found that alphabet writing fluency at the beginning of kindergarten explained between four and 13 percent of the unique variance in spelling accuracy at the end of kindergarten, depending on how much time the students were given to write; having no limit for writing resulted in greater variance explained than both 15 and 60 seconds (Puranik et al., 2017). Similar results have been found in French-speaking children who were approximately eight years old; in the children who were already writing faster than their peers, alphabet writing speed accounted for 80% of the unique variance in a measure that combined spelling and grammar accuracy, and 45% of the variance in children whose handwriting was slower, even after controlling for known predictors such as reading accuracy (Fayol & Miret, 2005).

However, two studies did not find a significant relation between alphabet writing fluency and spelling. A study by Kim and colleagues (2014) found a significant correlation between alphabet writing fluency and concurrent spelling accuracy in English-speaking kindergarten students, this relation did not survive the inclusion of several important controls, including semantic knowledge, phonological awareness, oral letter naming fluency, and reading. This differs from the studies of Puranik et al. (2017) and Fayol and Miret (2005), which did not include phonological awareness as a control. Another study by Wagner and colleagues (2011) of

English-speaking Grade 1 and Grade 4 students found that when order of the letters was not a factor in scoring, the number of alphabet letters printed correctly in one minute was not significantly correlated with concurrent spelling accuracy in either grade. Typically, letter order is an important element of alphabet writing tasks (e.g., Puranik et al., 2017) which makes it similar to the letter-pattern knowledge proposed to be important in spelling.

Two studies have limited the lexical access components of alphabet writing fluency by investigating alphabet copying fluency, where participants were able to see the letters of the alphabet in front of them while writing. Both studies were conducted in Spain with Spanish-speaking students and included the same spelling outcome measures: irregular word spelling accuracy and pseudoword spelling accuracy. Alphabet copying fluency was significantly correlated with concurrent pseudoword spelling accuracy in Grades 1 and 2 (Jiménez & Hernández-Cabrera, 2019; Rodríquez & Villarroel, 2017), and concurrent irregular spelling accuracy in Grade 2 (Jiménez & Hernández-Cabrera, 2019). Interestingly, however, alphabet copying fluency was not significantly correlated with longitudinal pseudoword spelling accuracy in Grade 3 (Rodríquez & Villarroel, 2017), or irregular word spelling accuracy in Grades 1 and 3 (Jiménez & Hernández-Cabrera, 2019; Rodríquez & Villarroel, 2017). The authors of both studies pointed to potential differences in the education system in Spain as the reason for the absence of longitudinal relations. Students are taught irregular word spellings at the beginning of school and are provided with systemic instruction in handwriting skills, indicating that instructional practices may be important to the development of early copying fluency and spelling accuracy.

The null results of these studies may be due to the noted differences in methodology, particularly how well they included and accounted for underlying cognitive processes.

Controlling for phonological awareness in the study by Kim and colleagues (2014) eliminated the relation between alphabet writing fluency and spelling accuracy. Phonological awareness is an important skill underlying accurate spelling, as discussed in the theories above by Ehri (2015) and Treiman and Kessler (2016); because its inclusion eliminated the relation between alphabet writing fluency and spelling accuracy, it is possible that the relation is small or linked to phonological awareness in some way. Furthermore, Wagner et al. (2011) diverged with other studies using alphabet writing fluency by not necessitating correct letter order when scoring. This difference, though minor, may change the cognitive requirements for participants. When students write the alphabet in the correct order, they need to consider the letters, how to form the letter shapes, the size of the letters, the case of the letters, and the order in which they should be written to be correct. These steps are reminiscent of the central and peripheral processes described by Bonin et al. (2015) and, in some ways, seem to be a more simplistic version of spelling. However, if participants are told that order does not matter, they will have one less thing to hold in their working memory when writing the letters of the alphabet. This difference makes Wagner et al. (2011)'s measure of alphabet writing fluency more dissimilar to spelling than other measures of the same skill and could account for the lack of a relation found between alphabet writing fluency and spelling accuracy in this study.

In sum, both alphabet writing fluency and alphabet copying fluency have usually been found to be related to spelling accuracy (e.g., Jiménez & Hernádez-Cabrera, 2019; Kent et al., 2014; Puranik et al., 2017). Consistently, this is the case with studies analyzing the zero-order correlations between them (e.g., Jiménez & Hernádez-Cabrera, 2019; Olinghouse, 2008). The exceptions to this lie in the inclusion of related controls; although two studies controlling for predictors such as intelligence and oral letter naming fluency found that this relation was maintained (Fayol & Miret, 2005; Puranik et al., 2017), one study that added phonological awareness as a control eliminated the relation (Kim et al., 2014). Thus, alphabet writing fluency can be considered one small piece of the puzzle, but certainly not the whole explanation of how spelling accuracy is achieved.

The findings to date support current theory on the relation between alphabet writing fluency and spelling. Returning to Bonin et al. (2015)'s three-stage model of spelling and handwriting combined with McCutchen (1996)'s Capacity Theory, the proposed relation is such that fluent alphabet writing indicates more automatic peripheral processes which free attention for higher-order processes such as building spellings. We see this in the significant correlations between alphabet writing fluency and spelling accuracy, as well as the maintenance of the relation even when variables such as letter knowledge or letter naming fluency are controlled. However, alphabet writing fluency may also be related to spelling accuracy in their shared central processes, which is illustrated by the differences in findings between studies that necessitated order of alphabet letters and those that did not. When order was required of writing alphabet letters, it was found to be related to spelling accuracy (e.g., Abbott, Berninger, & Fayol, 2010; Puranik et al., 2017), but was not when students could write the letters in any order they remembered (Wagner et al., 2011). This suggests that a process not unlike spelling may be occurring during alphabet writing, with students perhaps accessing central processes to make use of developing skills like letter patterns. When alphabet writing is fluent for students, it stands to reason that they are able to at least have the beginnings of automatic letter pattern knowledge and peripheral motor skills, freeing extra resources that can be used for accurate spelling which students who do not have fluent alphabet writing may not have. However, alphabet writing fluency only potentially accesses central processes; word writing or spelling is predicted to always access central processes (e.g., Bonin et al., 2015). How, then, might these findings differ in studies of word writing fluency?

Word Writing

Word writing fluency is the least studied, yet arguably most ecologically valid, measure of handwriting fluency. Currently, there is no clear definition of word writing fluency as only two studies to date have measured it and did so using different methods (Babiygit & Strainthorp, 2010; Pontart et al., 2013), but it can broadly be thought of as the speed of writing individual words. Some studies have used coarse measures such as the number of words that can be correctly written in one minute to assess word writing fluncy (e.g., Babyigit & Stainthorp, 2010). Recently, however, technological advances and the use of digitizing tablets to record handwriting in real-time have made measuring word writing fluency more precise (e.g., Pontart et al., 2013), providing the time in milliseconds it takes to write a single word.

Unlike studies of alphabet writing fluency, the results of word writing fluency studies have been mixed as to their relation with spelling accuracy. Pontart and colleagues (2013) used a digitizing tablet to record how quickly 84 French-speaking students in Grades 2 through 9 were able to write their first and last name three times in a row. Spelling accuracy was assessed separately using an experimental spelling task of common nouns. Pontart et al. (2013) found a moderate, positive correlation between word writing fluency on the name writing task and the percentage of words spelled incorrectly on the spelling test. Bobayigit & Stainthrop (2009) conducted a similar study with 57 Turkish-speaking students that they followed from Grade 1 to Grade 2. They found that handwriting speed, which was measured by having the Grade 1 students write the first three days of the week as many times as they could in one minute, was not correlated with the percentage of spelling errors they later made in a word and pseudoword spelling task in Grade 2.

Only two studies have been conducted on the relation between word writing fluency and spelling accuracy, and the major methodological differences between them may account for their different findings. While Pontart and colleagues (2013) measured spelling accuracy using real nouns, Babyigit & Strainthorp (2009) assessed spelling accuracy using a mix of real and pseudowords. Recall from the findings of the alphabet writing fluency studies that differences have been found in the relation between handwriting fluency and real word versus pseudoword spelling accuracy (Jiménez & Hernández-Cabrera, 2019; Rodríquez & Villarroel 2017). Combining the two in the outcome could make it difficult to detect the effect of word writing fluency on either and may account for the null results of Babyigit & Strainthorp (2009).

In addition to methodology, the languages in which the studies were conducted differ in orthographic complexity. The study by Pontart et al. (2013) was conducted with French-speaking students while Babyigit & Strainthrop (2009)'s participants spoke Turkish. In more shallow orthographies such as Turkish, orthographic rules are easier to grasp as phoneme-grapheme correspondences are simpler than those in deeper orthographies like French and tend to match what is heard in spoken language (Babyigit & Strainthrop, 2009). There is no need to hold complex rules in memory even if a word is not stored in the long-term lexical memory, freeing up cognitive resources and attentional capacity to devote to handwriting per Capacity Theory (McCutchen, 1996). In theory, Turkish-speaking students should have more cognitive resources to devote to writing words fluently and accurately than French-speaking students. These differences would be especially obvious in early childhood, when children learning deeper orthographies have fewer words in their lexical memory and more rules to hold in their working memory when printing.

In the very few studies to date, the languages and methodology differ too greatly to draw conclusions about the relations between word writing fluency and spelling accuracy. While one study points to a moderate relation between the two (Pontart et al., 2013), the other suggests no relation at all. Comparisons of handwriting fluency between languages varying in orthographic complexity would be valuable to rule out language as a factor in these differences. However, more studies, especially those controlling for other variables such as phonological awareness and letter reading fluency, are necessary to determine whether there is a relation between word writing fluency and spelling accuracy in any language.

Sentence and Paragraph Writing

Sentence or paragraph writing fluency is a measure of handwriting fluency that is typically found to be related to spelling accuracy. It counts how many words are written by a student within a certain timeframe as they write longer pieces of text. In some of these tasks, this is a sentence (Ding, Li, & Wu, 2020; Wagner, Puranik, Foorman, Forster, Wilson, Tschnikel, & Kantor, 2011; Wicki, Lichtsteiner, Geiger, & Müller, 2014; Yan, McBride-Change, Wagner, Zhang, Wong, & Shu, 2012) while others require a written or copied paragraph (Berninger, Yates, Cartwright, Rutberg, Remy, & Abbott, 1992; Bosga-Stork, Bosga, Ellis, & Muelenbroek, 2016; Graham, Berninger, Abbott, Abbott, & Whitaker, 1997). It is important to note that the methodology used in these studies differs – some studies use sentence writing while others use paragraph writing, and others still use paragraphing copying. Sentence and paragraph writing tasks are discussed together here as the differences between them are related to areas such as ideation and composition, which theoretically come after handwriting and spelling accuracy have been achieved (Hayes & Flower, 1980). Although differences in the amount of ideation required may differ between paragraph and sentence writing, as well as paragraph writing versus copying, this is not indicated in the results to date. As such, all studies are described together with notes indicating the methodology used as required.

The majority of studies to date have found a relation between sentence and paragraph writing fluency and spelling accuracy (e.g., Berninger et al., 1992; Bosga-Stork et al., 2016; Ding et al., 2020; Graham et al., 1997; Wicki et al., 2014; Yan et al., 2012). One of the first studies to do so was done by Graham and colleagues (1997) with 600 English-speaking students, 100 each in Grades 1 through 6. At each time point in this cross-sectional study, students were asked to complete a battery of tests which included copying a short paragraph and completing a standardized spelling test. At all grades, the authors found that paragraph copying fluency was significantly, moderately correlated with spelling accuracy, both concurrently and longitudinally. Similar findings in English-speaking (Berninger et al., 1992) and Cantonese-speaking students (Yan et al., 2012) in Grades 1 through 3, as well as German-speaking students in Grade 4 (Wicki et al., 2014) suggest that this relation between sentence and paragraph writing fluency and spelling accuracy persists across languages of varying orthographic complexity as well. It is clear, then, that the fluency of sentence and paragraph writing is related to current and future spelling accuracy in a number of different contexts.

This relation between sentence or paragraph writing fluency and spelling accuracy is also found in the presence of control variables. A particularly interesting longitudinal study of Chinese-speaking students found a relation between sentence writing fluency and spelling, even after controlling for other key predictors. Ding, Li, & Wu (2020) asked students to complete a sentence copying task in each of Grades 1, 3, 4, and 5 in addition to a battery of other tasks measuring spelling accuracy. Sentence copying fluency in Grade 3 predicted spelling accuracy in Grade 4, even after accounting for known predictors of spelling accuracy such as non-verbal IQ, phonological awareness, and rapid naming. These results point to a robust relation between sentence copying fluency and spelling accuracy that can survive the inclusion of multiple known predictors.

Few studies have failed to find a relation between sentence or paragraph writing fluency and spelling accuracy. Despite the findings of Ding et al. (2020), which supported a relation between sentence copying fluency and spelling accuracy, Wagner and colleagues (2011) found no significant concurrent correlation between the two in neither English-speaking Grade 1 nor Grade 4 students. Some studies found significant relations in earlier grades that did not persist as participants aged. For instance, Bosga-Stork and colleagues (2016) found that the paragraph copying fluency of Dutch-speaking students in Grade 1 did not significantly predict the spelling accuracy of those students in Grade 3, although it did significantly predict their spelling accuracy in Grade 2.

These null results may be explained once again by differences in methodology between studies of sentence and paragraph writing. The outcome measure of spelling accuracy is one such area that may impact the detection of a relation between sentence or paragraph writing fluency and spelling accuracy. Recall from previous sections that in their study, Wagner and colleagues (2011) measured spelling accuracy using a piece of text that the students were asked to compose rather than a separate spelling-to-dictation task as the other studies described in this section have used. Not only were the students focusing on handwriting and spelling at the same time, but they also needed large amounts of attention focused on other higher-order writing skills like ideation and composition (Hayes & Flower, 1980). This may confound their findings on both handwriting speed and spelling accuracy.

We also see potential developmental effects that differ between the language spoken by the participants. For example, although a relation is found between paragraph writing fluency in Grade 1 and spelling accuracy in Grade 3 in English-speaking students (Berninger et al., 1992), it is not found in same-aged Dutch-speaking students (Bosga-Stork et al., 2016). One possible explanation is that the age range where we see this relation varies across languages. For instance, handwriting automaticity may be achieved earlier in Dutch than in English, which could eliminate the dependent relation between handwriting fluency and spelling.

Based on the research to date, there appears to be a robust relation between sentence or paragraph writing fluency and spelling accuracy (e.g., Berninger et al., 1992; Bosga-Stork et al., 2016; Ding et al., 2020; Graham et al., 1997; Wicki et al., 2014; Yan et al., 2012), with some null results attributable to developmental or methodological differences. These findings are expected by theoretical predictions (LaBerge & Samuels, 1974; McCutchen, 1996) according to which spelling accuracy will improve as handwriting skills are more practiced and automatic. When students' handwriting is fluent, it allows them to redistribute cognitive resources to higher-order tasks like spelling accurately (Hayes & Flower, 1980; McCutchen, 1996). Similarly, when students can spell accurately and with less effort, it allows them to develop ideas and translate them into text with more ease (e.g., Graham et al., 1997). The bidirectional relation between spelling accuracy and writing sentences or paragraphs fluency is empirically and theoretically supported in the small amount of research completed thus far.

Meta-Analysis

The body of research on handwriting fluency is growing and in 2019, Feng and colleagues published the first meta-analysis on the relation between handwriting fluency and spelling accuracy in children and adolescents based on the results of seven studies. Of these, three studies measured spelling errors, which should theoretically be lower when handwriting fluency is high, and four measured spelling accuracy. Studies using all metrics of handwriting fluency were included (e.g., alphabet, word, and sentence writing fluency), although the type used in each of the seven studies are not specified in paper. The meta-analysis did not find a significant correlation between either handwriting fluency and spelling errors or handwriting fluency and spelling accuracy.

There are some caveats to this meta-analysis that should be noted here. First, the studies included in the meta-analysis use a wide range of metrics to assess handwriting fluency. In some, handwriting fluency was measured with alphabet writing, while others used word and sentence or paragraph writing fluency tasks. Based on the literature reviewed in the previous sections, we see that the type of task used can alter whether there is a relation between handwriting fluency and spelling outcomes. For instance, findings have been more robust for studies using sentence or paragraph writing fluency (e.g., Graham et al., 1997) compared to the mixed results of the few word writing fluency tasks to date (Babyigit & Strainthrop, 2009; Pontart et al., 2013). Second, not all of these studies were using children in the same age group. Some studies had young children under the age of 10 years while others included adolescents. Automatization of spelling and handwriting usually occurs around nine years old (Thibon, Gerber, & Kandel, 2018), which makes it unlikely that there would be a relation between the two beyond early to late childhood. Finally, it is worth noting the limited number of studies included; only seven studies were used in the meta-analysis, despite the larger number of studies of handwriting fluency available.

Interpretation of the authors' findings should be cautious as not all of the available evidence was included in their meta-analysis. These drawbacks may account for the null results of the meta-analysis. Future high-quality meta-analyses of specific writing tasks (e.g., alphabet, word and sentence or paragraph writing) or specific age groups are necessary to confirm or reject the findings of Feng et al. (2019).

Discussion

Key Findings

Across studies implementing all three methods of studying handwriting fluency, we generally see reports of a significant positive relation between handwriting fluency and spelling accuracy. This relation may vary due to the orthographic complexity of the language under study, the controls included in the analyses, and the age of the participants. However, the results overall provide support for a relation between handwriting fluency and spelling accuracy. Knowing this can help practitioners such as school psychologists and occupational therapists to design intervention plans for beginning writers; targeting slow or dysfluent handwriting may help to improve other writing processes such as spelling accuracy.

We see theoretically and in practice that handwriting is not just a motor task. It requires multiple steps before a letter, word, or text can be produced (Bonin et al., 2015). This is seen not only in the correlations between handwriting fluency and spelling, but also in their shared underlying skills (Berninger et al., 1992). Furthermore, the findings align with Cascade Theory (van Galen, 1991), which suggests that each central processing step before handwriting – such as knowledge of the target word, translating phonemes to graphemes, and so on – cascades into the peripheral processes of handwriting (e.g., speed, selecting letter shapes, letter size, script).

The correlation between handwriting speed and spelling accuracy lends support to the Capacity Theory (McCutchen, 1996) as well. When a child must focus their attention on both handwriting and spelling skills, they cannot do either rapidly or efficiently. The attention that must be devoted to handwriting constrains that which can be devoted to spelling, and vice versa. Furthermore, we see evidence of LaBerge and Samuels' (1974) model of automaticity. As a skill such as spelling becomes more automatic such that whole spellings can be accessed in long-term memory rather than built from known spelling rules, we are able to do it faster, which could be seen in more fluent handwriting.

Educational Implications

Given that both theoretical predictions and the empirical evidence to date generally support a relation between handwriting fluency and spelling accuracy (e.g., Graham et al., 1997; McCutchen, 1996; Pontart et al., 2013), emphasizing the teaching of handwriting in early elementary may be beneficial for students' literacy development. In Nova Scotia, the Department of Education and Early Childhood Development has made printing with appropriately spaced letters part of the English Language Arts curriculum in Primary and Grade 1 (Province of Nova Scotia, 2019). However, developing fluent handwriting with appropriately sized and formed letters is not a curriculum outcome in any elementary grade. Instead, the emphasis is placed on the conventions of writing – for instance, using correct capitalization or recognizing that words are written from left to right. The current research supports the inclusion of handwriting fluency as an additional outcome, particularly in early elementary. Even before students have learned to write words, alphabet writing fluency has been found to be a significant predictor of future spelling accuracy in Primary-grade students (e.g., Fayol & Miret, 2005; Puranik et al., 2017). Explicit teaching of how to form letters and how to do so fluently may help to make this process more automatic for students early, and according to theoretical predictions (e.g., McCutchen, 1996; LaBerge & Samuels, 1974), could provide more cognitive resources to focus on accurately spelling target words. This might provide a more solid foundation upon which students can build their literacy skills.

The relation between handwriting fluency and spelling accuracy can also help us to understand the skills that may be weaker in students who have difficulty with spelling. Assessing the handwriting fluency of a student referred for a psychoeducational assessment due to challenges with spelling may be of benefit when developing a complete picture of their learning profile. The Beery-Buktenica Test of Visual-Motor Integration (Beery, Buktenica, & Beery, 2010) is one commonly used measure of fine-motor coordination in Nova Scotia, but it emphasizes the fluency and accuracy of the formation of abstract shapes or lines. This does not tell us how quickly the student is able to access lexical representations of words. Based on theoretical predictions (e.g., Bonin et al., 2015), it also does not allow us to measure the literacy-based relation between handwriting fluency and spelling accuracy; the peripheral processes of interest in handwriting such as letter sizing, spacing, and formation are all specific to letters and words rather than shapes. Tests such as the Detailed Assessment of Speed of Handwriting (Barnett, Henderson, Scheib, & Schulz, 2007), which specifically assesses alphabet and word writing fluency, may provide us with more insight into why spelling is challenging for a student and which interventions could help them make gains.

Typical interventions for spelling difficulties include phonological awareness training by default (e.g., Sénéchal, Ouellette, Pagan, & Lever, 2012), but if handwriting fluency is contributing to or correlated with these challenges then it may also be a target for improvement. Few manualized interventions have enough empirical evidence to support their use in improving handwriting fluency (e.g., Handwriting Without Tears; Engel, Lillie, Zurawski, & Travers, 2018), but many general teaching strategies have been identified in the research to date. Implementing short, daily handwriting lessons lasting no longer than 15 minutes per day has been found to result in improvements in handwriting fluency (e.g., Berninger et al., 1997; Graham, McKeown, Kiuhara, & Harris, 2012). In addition, providing students with explicit feedback, modeling, and guided practice using visual cues has been shown to be helpful (Berninger et al., 1997; Datchuk & Kubina, 2013; Graham et al., 1997). Using these strategies to improve handwriting fluency may in turn benefit the growth of a student's spelling accuracy.

Future Directions

The study of handwriting fluency is only just beginning to grow in the literature, and there is plenty of room for future research. Studies of the relation between word writing speed and spelling outcomes are sparse (e.g., Babayigit & Strainthorp, 2009; Pontart et al., 2013) and should be investigated further, as this is the component of writing that we are most commonly asking young children to do in Nova Scotia (Province of Nova Scotia, 2019). No studies to date have used the handwriting fluency of spelling words, as one might in a spelling test, to predict future spelling outcomes. Relying only on single, well-practiced orthographic representations (in alphabet writing) or requiring ideation before writing in the case of sentence or paragraph writing may over- or under-estimate the cognitive processes purely involved in spelling (e.g., Hayes & Flower, 1980). It may also be of benefit to analyze the difference in predictive power, if any, between measures of alphabet writing, word writing, and sentence or paragraph writing fluency. Evidence to support one or more of these measures as predictors of future literacy may help us to better design curricula to be developmentally appropriate for students.

We also come across the question of directionality – does spelling accuracy predict handwriting fluency, or does handwriting fluency predict spelling accuracy? According to van Galen (1991) and Abbott et al. (2010), spelling accuracy is achieved before fluent handwriting. However, there is also the suggestion that spelling accuracy is a higher-order skill that can only be achieved after lower-order skills like fluent handwriting are mastered (e.g., Hayes & Flower, 1980). This has not been explored empirically in great detail but would be helpful when designing interventions to ensure that the appropriate skills are targeted for improvement in struggling students.

Finally, future research requires more nuance in how and why we measure handwriting fluency. Is it important that a child can legibly write a letter, or is it more valuable that they can efficiently write a word, sentence, or paragraph? In Nova Scotia, the curriculum places little emphasis on letter writing and instead expects students to be able to accurately spell words and express their ideas in text (Province of Nova Scotia, 2019). Furthermore, theory supports learning lower-order skills such as letter writing fluency before higher-order skills necessary for long-term success such as spelling and composing can be achieved (e.g., Hayes & Flower, 1980). Perhaps, however, there is space for both at different points of development; based on the available research, there are preliminary findings suggesting developmental effects of handwriting fluency on spelling accuracy (e.g., Bosga-Stork et al., 2016). Although obvious, it is worth pointing out that alphabet letter and word writing are different, especially when we appreciate that handwriting is not a purely motor task and is influenced by other cognitive components involved in written production. In a similar vein, we need consistency in how we define handwriting fluency (e.g., letter, word, or sentence or paragraph writing). This will allow for better interpretations and conclusions when looking at the body of transcription literature as a whole.

CHAPTER 2: STUDY

Introduction

Our society runs on literacy, defined here as reading and spelling abilities. In order to use written text to communicate at work, in school, or in our daily lives, one must be literate. It is for this reason that understanding the underpinnings of literacy is essential. This is especially important in early childhood, when literacy-related learning is most critical for long-term success (National Reading Panel, 2000; Annie E. Casey Foundation, 2010).

It is well known that literacy skills influence each other - children learn to read through spelling and learn to spell through reading (Davis & Bryant, 2006). Indeed, spelling and reading have been thought to rely on similar underlying processes, with Perfetti (1997) referring to them as “two sides of the same coin”. Ample research has been done on these processes, including studying spelling accuracy across early development. Despite this, there are still skills contributing to literacy that have yet to be captured in the literature. One potential skill is spelling fluency - the speed at which individual words are spelled accurately. The study of spelling fluency theoretically follows from parallel literature in reading fluency, which has been found to be a pillar in literacy development (National Reading Panel, 2000). We are uniquely positioned to explore spelling fluency more accurately than ever before by using an innovative new technology that records writing in real-time. In the present study, we ask whether spelling fluency is a predictor of reading and spelling outcomes in early childhood beyond what is accounted for by existing measures of spelling accuracy.

Theoretical Context

To better understand how spelling might help us predict future literacy skills, we begin by reviewing theory on spelling development in childhood, and how it might influence reading and future spelling development. The idea that accurate spelling could predict future reading and spelling ability naturally follows from theory suggesting that they support each other; children tend to learn letter patterns from reading which they then apply to spelling, and later use their understanding of letter-sound relations from spelling to read more accurately (Davis & Bryant, 2006; Frith, 1985). There is also obvious logic behind using spelling as a predictor of literacy in that a child capable of spelling a word correctly at one time point should still be able to spell it correctly at a later time point. Given that accurate spelling requires more complete orthographic representations of words in memory than reading (e.g., Holmes & Castles, 2001), it should also predict later reading ability.

Some theories suggest that the accuracy of spellings can tell us where a child is in their spelling development and may provide insight into the developmental trajectory of their literacy skills. One such model, phase theory, states that spelling development goes through three stages requiring an increasingly complex understanding of letter-sound correspondences – pre-alphabetic, partial alphabetic, and full alphabetic – before reaching the fourth and final consolidated alphabetic stage, or fully accurate spelling (see Ehri, 2015 for a review). Transitions between stages are characterized by a deepening understanding of letter-sound relations in spelling, beginning with no knowledge and ending with a complete ability to map sounds to letters. The Integration of Multiple Patterns framework (IMP; Treiman & Kessler, 2014) adds to this by suggesting that accurate spelling is achieved gradually through learning about how to use a combination of units of language, particularly phonemes (letter-sound correspondences), graphemes (letter patterns) and morphemes (the smallest meaningful parts of words), which occurs over the course of early childhood through exposure to written words.

Accuracy is not the only component of spelling that can provide us with insight into literacy development; the fluency of spelling may also be an important metric to consider, based in part on a robust parallel literature on reading fluency, or the speed of accurate word reading (e.g., Speece & Ritchey, 2005). According to LaBerge & Samuels (1974)'s information processing model, reading is a process; before being able to understand text, individual words must go through lower-order processes such as visual recognition and phonological processing. These lower-order processes require large amounts of attention, resulting in less attention being devoted to higher-order processes like whole-word reading. It is not until reading fluency is mastered that a reader can begin to shift their focus to accurately understanding individual words and the contextual meaning of text. This requires well-developed cognitive links between higher- and lower-order processes, which takes time and practice. Given that reading and spelling are so intertwined (e.g., Davis & Bryant, 2006), it is likely that spelling follows a similar process requiring mastery of fluency before accuracy. However, spelling fluency is arguably more complicated than reading fluency due to the addition of motor skills required to physically form letters; attention would need to be devoted to individual letter formation as well as phonological processing before spelling accuracy could be achieved (Bonin, Méot, Lagarrigue, & Roux, 2015).

Indeed, there is a small theoretical basis for understanding how spelling fluency might predict both spelling and reading development. One possibility for framing this may be through a staged model of skilled spelling development (Bonin et al., 2015). Bonin and colleagues (2015) proposed three stages in the writing process of skilled spellers. The first, input identification, is where the target word is identified and semantically recognized. The second stage is central processing, wherein the target word is translated into the letters needed to write it, known as its orthographic representation, by either decoding or accessing long-term memory to pull these representations into working memory until writing begins. The final stage is peripheral processing, where motor activation and the act of handwriting begins; this includes decisions such as the size and case of the letters, whether the letters should be joined or not, and the quality of the printing required of the task.

Each stage requires ample amounts of attention, especially in novice writers, and Capacity Theory (McCutchen, 1996) provides insight into how much attention is allocated to each stage and how this is prioritized during handwriting. It posits that novice writers do not yet have a large long-term memory bank of word spellings, or a lexicon, and instead rely on their working memory to facilitate the integration of the phonological, morphological, and orthographic rules at the central processing stage to produce an accurate spelling. They are also less familiar with the letter forms and motor movements needed to write the word at the peripheral processing stage and therefore may also need to devote attention here. Because working memory is a limited resource that can only focus on one unit of information at a once (Sweller, 1988; Sweller & Chandler, 1994), one cannot devote attention to both central and peripheral processes at the same time. This theoretically results in slower time to begin spelling as novice writers first focus on the central processing of the word before they can activate peripheral motor movements to initiate writing. When spellings are not yet accurate, recording the length of time it takes for a child to begin writing a word could provide an indication of the development of their lexicon – the longer it takes to begin producing a spelling, the more the child is relying on working rather than long-term memory. There is certainly a case for this in the parallel reading fluency literature with the automaticity of lexical access, or how quickly readers can either automatically recognize or decode individual words (e.g., Baddeley, Logie, Nimmo-Smith, & Brereton, 1985; Bowers, 1995). This also helps with establishing how advanced a child is in their literacy development, which may allow us to predict future reading and spelling skills.

Spelling Accuracy as a Predictor of Literacy

Despite the theory suggesting that both spelling accuracy and spelling fluency may predict future literacy development, only spelling accuracy and various methods of scoring it have been studied in depth. Indeed, the evidence to date supports binary spelling accuracy as a strong predictor of later spelling and reading ability. Accurate spelling at the end of Primary has been found to contribute 39% of the variance to models of Grade 1 reading skills (Clemens, Oslund, Simmons, & Simmons, 2014) while accurate spelling at the beginning of Grade 1 has been found to account for 6% of the variance in reading at the end of Grade 1 (Sénéchal, 2017). Findings have been similar when investigating accurate spelling as the outcome; correct spelling in Grade 1 has been found to significantly predict correct spelling in Grade 2, accounting for 66% of the total variance (Treiman, Kessler, Pollo, Byrne, & Olson, 2016). Some studies have attempted to score spellings using binary methods outside of letter-based accuracy. For instance, Treiman and colleagues (2016) proposed applying a binary score to the phonological plausibility of a spelling, with one point awarded if all phonemes, and only those phonemes, were represented regardless of the conventionality of the spelling (i.e., spelling *cat* as *kat* or *act*), and zero points awarded otherwise (i.e., spelling *cat* as *k* or *kats*). However, this metric did not perform as well as letter-based binary correctness in a direct comparison.

Recently, methods of scoring spelling accuracy outside of correct or incorrect have been used as predictors of reading and spelling ability. This is supported by models reviewed above such as phase theory (Ehri, 2015), which suggest that completely accurate spellings are not achieved until later in literacy development. The use of non-binary methods of scoring spelling accuracy – that is, scoring spellings on a continuum of correctness – have been gaining traction in studies of young children when binary scoring may not be developmentally appropriate. There are three general ways that spellings have been scored using non-binary methods (see Treiman, Kessler, Pollo, Byrne, & Olson, 2016 for an in-depth review). The first, letter sequence, considers a child's understanding of orthographic rules by awarding one point each for the presence of the correct first and last letters of a word as well as one point for each correct two-letter sequence (e.g., when correctly written, the word *hat* would get four points – one for *h*, one for *t*, one for *ha*, and one for *at*). Scoring using sound spelling considers phonology alone, with one point awarded for each correctly represented phoneme in a word, regardless of the position or whether conventional letters were used (e.g., *hat* would earn three points, as would *hta*). Mixed scoring considers both orthographic and phonological correctness. Various methods of mixed scoring exist, the most common coming from Tangel and Blachman (1992), but all generally score on a scale of zero to six points based on the orthographic correctness and phonological plausibility of a spelling; only words spelled conventionally correctly receive full points. By assessing the skills that are developmentally expected and important for children's spelling we are theoretically obtaining a metric that is more sensitive to a child's true literacy abilities, now and in the future, than binary scoring.

The evidence to date supports the use of non-binary spelling scores as predictors of later literacy, especially in children who are poorer or beginner spellers. Purely orthographic predictors such as letter sequence and purely phonological predictors such as sound spelling have been shown to significantly predict Grade 1 reading (Clemens et al., 2014; McBride-Chang, 1998) and Grade 2 spelling (Treiman et al., 2016) when first measured in Primary. In Primary, mixed scoring, which considers both orthographic and phonological correctness, has been found to significantly predict reading and spelling in Grade 1 (Ouellette & Sénéchal, 2017; Sénéchal, 2017), and to significantly predict reading and spelling in Grade 2 when measured in Grade 1

(Treiman et al., 2016; Treiman, Hulslander et al., 2019). Studies directly comparing the predictive power of these metrics have found that Primary orthographic scores tend to be stronger predictors of Grade 1 spelling than both mixed and phonological scores (Treiman, Hulslander et al., 2019; Treiman, Kessler, & Caravolas, 2019). It is important to note, however, that non-binary metrics only outperform binary metrics when children are unable to spell any words correctly. Treiman, Kessler, and Caravolas (2019) found that binary correctness in the spelling of British children at the end of Reception Year and at the beginning of Year 1 was the best predictor of spelling ability in Grade 2 in all children except those who were unable to spell any words correctly. Therefore, there is some variability in the usefulness of accuracy scores depending on the baseline performance on the child.

Certainly, binary and non-binary spelling accuracy are useful predictors of reading and spelling skills, but they do not tell the full story of literacy development; there is still variance for which there is no explanation and theory highlighting the importance of other skills such as spelling fluency. In a study of English-speaking Primary students, Ouellette and Sénéchal (2017) included mixed spelling scores in models predicting reading and spelling in Grade 1. Even when including other known predictors, such as alphabet knowledge, vocabulary, and phonological awareness in Primary, these models only accounted for 52% of the variance in Grade 1 reading and 33% of the variance in Grade 1 spelling. It is unclear if the addition of other binary and non-binary predictors to the model would increase the amount of variance accounted for, or if there is another skill that has yet to be measured contributing to literacy. Current theory would suggest the latter; despite theory highlighting the importance of its parallel reading fluency (e.g., LaBerge & Samuels, 1974), spelling fluency has been largely ignored in studies of literacy development. It is for this reason that we focus on spelling fluency as a predictor of reading and spelling outcomes in the current study.

Spelling Fluency as a Predictor of Literacy

Spelling fluency has rarely been investigated as a predictor of reading and spelling development, despite a growing theoretical basis pointing towards its potential importance (e.g., Bonin et al., 2015; McCutchen, 1996). Further study of spelling fluency may be warranted based on the evidence supporting the importance of its counterpart, reading fluency. Reading fluency is not only highly correlated with other reading skills and spelling (e.g., Martin-Chang, Ouellette, & Madden, 2014; Moll & Landerl, 2009; Ouellette, Martin-Chang, & Rossi, 2017), but it is also recognized as a primary predictor of future literacy. In their 2000 report on evidence-based reading instruction, the National Reading Panel identified reading fluency as one of the essential skills underpinning literacy. It has also been considered an indicator of skilled reading because it is necessary for reading comprehension, a critical skill for lifelong literacy success; one must be able to read text fluently before sense can be made of what has been read (Fuchs, Fuchs, Hosp, & Jenkins, 2001). In the numerous theories of spelling development (e.g., the IMP framework by Treiman & Kessler, 2014; Ehri's phase theory, 2015), fluent spelling is not described as a goal or piece of the process. It is surprising, given the emphasis on reading fluency and the established relation between reading and spelling, that this research has rarely been extended to include spelling fluency.

Predictions about the role of spelling fluency in literacy development can be drawn from the broader literature on handwriting fluency, a term which also encompasses alphabet writing fluency. Studies of alphabet writing fluency, which measure how many letters are written in a given timeframe, have consistently found it to be a significant predictor of future spelling accuracy (e.g., Abbott, Berninger, & Fayol, 2010; Jiménez & Hernádez-Cabrera, 2019; Kent et al., 2014; Kim et al., 2014; Morin, Lavoie, & Montesinos, 2012; Olinghouse, 2008; Pontart et al., 2013; Puranik & Al Otaiba, 2012; Rodríquez & Villarroel, 2017; Salas & Silvente, 2020), although this has not yet been extended to word reading accuracy. One such study by Puranik and colleagues (2017) found that letter writing fluency at the beginning of kindergarten explained up to 13 percent of the unique variance in spelling accuracy by the end of kindergarten. Given that fluent letter writing is a necessary step in being able to spell words fluently, it follows that spelling fluency should also be a predictor of future spelling accuracy.

To our knowledge, only two studies have investigated the relation between spelling fluency and future spelling accuracy, although findings on whether this relation exists have been mixed and again have not been extended to word reading accuracy. A study by Pontart and colleagues (2013) of French-speaking students in Grades 2 through 9 found a moderate, positive correlation between name spelling fluency and spelling accuracy on a spelling test. A similar study by Babayigit and Stainthrop (2009) followed Turkish-speaking students from Grade 1 to Grade 2 but did not find a significant correlation between spelling fluency in Grade 1 and spelling accuracy in Grade 2. The contrasting findings from these studies as well as the sparse literature on spelling fluency as a predictor of spelling and reading accuracy are notable and worthy of further investigation. In the current work, we intended to replicate and extend these findings using innovative new technology that allows us to record spelling in real-time. We also explored, for the first time, the predictive power of spelling fluency on reading outcomes.

Present Study

The present study examined whether a new variable, spelling fluency, can predict reading and spelling skills in early childhood. It is known that both binary and non-binary metrics of spelling accuracy are predictors of literacy skills, particularly between Primary and Grade 2 (Clemens, Oslund, Simmons, & Simmons, 2014; McBride-Chang, 1998; Ouellette & Sénéchal, 2017; Sénéchal, 2017; Treiman et al., 2016; Treiman, Hulslander, et al., 2019; Treiman, Kessler, & Caravolas, 2019). However, the role of spelling fluency is less well-known, especially for reading outcomes. Therefore, we asked whether spelling fluency can offer additional insight into children's reading and spelling abilities beyond what is currently accounted for by binary and non-binary measures of spelling accuracy.

Our research study addressed three main questions. The first question asked whether a model that included Grade 1 spelling fluency as a predictor of concurrent reading accuracy was superior to models that only included binary and non-binary measures of spelling accuracy as predictors. Our second question extended the first by investigating this longitudinally; we asked whether this was the case in a model predicting Grade 2 reading accuracy. We hypothesized that spelling fluency in Grade 1 was a significant predictor of reading outcomes in Grade 1 and Grade 2, beyond what is accounted for by known predictors including binary and non-binary spelling accuracy. Although no theory or research has examined the predictive power of spelling fluency on reading, the predicted results can be understood through Capacity Theory (McCutchen, 1996) and the staged model of writing (Bonin et al., 2015) in addition to previous work on handwriting fluency. In short, if one is focused on quickly writing letters, they cannot focus on the spelling rules contributing to accurate spelling (Graham, Berninger, Abbott, Abbott, & Whitaker, 1997; Wicki, Lichtsteiner, Geiger, & Müller, 2014; Medwell & Wray, 2007). Given that accurate, fluent spelling requires more complete representations of words and letters in memory than reading (e.g., Holmes & Castles, 2001), it follows that fluent spelling would be predictive of more accurate word reading.

Additionally, we asked whether a model that included Grade 1 spelling fluency as a predictor of Grade 2 spelling accuracy was superior to models that only included binary and non-binary measures of spelling accuracy. Although the results of previous work focused explicitly on spelling fluency have been mixed as to whether there is a relation between spelling fluency and spelling accuracy (Bobayigit & Stainthrop, 2009; Pontart et al., 2013), studies of alphabet writing fluency consistently point to it being a significant predictor of spelling accuracy (e.g., Puranik et al., 2017). In addition to empirical work, we use Capacity Theory and the staged model of writing (Bonin et al., 2015; McCutchen, 1996) as the theoretical foundation for our hypothesis that spelling fluency in Grade 1 would be a significant predictor of spelling outcomes in Grade 2, beyond what is accounted for by binary and non-binary spelling accuracy. As described above, once the lexicon is developed to the extent that whole-word representations of spellings are readily accessible in memory, spelling fluency will increase as a result (McCutchen, 1996). Therefore, faster onset to begin writing in Grade 1 would suggest that spelling will be more accurate in Grade 2.

The present study measured the time-course of spelling to evaluate students' latency to begin spelling a word accurately, which we defined as spelling fluency. Using writing onset latency as our measure of spelling fluency is consistent with lexical access or word recognition time in the parallel reading fluency literature (e.g., e.g., Baddeley, Logie, Nimmo-Smith, & Brereton, 1985; Bowers, 1995). One year later, students' word reading ability and spelling accuracy were assessed to examine the predictive power of spelling fluency on these literacy outcomes. Participants also completed measures to characterize their overall handwriting speed and phonological awareness, which allowed us to control for the effects of prior knowledge and varying motor skills on spelling ability.

Method

Participants

Three hundred thirty-eight Grade 1 students were recruited from schools across Nova Scotia to participate in a study of longitudinal literacy development. Of these, 132 students (70 female), who spoke English as a first language and had completed the previous tasks in the testing battery with time remaining participated in the spelling fluency portion of the study. Data collection occurred between January 2019 to January 2020. Due to technical errors with recording their spellings, 8 participants (6%) were excluded, resulting in a final sample of 124 participants (n = 64 female) in Grade 1 aged 6;3 to 7;10 (M = 6;10, SD = 0;4).

Data collection in Grade 2 was planned for January 2020 to May 2020. However, due to the COVID-19 pandemic and subsequent school closures, data collection in Grade 2 ended in March 2020. Of the 124 participants who completed Grade 1 spelling fluency measures, only 41 participants (33%) completed Grade 2 spelling and reading measures. Current research suggests that a dataset of up to 50% missing data is acceptable to avoid inflating Type I error rates (e.g., Graham, 2009); thus, 41 participants from the remaining 83 participants who completed measures in Grade 1 but not Grade 2 of the study were selected to be included in the final sample. Participants were not eligible to be included in the final sample if they had any missing data in Grade 1 (n = 20). To ensure that the final sample was equitable and representative of traditionally underrepresented groups per the Society for Research in Child Development (2020), participants were automatically included in the final sample if they were from a minority group (n = 12) or low socio-economic background (n = 5). Socio-economic status (SES) was measured using the Hollingshead Four-Factor Index (Hollingshead, 1975), with possible scores ranging from eight to 66. Participants were divided into quartiles based on the SES scores of our sample.

All participants in the first quartile (SES of 34 or less) were considered to be from a low socio-economic background and automatically included in the final sample, as described above. An equal number of participants were randomly selected from the remaining three quartiles (n = 8 per quartile, n = 24 randomly selected) to avoid oversampling high SES students. This resulted in a total of 82 students (n = 48 female) aged 6;3 to 7;10 (M = 6;10, SD = 0;5), for the longitudinal analyses. Missing data was multiply imputed; the procedure for this is described in more depth below. Summary statistics for all participants are reported in Table 1.

Procedures and Measures

Students completed all tasks individually with a trained research assistant. Tasks were administered in the order outlined below as part of a larger testing battery that took approximately two hours to complete. Although other items from the testing battery were included as part of the multiple imputation procedure described below, only those included in the primary analyses are detailed here.

Phonological awareness. In Grade 1, participants completed the Blending and Deletion sections of the Woodcock Reading Mastery Test – Third Edition (WRMT-III; Woodcock, 2011). In the Blending task, examiners said individual phonemes aloud to participants and asked them to say the phonemes together fluently. In the Deletion task, participants were read whole words and asked to remove individual phonemes from them verbally. Both tasks ended after the participant had completed all items or had four consecutive scores of zero. The score was the total number of items on both tasks that were answered correctly.

Word reading. In Grades 1 and 2 of the study, students completed the Word Identification subtest of the WRMT-III. In this task, participants were asked to read as many words as they could from a list of words progressively increasing in difficulty. The task ended after the child reached the end of the word list or incorrectly read four consecutive words. Scoring was done in real-time, but all responses were recorded to be scored for a final time by a research assistant. Correct responses were awarded one point; all other responses were awarded zero points. Raw and standard scores are reported here, but only raw scores were used in the analyses.

Word reading fluency. In Grade 1, participants completed the Test of Word Reading Efficiency – Second Edition (TOWRE-2), designed by Torgesen, Wagner, and Rashotte (2012), to obtain measures of word reading fluency and accuracy. The task consists of two subtests: Sight Word Efficiency and Phonemic Decoding Efficiency. Participants had 45 seconds to read as many items as quickly as they could. In Sight Word Efficiency, participants read a list of real words out loud that increase in length and difficulty as they progress. In Phonemic Decoding Efficiency, participants were asked to read a list of non-real words out loud that increased in length and difficulty as they progressed. The experimenter also had a list of these words to mark real-time errors and end points. Participants were recorded and scored by a second scorer to ensure inter-rater reliability. Raw and standard scores are reported here, but only raw scores were used in the analyses.

Handwriting fluency. The Alphabet subtest of the Detailed Assessment of Speed of Handwriting (DASH; Barnett, Henderson, Scheib, & Schulz, 2007) was selected to provide a control measure of handwriting fluency. In Grade 1 only, participants were instructed to write every letter of the alphabet in lower case as many times as possible in one minute. They received one point for each correctly written and ordered letter. Letters were written using a Wacom Intuos Inking Pen on a lined sheet of paper overlaid on a graphics tablet (Wacom Intuos Pro Paper Edition), which was connected to a laptop running *Eye and Pen 2* software (Alamargot, Chesnet, Dansac, & Ros, 2006). Because only one subtest from this task was administered, we only report raw scores here.

Experimental spelling. The experimental spelling task was used to obtain our measures of spelling fluency, binary spelling accuracy, and non-binary spelling accuracy in Grade 1. We selected ten simple words (*dog, man, one, said, blue, come, plug, went, limp, tree*) which were originally used by Byrne & Fielding-Barnsley (1993) and later by Treiman et al. (2016) in studies of spelling accuracy. Words were presented in that order for all participants.

Students wore a set of headphones connected to a computer running *Eye and Pen 2* software (Alamargot et al., 2006). Participants were asked to spell the words on a sheet of paper with ten lines and boxes overlaid on a Wacom Intuos Pro Paper Edition tablet and a Wacom Intuos Inking Pen so that handwriting could be recorded. Through their headphones, participants heard an audio recording of a Nova Scotian female speaker reading the target words, first alone, then in the context of a sentence, then alone again. They were instructed to write the word beginning on the first line and, when finished, to tap the numbered box at the end. Tapping this box ended the handwriting recording and triggered the audio recording of the next word. This was done for all ten words. Participants completed three practice trials prior to beginning the spelling test; in the first the experimenter guided the participant through the procedure with no words triggered, and in the final two the participant followed the procedure outlined above to write the words *big* and *hat*.

Spellings were transcribed into a spreadsheet to be scored for accuracy. Per Treiman et al. (2016), letter reversals (i.e., writing *b* instead of *d*) were counted as the correct letters. Spellings were coded for accuracy by two independent scorers using four methods: binary correctness, letter sequence, sound spelling, and mixed (see Table 2 for descriptions and examples). These were selected so that the non-binary phonological, orthographic, and combination methods of scoring would each be represented using the metrics most strongly correlated with Grade 2 spelling, based on Treiman et al. (2016)'s findings. To determine whether a given phonological spelling was plausible, the Grade 1 Monosyllable Correspondences for Ponto (Kessler, 2009) was used manually by scorers. Any disagreements between scorers were resolved by a third independent party.

Conventional spelling. The Spelling subtest of the British Ability Scales – Third Edition (BAS3; Elliot & Smith, 2011) was administered in Grade 2 to obtain a measure of conventionally correct spelling. Participants were provided a worksheet, pencil, and eraser and read a series of words by the examiner. Target words were presented alone, then in the context of a sentence, then alone again. Participants were asked to spell the word as best as they could and encouraged to check and correct their work. Words could be repeated one additional time if necessary. The task ended when the child completed the final item or after spelling eight words in a set incorrectly. All words were scored using binary correctness, with one point given for each correctly spelled word. Raw scores are reported here.

Results

Using *Eye and Pen 2* (Alamargot et al., 2006), spellings from Grade 1 of the study were coded for fluency. We measured writing onset latency time, defined as the time from when the target word was heard by the participant to when the pen touched the paper. These data were extracted to a word processing file and cleaned using a script in R Studio (R Core Team, 2021). Data was missing for 3% of the words (50/1320 words). Outliers (defined as +/- 3 standard deviations from the group mean) were removed from the words written for all 132 participants who participated in the study in Grade 1 as part of the cleaning process, resulting in a total of

9.9% of data excluded (126/1270 words). The final metric of writing onset latency used for the present study was the mean writing onset latency averaged across the number of words written correctly for each participant.

Word spellings were similarly coded for accuracy using the binary and non-binary methods described above. Spellings were excluded from analysis if the participant wrote more than one word (e.g., *my dog*) or a number instead of a word (e.g., *1* instead of *one*). A total of 0.6% (7/1270) of words were removed for this reason. The final metric used for all accuracy scores was the participant's total score divided by the total possible score on each measure (e.g., 10 for binary accuracy, 47 for letter sequence, 60 for mixed scoring, and 33 for sound spelling).

Multiple Imputations

Multiple imputations of the missing Grade 2 data for the 41 selected participants were performed. This was done by chained equations with predictive mean matching using the mice package in R Studio (van Buuren & Groothuis-Oudshoorn, 2011; van Buuren, 2018). The a priori variables of interest for the hierarchical linear regression models (e.g., Grades 1 and 2 WRMT-III Word Identification, Grades 1 and 2 metrics of spelling accuracy, WRMT-III Blending and Deletion, DASH Alphabet Writing, and writing onset latency) were included in the multiple imputation model.

Auxiliary variables were also selected from the full testing battery to be included in the model. This was first done using binary logistic regressions to see whether key demographics and validated, standardized test scores predicted missingness of Grade 2 data (Logan, 2021). Sex, Grade 1 TOWRE-2 Phonemic Decoding Efficiency, and Grade 1 WASI-2 Matrix Reasoning significantly predicted missingness (see Table 3 for the full results of the logistic regression). Correlations were also run to see which variables were significantly correlated with the variables to be imputed; that is, Grade 2 WRMT-III Word Identification and BAS Spelling (Nguyen et al., 2017). Variables included from Grade 1 were experimental measures of prosodic sensitivity, morphological analysis using word analogies, and morphological awareness using sentence completion. Grade 2 variables included were Gates-MacGinitie Reading Comprehension (MacGinitie, MacGinitie, Maria, & Dreyer, 2000), Test of Silent Reading Efficiency (TOSREC; Wagner, Torgesen, Rashotte, & Pearson, 2010) total score, TOWRE-2 Sight Word Efficiency, TOWRE-2 Phonemic Decoding Efficiency, Comprehensive Test Of Phonological Processing – Second Edition (CTOPP-2; Wagner, Torgesen, Rashotte, & Pearson, 2013) total score, Clinical Evaluation of Language Fundamentals – Fifth Edition (CELF-5; Wiig, Semel, & Secord, 2013) syntax recalling sentences task, and experimental measures of prosodic listening, morphological awareness using sentence completion, morphological analysis using pictures, morphological decoding using a parsing task, syntactic parsing, and punctuation knowledge (see Table 4 for correlations). All predictive and correlated variables were included in the multiple imputation model as auxiliary variables. Because of the high percentage of missing data, 40 imputations were performed (Graham, Olchowski, & Gilreath, 2007).

Hierarchical Linear Regressions

Hierarchical linear regressions were completed using the stats and mice packages in R (R Core Team, 2021; van Buuren & Groothuis-Oudshoorn, 2011). Assumptions of linearity and sufficient sample size were checked prior to models being run, and assumptions of homoscedasticity and normality of residuals were checked after the models were run (Knapp, 2017). Multicollinearity was checked as part of the multiple imputations and therefore was assumed for the models as well. Methods for completing the hierarchical linear regressions for the imputed data followed the steps in Heymans & Eekhout (2019).

RQ1: Grade 1 spelling fluency predicting Grade 1 reading. To explore whether models predicting Grade 1 reading accuracy were significant improved by including Grade 1 spelling fluency alone and in addition to measures of accuracy, hierarchical multiple regressions were performed with all 124 participants who completed Grade 1 spelling fluency measures. The first model explored this question with only writing onset latency as a predictor variable. In Step 1, we controlled for age, phonological awareness, and handwriting fluency. These control variables accounted for 33.26% of the variance in Grade 1 reading accuracy. In Step 2, writing onset latency was included as a predictor. The inclusion of writing onset latency decreased the percentage of variance accounted for by 0.48%, although this was not significantly different from zero ($F_{(1, 113)} = 0.19$, $f^2 = 0.01$, $p = .67$). The overall variance accounted for was 32.78% and was significant with a large effect ($F_{(4, 113)} = 15.26$, $f^2 = 1.03$, $p < .001$). Only the control variables of phonological awareness ($\beta = 1.27$, $p < .001$) and handwriting fluency ($\beta = 0.14$, $p = .02$) were significant predictors of Grade 1 reading accuracy. Results are summarized in Table 5.

The second model investigated whether spelling fluency significantly improved a model predicting concurrent reading accuracy that included binary spelling accuracy as a predictor. As described above, the control variables accounting for 33.26% of the variance were entered in Step 1. In Step 2, binary accuracy was included as a predictor and accounted for an additional 14.81% of the variance in Grade 1 reading accuracy, which was significant with a large effect ($F_{(1, 109)} = 32.86$, $f^2 = 0.49$, $p < .001$). Writing onset latency was added to the predictor variables in Step 3 and decreased the percentage of variance accounted for by 0.30%, although this was not significantly different from zero ($F_{(1, 108)} = 0.38$, $f^2 = 0.01$, $p = .54$). The final model accounted for 47.77% of the variance, which was significant with a large effect ($F_{(5, 108)} = 21.67$, $f^2 = 1.02$, $p < .001$). Binary spelling accuracy ($\beta = 11.33$, $p < .001$) and phonological awareness

($\beta = 0.81$, $p < .001$) were both significant predictors, but writing onset latency was not ($\beta = 0.00$, $p = .54$). Results are summarized in Table 6.

The third model investigated whether the addition of spelling fluency significantly improved a model predicting concurrent reading that included letter sequence score as a predictor. Step 1 included the control variables of age, phonological awareness, and handwriting fluency and accounted for 33.26% of the variance in Grade 1 reading accuracy. In Step 2, the letter sequence score was added to the model and accounted for an additional 15.69% of the variance, which was significant with a large effect ($F_{(1, 113)} = 35.99$, $f^2 = 0.48$, $p < .001$). Writing onset latency was added in Step 3, and decreased the percentage of variance accounted for by 0.05%, but this was not significantly different from zero ($F_{(1, 112)} = 0.89$, $f^2 = 0.00$, $p = .35$). The final model accounted for 48.90% of the variance in Grade 1 reading accuracy, which was significantly different from zero with a large effect ($F_{(5, 112)} = 23.39$, $f^2 = 1.02$, $p < .001$). Only letter sequence score ($\beta = 17.41$, $p < .001$) and phonological awareness ($\beta = 0.63$, $p = .001$) were significant predictors; writing onset latency was not ($\beta = 0.00$, $p = .35$). Results are summarized in Table 7.

The fourth model investigated whether the addition of spelling fluency significantly improved a model predicting concurrent reading that included sound scoring as a predictor. Step 1 included age, phonological awareness, and handwriting fluency as control variables and accounted for 33.26% of the variance in Grade 1 reading accuracy. Step 2 included the sound spelling score, which increased the percentage of variance accounted for by 2.13%; this was significantly different from zero with a small effect ($F_{(1, 113)} = 21.21$, $f^2 = 0.07$, $p < .001$). Writing onset latency was added as a predictor in Step 3, which decreased the percentage of variance accounted for by 0.57%, but this was not significantly different from zero ($F_{(1, 112)}$ =

0.69, f^2 = 0.02, p = .41). Overall, the final model accounted for 34.82% of the variance in Grade 1 reading accuracy and was significantly different from zero with a large effect ($F_{(5, 112)}$ = 13.50, f^2 = 1.03, p < .001). Only the sound score (β = 9.16, p = .04) and phonological awareness (β = 1.08, p < .001) were significant predictors; writing onset latency was not (β = 0.00, p = .88). Results are summarized in Table 8.

The fifth model investigated whether the addition of spelling fluency significantly improved a model predicting concurrent reading accuracy that included mixed scoring as a predictor. Step 1 included age, phonological awareness, and handwriting fluency as control variables and accounted for 33.26% of the variance in Grade 1 reading accuracy. Step 2 included the mixed spelling score, which increased the percentage of variance accounted for by 10.08%; this was significant with a moderate effect ($F_{(1, 113)}$ = 21.21, f^2 = 0.24, p < .001). Writing onset latency was added as a predictor in Step 3, which decreased the percentage of variance accounted for by 0.16%, but this was not significantly different from zero ($F_{(1, 112)}$ = 0.69, f^2 = 0.00, p = .41). Overall, the final model accounted for 43.18% of the variance in Grade 1 reading accuracy and was significantly different from zero with a large effect ($F_{(5, 112)}$ = 18.78, f^2 = 1.02, p < .001). Only the mixed score (β = 17.76, p < .001) and phonological awareness (β = 0.83, p < .001) were significant predictors; writing onset latency was not (β = 0.00, p = .41). Results are summarized in Table 9.

Because spelling fluency was not a significant predictor of reading accuracy alone or beyond what was accounted for by measures of spelling accuracy, it was worth investigating whether it would be a significant predictor of reading fluency. An exploratory hierarchical multiple regression was conducted with Grade 1 scores from the TOWRE-2 Sight Word Efficiency subtest as the outcome variable. Age, phonological awareness, and handwriting fluency were included as control variables at Step 1 and accounted for 28.79% of the variance in Grade 1 reading fluency. Letter sequence was added at Step 2; we selected letter sequence as the measure of spelling accuracy for this model as it accounted for the most variance of any of the accuracy metrics in the planned models above. Letter sequence increased the percentage of variance accounted for by 10.61%, which was significantly different from zero with a moderate effect ($F_{(1, 113)} = 21.36, f^2 = 0.28, p < .001$). At Step 3, writing onset latency was added and contributed an additional 1.15% of the variance, but this was not significantly different from zero ($F_{(1, 112)} = 3.20, f^2 = 0.03, p = .08$). The overall variance accounted for by the final model was 40.55%, which was significant with a large effect ($F_{(5, 112)} = 16.96, f^2 = 1.03, p < .001$). Like the planned models, both the letter sequence score ($\beta = 39.67, p < .001$) and phonological awareness ($\beta = 1.54, p < .01$) were significant predictors of concurrent word reading fluency. Writing onset latency, however, was not a significant predictor of Grade 1 reading fluency ($\beta = 0.00, p = .07$). Results are summarized in Table 10.

RQ2: Grade 1 spelling fluency predicting Grade 2 reading. To explore whether models including spelling fluency in Grade 1 were superior to those with only controls or that included various measures of spelling accuracy, hierarchical multiple regressions were run. These models used the 82 participants who participated in Grade 1 of the study and had real or imputed data for Grade 2 of the study.

The first model investigated whether spelling fluency was a significant predictor of future reading accuracy beyond what was accounted for by controls. Step 1 included age, phonological awareness, and handwriting fluency as known control variables, which together accounted for 31.59% of the variance in Grade 2 reading accuracy. Writing onset latency was included as a predictor at Step 2 and decreased the percentage of variance accounted for by 3.45%; this difference was not significantly different from zero ($F_{(1, 74)} = 0.52$, $f^2 = 0.13$, $p = .47$). The overall variance accounted for in the final model was 28.14%, which was significantly different from zero with a large effect ($F_{(4, 75)} = 6.24$, $f^2 = 1.04$, $p < .001$). Only phonological awareness was a significant predictor of future reading accuracy ($\beta = 0.93$, $p < 0.001$).

The second model also explored the significance of spelling fluency as a predictor of future reading accuracy but included Grade 1 reading accuracy as an autoregressor. At Step 1, age, phonological awareness, and handwriting fluency were again included as controls and accounted for 31.59% of the variance in Grade 2 reading accuracy. Grade 1 reading accuracy was included at Step 2 and accounted for an additional 17.23% of the variance; this was significantly different from zero with a moderate effect ($F_{(1, 77)} = 12.18$, $f^2 = 0.36$, $p < .001$). At Step 3, writing onset latency was added. It decreased the variance accounted for by 2.45%, but this was not significantly different from zero ($F_{(1, 76)} = 0.86$, $f^2 = 0.05$, $p = .36$). Overall, the final model accounted for 46.37% of the variance and was significant with a large effect ($F_{(5, 74)} = 8.71$, $f^2 = 1.02$, $p < .001$). Grade 1 reading accuracy ($\beta = 0.37$, $p < .001$) and phonological awareness ($\beta = 0.56$, $p < .05$) were significant predictors of Grade 2 reading accuracy. Results for both models are summarized in Table 11.

The third model investigated whether the addition of spelling fluency improved upon a model predicting future reading accuracy beyond what was accounted for by binary accuracy. As with the models above, age, phonological awareness, and handwriting fluency were included as control variables at Step 1, accounting for 31.59% of the variance in Grade 2 reading accuracy. At Step 2, binary accuracy was added and explained an additional 6.91% of the variance; this was significantly different from zero with a moderate effect ($F_{(1, 77)} = 5.11$, $f^2 = 0.18$, $p < .05$). Writing onset latency was added at Step 3 and decreased the variance explained by 2.54%, but this was not significantly different from zero ($F_{(1, 74)} = 0.26, f^2 = 0.07, p = .61$). The final model accounted for 35.96% of the variance in Grade 2 reading accuracy and was significant with a large effect ($F_{(4, 74)} = 6.37, f^2 = 1.02, p < .001$). Only phonological awareness ($\beta = 0.75, p < .01$) and binary spelling accuracy ($\beta = 5.64, p < .05$) were significant predictors of Grade 2 reading accuracy. Writing onset latency did not contribute significant additional variance to the model, nor was it a significant predictor of Grade 2 reading accuracy ($\beta = 0.00, p = .62$).

The fourth model explored the same question as the previous, but included Grade 1 reading accuracy as an autoregressor. Step 1 included the control variables of age, phonological awareness, and handwriting fluency which accounted for 31.59% of the variance. Step 2 included Grade 1 reading accuracy, which explained an additional 17.23% of the variance and was significantly different from zero with a large effect ($F_{(1, 77)} = 12.18, f^2 = 0.36, p < .001$). Binary spelling accuracy was added at Step 3 and decreased the variance accounted for by 0.22%, although this was not significant ($F_{(1, 76)} = 0.13, f^2 = 0.00, p = .72$). Writing onset latency was included at Step 4 and also decreased the variance accounted for by 2.45%; this was also not significant ($F_{(1, 73)} = 0.17, f^2 = 0.05, p = .68$). The final model accounted for 46.15% of the variance in Grade 2 reading accuracy and was significant with a large effect ($F_{(6, 73)} = 7.31, f^2 = 1.02, p <.001$). Grade 1 word reading accuracy was a significant predictor ($\beta = 0.35, p < .01$), as was phonological awareness ($\beta = 0.55, p < .05$). The predictive value of binary spelling accuracy did not survive the inclusion of the autoregressor and was no longer a significant predictor of Grade 2 reading accuracy ($\beta = 0.55, p = .73$). Writing onset latency did not explain significant additional variance in Grade 2 reading accuracy, nor was it a significant predictor ($\beta = 0.00, p = .68$). Results for both models are summarized in Table 12.

The fifth model investigated whether spelling fluency improved upon a model predicting future reading accuracy beyond what was accounted for by letter sequence scores. Step 1 included age, phonological awareness, and handwriting fluency as controls, accounting for 31.59% of the variance in Grade 2 reading accuracy. At Step 2, the letter sequence score was added and explained an additional 6.61% of the variance; this was significantly different from zero with a moderate effect ($F_{(1, 77)} = 54.73$, $f^2 = 0.18$, $p < .05$). Writing onset latency was added at Step 3 and decreased the variance explained by 2.35%, but this was not significantly different from zero ($F_{(1, 74)} = 0.54$, $f^2 = 0.07$, $p = .46$). The final model accounted for 35.85% of the variance in Grade 2 reading accuracy and was significantly different than zero with a large effect ($F_{(5, 74)} = 6.55$, $f^2 = 1.03$, $p < .001$). Only phonological awareness ($\beta = 0.69$, $p < .01$) and letter sequence score ($\beta = 8.24$, $p < .05$) were significant predictors of Grade 2 reading accuracy. Writing onset latency did not contribute significant additional variance to the model, nor was it a significant predictor of Grade 2 reading accuracy ($\beta = 0.00$, $p = .47$).

The sixth model was similar to the fifth, but included Grade 1 reading accuracy as an autoregressor for Grade 2 reading accuracy predicted by spelling fluency and letter sequence scores. Step 1 included the control variables of age, phonological awareness, and handwriting fluency which accounted for 31.59% of the variance. Step 2 included Grade 1 reading accuracy, which explained an additional 17.23% of the variance and was significantly different from zero with a large effect ($F_{(1, 77)} = 12.18$, $f^2 = 0.36$, $p < .001$). Letter sequence scores were added at Step 3 and decreased the variance accounted for by 0.37%, although this was not significant ($F_{(1, 76)} = 0.13$, $f^2 = 0.01$, $p = .72$). Writing onset latency was included at Step 4 and also decreased the variance accounted for by 2.41%; this was also not significant ($F_{(1, 73)} = 0.17$, $f^2 = 0.05$, $p = .68$). The final model accounted for 46.04% of the variance in Grade 2 reading accuracy and was significantly different from zero with a large effect ($F_{(6, 73)} = 7.49$, $f^2 = 1.02$, $p <.001$). Grade 1 word reading accuracy was a significant predictor ($\beta = 0.35$, $p < .01$), as was phonological awareness ($\beta = 0.54$, $p < .05$). The predictive value of letter sequence scoring did not survive the inclusion of the autoregressor and was no longer a significant predictor of Grade 2 reading accuracy ($\beta = 1.56$, $p = .66$). Writing onset latency did not explain significant additional variance in Grade 2 reading accuracy, nor was it a significant predictor ($\beta = 0.00$, $p = .65$). Results for both models are summarized in Table 13.

The seventh model investigated whether spelling fluency improved upon a model predicting future reading accuracy beyond what was accounted for by sound spelling. Step 1 included age, phonological awareness, and handwriting fluency as controls, accounting for 31.59% of the variance in Grade 2 reading accuracy. At Step 2, the sound spelling score was added and explained an additional 4.28% of the variance; this was significantly different from zero with a small effect ($F_{(1, 77)} = 4.73$, $f^2 = 0.12$, $p < .05$). Writing onset latency was added at Step 3 and decreased the variance explained by 2.66%, but this was not significantly different from zero ($F_{(1, 74)} = 0.52$, $f^2 = 0.08$, $p = .47$). The final model accounted for 33.21% of the variance in Grade 2 reading accuracy and was significantly different than zero with a large effect ($F_{(5, 74)} = 6.24$, $f^2 = 1.03$, $p < .001$). Only phonological awareness ($\beta = 0.81$, $p < .01$) and sound spelling score ($\beta = 9.50$, $p < .05$) were significant predictors of Grade 2 reading accuracy. Writing onset latency did not contribute significant additional variance to the model, nor was it a significant predictor of Grade 2 reading accuracy ($\beta = 0.00$, $p = .47$).

The eighth model added Grade 1 reading accuracy to investigate the predictive value of spelling fluency and sound spelling when an autoregressor was present. Step 1 included the control variables of age, phonological awareness, and handwriting fluency which accounted for

31.59% of the variance. Step 2 included Grade 1 reading accuracy, which explained an addition 17.23% of the variance and was significantly different from zero with a large effect ($F_{(1, 77)}$ = 12.18, f^2 = 0.36, p < .001). Sound spelling scores were added at Step 3 and accounted for an additional 0.34% of the variance, although this was not significant ($F_{(1, 76)}$ = 1.12, f^2 = 0.01, p = .29). Writing onset latency was included at Step 4 and decreased the variance accounted for by 2.13%; this was also not significant ($F_{(1, 73)}$ = 0.38, f^2 = 0.05, p = .54). The final model accounted for 47.03% of the variance in Grade 2 reading accuracy and was significantly different from zero with a large effect ($F_{(6, 73)}$ = 7.49, f^2 = 1.02, p <.001). Grade 1 word reading accuracy was a significant predictor (β = 0.34, p < .01), as was phonological awareness (β = 0.53, p < .05). The predictive value of sound spelling scores did not survive the inclusion of the autoregressor and was no longer a significant predictor of Grade 2 reading accuracy (β = 4.57, p = .66). Writing onset latency did not explain significant additional variance in Grade 2 reading accuracy, nor was it a significant predictor (β = 0.00, p = .65). Results for both models are summarized in Table 14.

The ninth model investigated whether spelling fluency improved upon a model predicting future reading accuracy beyond what was accounted for by mixed scores. Step 1 included age, phonological awareness, and handwriting fluency as controls, accounting for 31.59% of the variance in Grade 2 reading accuracy. At Step 2, the mixed score was added and explained an additional 7.62% of the variance; this was significantly different from zero with a moderate effect ($F_{(1, 77)}$ = 6.86, f^2 = 0.20, p < .05). Writing onset latency was added at Step 3 and decreased the variance explained by 2.10%, but this was not significantly different from zero ($F_{(1, 74)}$ = 0.65, f^2 = 0.06, p = .42). The final model accounted for 37.11% of the variance in Grade 2 reading accuracy and was significantly different than zero with a large effect ($F_{(5, 74)}$ =

6.87, $f^2 = 1.03$, $p < .001$). Only phonological awareness ($\beta = 0.71$, $p < .01$) and mixed score ($\beta = 11.22$, $p < .05$) were significant predictors of Grade 2 reading accuracy. Writing onset latency did not contribute significant additional variance to the model, nor was it a significant predictor of Grade 2 reading accuracy ($\beta = 0.00$, $p = .43$).

The tenth and final model investigated the predictive value of spelling fluency and mixed spelling on Grade 2 reading accuracy when Grade 1 reading accuracy was added as an autoregressor. Step 1 included the control variables of age, phonological awareness, and handwriting fluency which accounted for 31.59% of the variance. Step 2 included Grade 1 reading accuracy, which explained an addition 17.23% of the variance and was significantly different from zero with a large effect ($F_{(1, 77)} = 12.18$, $f^2 = 0.36$, $p < .001$). Mixed spelling scores were added at Step 3 and accounted for an additional 0.20% of the variance, although this was not significant ($F_{(1, 76)} = 0.86$, $f^2 = 0.00$, $p = .36$). Writing onset latency was included at Step 4 and decreased the variance accounted for by 2.22%; this was also not significant ($F_{(1, 73)} = 0.33$, $f^2 = 0.44$, $p = .57$). The final model accounted for 46.80% of the variance in Grade 2 reading accuracy and was significantly different from zero with a large effect ($F_{(6, 73)} = 7.68$, $f^2 = 1.02$, $p < .001$). Grade 1 word reading accuracy was a significant predictor ($\beta = 0.32$, $p < .01$), as was phonological awareness ($\beta = 0.53$, $p < .05$). The predictive value of mixed spelling scores did not survive the inclusion of the autoregressor and was no longer a significant predictor of Grade 2 reading accuracy ($\beta = 4.14$, $p = .33$). Writing onset latency did not explain significant additional variance in Grade 2 reading accuracy, nor was it a significant predictor ($\beta = 0.00$, $p = .57$). Results for both models are summarized in Table 15.

RQ3: Grade 1 spelling fluency predicting Grade 2 spelling accuracy. To explore the question of whether models including spelling fluency in Grade 1 were superior to those that included control variables and the various measures of accuracy, hierarchical multiple regressions were performed. As with the models of Grade 2 reading, the 82 participants who completed the Grade 1 spelling fluency measures and had real or imputed data at Grade 2 were included.

The first model investigated whether the inclusion of spelling fluency resulted in significantly more variance explained than what was already accounted for by control variables. At Step 1, age, phonological awareness, and handwriting fluency were entered and accounted for 15.13% of the variance in Grade 2 spelling accuracy. Writing onset latency was added at Step 2 and decreased the variance explained by 3.47%, although this was not significantly different from zero ($F_{(1, 75)} = 0.18$, $f^2 = 0.33$, $p = .67$). The model overall accounted for 11.66% of the variance but was not significantly different from zero ($F_{(4, 75)} = 1.81$, $f^2 = 1.09$, $p = .14$), suggesting that the model fit was poor. Results are summarized in Table 16.

The second model investigated whether including spelling fluency was superior to only including control variables and binary spelling accuracy when predicting future binary spelling accuracy. The control variables of age, phonological awareness, and handwriting fluency were entered at Step 1 and accounted for 15.13% of the variance in Grade 2 spelling accuracy. Binary spelling accuracy was entered at Step 2 and accounted for an additional 9.27% of the variance in the model; this was significantly different from zero with a large effect ($F_{(1, 77)} = 5.35$, $f^2 = 0.40$, $p < .05$). At Step 3, writing onset latency was added and decreased the variance explained by 2.95%, although this was not significantly different from zero ($F_{(1, 74)} = 0.52$, $f^2 = 0.14$, $p = .47$). The final model accounted for 21.45% of the variance in Grade 2 spelling accuracy and was significantly different from zero with a large effect ($F_{(5, 74)} = 2.59$, $f^2 = 1.05$, $p < .05$). Only binary spelling accuracy was a significant predictor ($\beta = 4.96$, $p < 0.05$). Writing onset latency did not contribute significant additional variance, nor was it a significant predictor of Grade 2 spelling accuracy ($\beta = 0.00$, $p = .47$). Results are summarized in Table 17.

The third model investigated whether a model including spelling fluency was superior to one with letter sequence scores when predicting future binary spelling accuracy. Step 1 included the control variables of age, phonological awareness, and handwriting fluency accounting for 15.13% of the variance. Letter sequence scores were entered at Step 2 and explained an additional 8.28% of the variance; this was significantly different from zero with a large effect ($F_{(1, 77)} = 5.11$, $f^2 = 0.37$, $p < .05$). At Step 3, writing onset latency was added and decreased the variance explained by 1.99%, but this was not significantly different from zero ($F_{(1, 74)} = 0.94$, $f^2 = 0.10$, $p = .34$). Overall, the final model accounted for 21.42% of the variance and was significant with a large effect ($F_{(5, 74)} = 2.64$, $f^2 = 1.05$, $p < .05$). Only letter sequence was a significant predictor of Grade 2 spelling accuracy ($\beta = 7.29$, $p < 0.05$). Writing onset latency did not explain additional variance, nor was it a significant predictor of future spelling accuracy ($\beta = 0.00$, $p = .34$). Results are summarized in Table 18.

The fourth model investigated whether a model including spelling fluency was superior to one with sound spelling scores when predicting future binary spelling accuracy. Step 1 included the control variables of age, phonological awareness, and handwriting fluency accounting for 15.13% of the variance. Sound spelling scores were entered at Step 2 and explained an additional 6.67% of the variance; however, this was not significantly different from zero ($F_{(1, 77)} = 2.74$, $f^2 = 0.32$, $p = .10$). At Step 3, writing onset latency was added and decreased the variance explained by 2.42%, but this was also not significantly different from zero ($F_{(1, 74)} = 0.68$, $f^2 = 0.45$, $p = .41$). Overall, the final model accounted for 15.34% of the variance and was not significantly different from zero ($F_{(5, 74)} = 2.07$, $f^2 = 1.07$, $p = .08$), which suggests poor model fit overall. Writing onset latency did not explain additional variance, nor was it a significant predictor of future spelling accuracy ($\beta = 0.00$, $p = .42$). Results are summarized in Table 18.

The final model investigated whether a model including spelling fluency was superior to one with mixed spelling scores when predicting future binary spelling accuracy. The control variables of age, phonological awareness, and handwriting fluency were entered at Step 1 and accounted for 15.13% of the variance in Grade 2 spelling accuracy. Mixed spelling accuracy was entered at Step 2 and accounted for an additional 8.13% of the variance in the model; this was significantly different from zero with a large effect ($F_{(1, 77)} = 5.57$, $f^2 = 0.37$, $p < .05$). At Step 3, writing onset latency was added and decreased the variance explained by 2.08%, although this was not significantly different from zero ($F_{(1, 74)} = 0.94$, , $f^2 = 0.10$, $p = .34$). The final model accounted for 21.18% of the variance in Grade 2 spelling accuracy and was significant with a large effect ($F_{(5, 74)} = 2.67$, $f^2 = 1.05$, $p < .05$). Only mixed spelling accuracy was a significant predictor ($\beta = 9.16$, $p < .05$). Writing onset latency did not contribute significant additional variance, nor was it a significant predictor of Grade 2 spelling accuracy ($\beta = 0.00$, $p = .33$). Results are summarized in Table 19.

Discussion

The purpose of the present study was to investigate whether spelling fluency could add to our understanding of future literacy skills. Specifically, we asked whether Grade 1 spelling fluency was a significant predictor and explained significant additional variance in Grade 1 and Grade 2 reading accuracy, as well as Grade 2 spelling accuracy after accounting for binary, orthographic-based, phonological-based, and mixed methods of scoring Grade 1 spelling accuracy. We hypothesized that spelling fluency would serve as a significant predictor for all areas of literacy evaluated; however, the results of our study do not support these hypotheses. Spelling fluency, measured here using writing onset latency, was not a significant predictor of Grade 1 or Grade 2 reading or spelling accuracy. It was also not a predictor of Grade 1 reading fluency. Models including writing onset latency did not explain significantly more variance in concurrent or future literacy skills than models including any of the various measures of spelling accuracy. Although not a primary research question, we were able to demonstrate that binary and non-binary methods of scoring spelling accuracy were significant predictors of Grade 2 spelling accuracy and Grade 1 reading accuracy and fluency, with effect sizes ranging from small to large.

We turn first to the unexpected finding that spelling fluency did not serve as a predictor or explain additional variance in the models of future and concurrent literacy skills. Given the ample evidence to suggest a positive relation between handwriting fluency and future spelling (e.g., Fayol & Miret, 2005; Pontart et al., 2013; Puranik et al., 2017; Wicki et al., 2014) in addition to parallel evidence suggesting a role for reading fluency in literacy development (e.g., National Reading Panel, 2000) this was surprising. However, this is not to say that there is not a role for spelling fluency in the current theories of literacy development. Although the present study does not support spelling fluency as a significant predictor of current or future literacy, the measurement techniques used or age of the sample could explain our null results.

One possibility for why our findings were dissimilar to those in previous works may be the use of a novel measurement of spelling fluency. Where the measure used in the current work was experimental, previous research has most commonly used alphabet writing fluency which may be tapping into a distinct set of skills compared to our measure. Returning to Bonin et al. (2015)'s multi-step model of skilled spelling, it is possible that alphabet writing may not necessitate lexical access during the central orthographic processing step in the same way that spelling does. If this is the case, then alphabet writing fluency may serve as a proxy for handwriting speed and captures only the peripheral processes step in Bonin et al. (2015)'s model. Its significance as a predictor may be in that it represents automatization of the peripheral motor processes, which would make available working memory resources for more complex tasks like accurate spelling, per Capacity Theory (McCutchen, 1996).

It could also be that the use of alphabet writing may also be a more reliable measure of handwriting fluency than asking students to spell words, particularly when they are as young as the students included in our sample. The spelling accuracy of our participants was approximately 50%, which suggests not only that spelling was challenging for them, but that significant cognitive resources were required to attempt to produce correct spellings (McCutchen, 1996). Asking students who were at the very beginning of learning to spell to focus on writing letters fluently, size letters correctly, and spelling accurately may have overloaded their working memory, resulting in null findings. Skilled spellers may have more capacity to focus on both components of writing at the same time than novice spellers. This is consistent with the few studies of spelling fluency conducted to date. As discussed previously, Bobayigit & Stainthrop (2009) found no longitudinal correlation between spelling fluency in Grade 1 and the percentage of spelling errors made in Grade 2. However, Pontart and colleagues (2013) did find a significant relation between spelling fluency and spelling accuracy, but their students were older and ranged from Grade 2 through Grade 9. The results of the present study in combination with those of Bobayigit & Stainthrop (2009) point to the potential for developmental differences in the predictive validity of spelling fluency. It is a possibility that spelling fluency is a predictor of future reading and spelling outcomes, but only once foundational processes like fluent letter writing are established. Thus, we may only see spelling fluency serve as a significant predictor of future literacy outcomes in older students.

It is possible still, however, that the relation between spelling fluency and spelling and reading accuracy is small, if it exists at all. Although current theory refers to automatization of the processes used in handwriting as freeing resources in one's working memory to allow for more accurate spelling (Bonin et al., 2015; McCutchen, 1996), there is sometimes differentiation between automatization of lower- and higher-order skills (e.g., LaBerge & Samuels, 1974; Hayes & Flower, 1980). The research generally agrees that when lower-order skills like spelling fluency are automatic, it frees cognitive resources to be used for higher-order skills (e.g., Medwell & Wray, 2007). However, it is unclear whether spelling and reading accuracy are lower- or higher-order skills. Higher-order skills are typically more abstract and broader, such as narrative writing, planning, ideation, and comprehension (Hayes & Flower, 1980). It may be that, like fluent spelling, reading and spelling accuracy are also lower-order skills; achieving fluent spelling may very well free cognitive resources as theories such as Capacity Theory suggest, but not for tasks at the same level.

Although secondary to the purpose of the present study, our findings regarding spelling accuracy are also worth some discussion. The present study found that binary and orthographic-based non-binary methods of scoring accuracy explained the most variance in future spelling accuracy, with moderate to large effect sizes. This replicates the findings of previous studies of spelling accuracy (Treiman et al., 2016; Treiman, Hulslander et al., 2019; Treiman, Kessler, & Caravolas, 2019) while also extending them to include concurrent reading accuracy and fluency for the first time; non-binary methods of scoring spelling were predictive of accurate and fluent reading in Grade 1. Like these studies, which directly compared the various methods of scoring spelling accuracy, the models including letter sequence scoring explained slightly more variance than those that included binary accuracy. This again may be due to the low mean accuracy of our overall sample; because they had low binary accuracy scores, letter sequence scoring better allowed them to demonstrate their spelling knowledge and development (Treiman et al., 2016). These findings lend support to Ehri (2015)'s phase theory of spelling. Development of accurate spelling occurs in stages, and the finding that words using unconventional or "temporary" spellings predicted concurrent reading and future spelling suggests that children are making gains in their literacy development despite not having fully correct spelling knowledge.

Certain limitations in the present study require the results to be interpreted with caution and should be explored in future research. Due to the COVID-19 pandemic, we were unable to complete the measures of reading and spelling accuracy with all students in Grade 2 who completed the testing battery in Grade 1. The use of multiple imputations allowed for the use of some of these participants, but the total sample size for the longitudinal analyses is still smaller than originally anticipated. Detecting the small effect of spelling fluency may have been difficult given this limitation, particularly after accounting for well-established predictors like word reading and phonological awareness. This is especially true when considering that some of the longitudinal models of spelling development were not significant; the small sample size and multiply imputed data limited our ability to add additional predictors to improve model fit. Poor model fit may also be explained by the difference in the measures of spelling accuracy used; in Grade 1, students completed an experimental measure of spelling accuracy while in Grade 2, the measure was part of a standardized assessment. Although used in previous work (e.g., Tangel & Blachman, 1992; Treiman et al., 2016), it is possible that the Grade 1 measure of spelling was not reliable; future work may wish to investigate the reliability of this tool further.

Despite these limitations, our study adds value to the practice of how we evaluate literacy development. Although the hypotheses regarding spelling fluency were not supported in the current research, our findings point to the possibility that the spelling metrics used in psychoeducational and clinical assessments (e.g., the Spelling subtests on the Weschler Individual Achievement Test – Third Edition [WIAT-III; Wechsler, 2009] and the Test of Written Language – Fourth Edition [TOWL-4; Hammill & Larsen, 2009]) currently provide a good deal of information about a child's literacy skills. This was the case of reading, as 48% of the variance in concurrent reading and 38% of the variance in future reading was explained by our models that included binary accuracy as a predictor. It is important to note, however, that models using non-binary accuracy measures as predictors of future and concurrent reading explained equal or slightly more variance than models using binary accuracy as a predictor. These findings were not the primary purpose of the current study and thus should be interpreted with caution, but lend preliminary support to qualitatively evaluating student spellings for non-binary accuracy as well. When a student's binary accuracy scores are lower than what would be expected for their age (e.g., below the 25th percentile), investigating how close to correct a student is in terms of the letters represented in their spellings might provide a more nuanced idea of where the student is in their spelling development. Future research may wish to investigate the added benefit of including error scoring or non-binary metrics of spelling in psychoeducational assessments as well, particularly when accuracy is low.

The findings of the present study also have implications for educational curricula, especially in Nova Scotia. Spelling fluency is currently not included as an educational outcome in the elementary school curriculum, although both conventional and "temporary" or unconventional spellings are (Department of Education and Early Childhood Development, 2019). Our finding that non-binary spelling accuracy serves as a significant predictor of future and concurrent reading accuracy fits with previous literature (e.g., Ehri, 2015; Treiman et al., 2016) to support the inclusion of temporary spellings as a literacy outcome in early elementary. This is not without some caveats, however; although binary and non-binary spelling accuracy significantly predicted both future reading and spelling accuracy, the model fit when spelling accuracy was the outcome was poor. Thus, although our findings are aligned with previous work, they are preliminary and require further investigation to develop a better understanding of the insight that non-binary spelling accuracy can provide.

There are many avenues for future research that have been raised in the present study. First, in order to evaluate whether there is a developmental difference in the role of spelling fluency in literacy, a comparison of the predictive validity of spelling fluency in younger versus older elementary students is recommended. Second, more consensus in the literature on the definition of handwriting fluency would be beneficial. An initial step in achieving this may be to compare the various measures of handwriting fluency, including alphabet writing, word writing, and narrative writing, to assess their correlations with and predictive validity of other related literacy skills. Finally, parsing apart what current measures of handwriting fluency assess would be useful in furthering the literature. Is the predictive value found in previous studies, particularly that of alphabet writing fluency, attributable to lexical access or motor skills? Would measures of visual-motor integration that are picture- or drawing-based, such as the Beery-Buktenica Test of Visual Motor Integration (Beery, Buktenica, & Beery, 2010), offer the same level of predictive validity as orthographic measures of handwriting fluency? A deeper exploration of these questions in future research could result in better understanding of the cognitive underpinnings of reading and spelling as well as what we truly care about: how best to support students in their literacy development.

Table 1

Summary and Background Statistics for All Participants

	Grade 1 Only			Grade 1 and Grade 2		
	n	Mean (SD)	Range	*n*	Mean (SD)	Range
Age (years; months)	124	6;9 (0;4)	6;3 – 7;10	82	6;9 (0;5)	6;3 – 7;10
Hollingshead SES	110	45.91 (13.29)	14 – 66	80	44.77 (13.70)	14 – 66
Ancestry						
European	70			44		
Acadian	8			6		
Asian	4			3		
African Nova Scotian	9			7		
African	7			7		
Middle Eastern	1			1		
Aboriginal	1			1		
Unknown/not listed	24			13		
Grade 1						
TOWRE-2 Sight Word Efficiency (standardized)	124	104.65 (16.50)	63 – 143	82	105.10 (15.75)	63 – 143
TOWRE-2 Phonemic Decoding Efficiency (standardized)	116	96.22 (14.21)	62 – 130	82	95.84 (14.35)	62 – 129
WRMT-III Word Identification (standardized)	124	105.08 (14.67)	68 – 133	82	106.05 (14.17)	70 – 133

DASH Alphabet Writing N letters	124	19.08 (8.07)	3 – 47	82	19.73 (8.72)	3 – 47
WRMT-III Total Score (Blending + Deletion)	124	11.32 (2.88)	0 – 16	82	11.54 (2.49)	4 – 15
Accuracy						
Binary	124	4.75 (2.50)	0 – 10	82	5.06 (2.47)	0 – 10
Letter Sequence	124	32.03 (9.09)	5 – 47	82	33.29 (8.39)	9 – 47
Sound Score	124	28.44 (4.62)	9 – 33	82	29.30 (3.90)	13 – 33
Mixed	124	45.37 (8.87)	15 – 60	82	46.98 (8.12)	19 – 60
Writing Onset Latency (ms)	118	4102.53 (934.81)	1731 – 6369	80	4148.36 (994.36)	1731 – 6369
Grade 2						
WRMT-III Word ID (standardized)				82	101.41 (12.32)	70 – 123
BAS Spelling				82	14.52 (3.54)	8 – 24

Table 2

Descriptions and Examples of Scoring Methods Used

Scoring Method	Description	Examples
Binary correctness	1 point for each fully correct spelling	1 = *hat* 0 = *hta*
Sound spelling (non-binary phonological)	1 point for each correctly represented phoneme, regardless of conventional phoneme representation and position	3 = *cat* 3 = *kat* 3 = *akt* 2 = *ca* 1 = *c* 0 = *l*
Letter sequence (non-binary orthographic)	1 point for correct first letter, 1 point for correct last letter, 1 point for each correct two-letter sequence	4 = *plug* 3 = *plg* 2 = *pg* 1 = *g* 0 = *o*
Mixed (non-binary orthographic and phonological)	6 points for fully correct spelling, 5 points for phonologically plausible incorrect spelling, 4 points for phonologically plausible unconventional spelling, 3 points for more than one but not all phonemes, 2 points for one phoneme with correct letters, 1 point for one phoneme with unconventional letter	6 = *blue* 5 = *blu* 4 = *bloe* 3 = *bl* 2 = *b* 1 = *o* 0 = *gr*

Table 3

Logistic Regression for Grade 1 Variables Predicting Missingness of Grade 2 BAS Spelling and WRMT-III Word Identification

Variable	β	SE	Z	Odds Ratio	95% CI OR
Intercept	35.75	12553.93	0.003	10918518.02	0 – inf
Girl[a]	-2.14*	0.94	-2.29	0.12	0.02 – 0.74
Age	-0.14	0.11	-1.28	0.87	0.70 – 1.08
Other Language Spoken[b]	2.68	1.82	1.47	14.60	0.41 – 521.42
Diagnosis[c]	-1.07	1.42	-0.75	0.34	0.02-5.58
Hollingshead SES	0.01	0.04	0.29	1.01	0.94 – 1.09
WASI-2 Vocabulary	-0.12	0.20	-0.62	0.88	0.60 – 1.31
TOWRE-2 Phonemic	-0.26*	0.10	-2.62	0.77	0.64 – 0.94
Decoding Efficiency					
WASI-2 Matrix Reasoning	-0.27*	0.13	-2.09	0.76	0.59 – 0.98
WISC-IV Backward Digit Span	2.31	3.66	0.63	10.03	0.01 – 13194.26
Reading Frequency at Home	-21.19	3238.53	-0.01	0.0003	0 – inf

[a]Female = 1, Male = 0
[b]Yes = 1, No = 0
[c]Yes = 1, No = 0
*$p < .05$

Table 4

Correlations Between Variables Explored for Grade 2 BAS Spelling and WRMT-III Word Identification Imputation

Variable	BAS Spelling (Pearson's r)	WRMT-III Word Identification (Pearson's r)
Grade 1		
Morphological Awareness – Sentence Combining	0.20	0.41*
Morphological Awareness – Word Analogy	0.05	0.34*
Prosodic Sensitivity	0.22	0.34*
Grade 2		
Gates-MacGinitie Reading Test – Reading Comprehension	0.24	0.59*
TOSREC Total Score	0.25	0.68*
TOWRE-2 Sight Word Efficiency	0.41*	0.88*
TOWRE-2 Phonemic Decoding Efficiency	0.34*	0.78*
Prosodic Listening	0.28*	0.51*
Morphological Awareness – Sentence Combining	0.24	0.53*
Morphological Analysis	-0.14	0.35*
Morphological Decoding	0.27	0.65*
CTOPP-2 Total Score	0.02	0.35*
CELF-5 Syntax Recalling Sentences	0.20	0.45*
Syntax Parsing	0.14	0.42*
Punctuation Knowledge	0.14	0.48*

*$p < .05$

Table 5

Hierarchical Linear Regression for Grade 1 WRMT-III Word Identification (Word Reading Accuracy) Using Writing Onset Latency

Step	Variable	β	β SE	% ΔR^2
1	WRMT-III phonological awareness (blending and deletion total)	1.27***	0.18	n/a
1	Age (in months)	-0.19	0.12	n/a
1[a]	DASH Alphabet Writing	0.14*	0.06	n/a
2[b]	Writing onset latency	0.00	0.00	-0.30

Note. Reported beta weights are from the final step in the model.
[a]Step 1: $R^2 = 33.26\%$; $F_{(3, 114)} = 20.44$, $p < .001$
[b]Step 2: $R^2 = 32.78\%$; $F_{(4, 113)} = 15.26$, $p < .001$
*$p < .05$. **$p < .01$. ***$p \leq .001$.

Table 6

Hierarchical Linear Regression for Grade 1 WRMT-III Word Identification (Word Reading Accuracy) Using Binary Spelling Accuracy

Step	Variable	β	β SE	% ΔR^2
1	WRMT-III phonological awareness (blending and deletion total)	0.81***	0.18	n/a
1	Age (in months)	-0.15	0.11	n/a
1[a]	DASH Alphabet Writing	0.07	0.06	n/a
2[b]	Binary accuracy	11.33***	1.97	14.81***
3[c]	Writing onset latency	0.00	0.00	-0.30

Note. Reported beta weights are from the final step in the model.
[a]Step 1: R^2 = 33.26%; $F_{(3, 114)}$ = 20.44, $p < .001$
[b]Step 2: R^2 = 48.07%; $F_{(4, 109)}$ = 27.15, $p < .001$
[c]Step 3: R^2 = 47.77%; $F_{(5, 108)}$ = 21.67, $p < .001$
*$p < .05$. **$p < .01$. ***$p \leq .001$.

Table 7

Hierarchical Linear Regression for Grade 1 WRMT-III Word Identification (Word Reading Accuracy) Using Letter Sequence Scoring

Step	Variable	β	β SE	% ΔR^2
1	WRMT-III phonological awareness (blending and deletion total)	0.63**	0.19	n/a
1	Age (in months)	-0.16	0.11	n/a
1[a]	DASH Alphabet Writing	0.05	0.06	n/a
2[b]	Letter sequence score	17.41***	2.88	15.69***
3[c]	Writing onset latency	0.00	0.00	-0.05

Note. Reported beta weights are from the final step in the model.
[a]Step 1: $R^2 = 33.26\%$; $F_{(3, 114)} = 20.44$, $p < .001$
[b]Step 2: $R^2 = 48.95\%$; $F_{(4, 113)} = 29.04$, $p < .001$
[c]Step 3: $R^2 = 48.90\%$; $F_{(5, 112)} = 23.39$, $p < .001$
*$p < .05$. **$p < .01$. ***$p \leq .001$.

Table 8

Hierarchical Linear Regression for Grade 1 WRMT-III Word Identification (Word Reading Accuracy) Using Sound Scoring

Step	Variable	β	β SE	% ΔR^2
1	WRMT-III phonological awareness (blending and deletion total)	1.08***	0.20	n/a
1	Age (in months)	-0.20	0,12	n/a
1[a]	DASH Alphabet Writing	0.11	0.06	n/a
2[b]	Sound score	9.16*	4.30	2.13*
3[c]	Writing onset latency	0.00	0.00	-0.57

Note. Reported beta weights are from the final step in the model.
[a]Step 1: R^2 = 33.26%; $F_{(3, 114)}$ = 20.44, $p < .001$
[b]Step 2: R^2 = 35.39%; $F_{(4, 113)}$ = 17.02, $p < .001$
[c]Step 3: R^2 = 34.82%; $F_{(5, 112)}$ = 13.50, $p < .001$
*$p < .05$. **$p < .01$. ***$p \leq .001$.

Table 9

Hierarchical Linear Regression for Grade 1 WRMT-III Word Identification (Word Reading Accuracy) Using Mixed Scoring

Step	Variable	β	β SE	% ΔR^2
1	WRMT-III phonological awareness (blending and deletion total)	0.83***	0.06	n/a
1	Age (in months)	-0.18	0.11	n/a
1[a]	DASH Alphabet Writing	0.07	0.06	n/a
2[b]	Mixed score	17.76***	3.82	10.08***
3[c]	Writing onset latency	0.00	0.00	-0.16

Note. Reported beta weights are from the final step in the model.
[a]Step 1: R^2 = 33.26%; $F_{(3, 114)} = 20.44$, $p < .001$
[b]Step 2: R^2 = 43.34%; $F_{(4, 113)} = 23.37$, $p < .001$
[c]Step 3: R^2 = 43.18%; $F_{(5, 112)} = 18.78$, $p < .001$
*$p < .05$. **$p < .01$. ***$p \leq .001$.

Table 10

Hierarchical Linear Regression for Grade 1 TOWRE-2 Sight Word Efficiency (Word Reading Fluency)

Step	Variable	β	β SE	% ΔR^2
1	WRMT-III phonological awareness (blending and deletion total)	1.54**	0.54	n/a
1	Age (in months)	-0.35	0.31	n/a
1[a]	DASH Alphabet Writing	0.13	0.16	n/a
2[b]	Letter sequence	39.67***	8.07	10.61***
3[c]	Writing onset latency	0.00	0.00	1.15

Note. Reported beta weights are from the final step in the model.
[a]Step 1: R^2 = 28.79%; $F_{(3, 114)}$ = 20.44, $p < .001$
[b]Step 2: R^2 = 39.40%; $F_{(4, 113)}$ = 20.01, $p < .001$
[c]Step 3: R^2 = 40.55%; $F_{(5, 112)}$ = 16.96, $p < .001$
*$p < .05$. **$p < .01$. ***$p \leq .001$.

Table 11

Hierarchical Linear Regression for Grade 2 WRMT-III Word Identification (Word Reading Accuracy) Using Writing Onset Latency

Step	Variable	β	β SE	% ΔR^2
	Without autoregressor[a]			
1	WRMT-III phonological awareness (blending and deletion total)	0.93***	0.22	n/a
1	Age (in months)	-0.21	0.13	n/a
1	DASH Alphabet Writing	0.06	0.06	n/a
2	Writing onset latency	0.00	0.00	-3.45
	With autoregressor[b]			
1	WRMT-III phonological awareness (blending and deletion total)	0.56*	0.22	n/a
1	Age (in months)	-0.16	0.12	n/a
1	DASH Alphabet Writing	0.00	0.06	n/a
2	Grade 1 WRMT-III Word Identification	0.37**	0.11	17.23**
3	Writing onset latency	0.00	0.00	-2.45

Note. Reported beta weights are from the final step in the model.
[a]Step 1: R^2 = 31.59%; $F_{(3, 78)} = 9.54$, $p < .001$.
Step 2: R^2 = 28.14%; $F_{(4, 75)} = 6.24$, $p < .001$.
[b]Step 1: 31.59%; $F_{(3, 78)} = 9.54$, $p < .001$.
Step 2: R^2 = 48.82%; $F_{(4, 77)} = 11.78$, $p < .001$.
Step 3: R^2 = 46.37%; $F_{(5, 74)} = 8.71$, $p < .001$.
*$p < .05$. **$p < .01$. ***$p \leq .001$.

Table 12

Hierarchical Linear Regression for Grade 2 WRMT-III Word Identification (Word Reading Accuracy) Using Binary Spelling Accuracy

Step	Variable	β	β SE	% ΔR^2
	Without autoregressor[a]			
1	WRMT-III phonological awareness (blending and deletion total)	0.75**	0.22	n/a
1	Age (in months)	-0.21	0.12	n/a
1	DASH Alphabet Writing	0.03	0.06	n/a
2	Binary accuracy	5.64*	2.49	6.91*
3	Writing onset latency	0.00	0.00	-2.54
	With autoregressor[b]			
1	WRMT-III phonological awareness (blending and deletion total)	0.55*	0.22	n/a
1	Age (in months)	-0.16	0.12	n/a
1	DASH Alphabet Writing	0.00	-0.02	n/a
2	Grade 1 WRMT-III Word Identification	0.35**	0.12	17.23**
3	Binary spelling accuracy	0.93	2.63	-0.22
4	Writing onset latency	0.00	0.00	-2.45

Note. Reported beta weights are from the final step in the model.
[a]Step 1: R^2 = 31.59%; $F_{(3, 78)}$ = 9.54, $p < .001$.
Step 2: R^2 = 38.50%; $F_{(4, 77)}$ = 8.78, $p < .001$.
Step 3: R^2 = 35.96%; $F_{(45, 74)}$ = 6.37, $p < .001$.

[b]Step 1: 31.59%; $F_{(3, 78)} = 9.54$, $p < .001$.
Step 2: $R^2 = 48.82\%$; $F_{(4, 77)} = 11.78$, $p < .001$.
Step 3: $R^2 = 48.60\%$; $F_{(5, 76)} = 9.60$, $p < .001$.
Step 4: 46.15%; $F_{(6, 73)} = 7.31$, $p < .001$.
*$p < .05$. **$p < .01$. ***$p \leq .001$.

Table 13

Hierarchical Linear Regression for Grade 2 WRMT-III Word Identification (Word Reading Accuracy) Using Letter Sequence

Step	Variable	β	β SE	% ΔR^2
	Without autoregressor[a]			
1	WRMT-III phonological awareness (blending and deletion total)	0.69**	0.23	n/a
1	Age (in months)	-0.22	0.12	n/a
1	DASH Alphabet Writing	0.02	0.06	n/a
2	Letter sequence	8.24*	3.43	6.61*
3	Writing onset latency	0.00	0.00	-2.35
	With autoregressor[b]			
1	WRMT-III phonological awareness (blending and deletion total)	0.54*	0.22	n/a
1	Age (in months)	-0.17	0.12	n/a
1	DASH Alphabet Writing	0.00	0.06	n/a
2	Grade 1 WRMT-III Word Identification	0.35**	0.12	17.23**
3	Letter sequence	1.56	3.50	-0.37
4	Writing onset latency	0.00	0.00	-2.41

Note. Reported beta weights are from the final step in the model.
[a]Step 1: R^2 = 31.59%; $F_{(3, 78)} = 9.54$, $p < .001$.
Step 2: R^2 = 38.20%; $F_{(4, 77)} = 9.05$, $p < .001$.
Step 3: R^2 = 35.85%; $F_{(5, 74)} = 6.55$, $p < .001$.
[b]Step 1: 31.59%; $F_{(3, 78)} = 9.54$, $p < .001$.

Step 2: $R^2 = 48.82\%$; $F_{(4, 77)} = 11.78$, $p < .001$.
Step 3: $R^2 = 48.45\%$; $F_{(5, 76)} = 9.84$, $p < .001$.
Step 4: 46.04%; $F_{(6, 73)} = 7.49$, $p < .001$.
*$p < .05$. **$p < .01$. ***$p \leq .001$.

Table 14

Hierarchical Linear Regression for Grade 2 WRMT-III Word Identification (Word Reading Accuracy) Using Sound Spelling

Step	Variable	β	β SE	% ΔR^2
	Without autoregressor[a]			
1	WRMT-III phonological awareness (blending and deletion total)	0.81**	0.22	n/a
1	Age (in months)	-0.22	0.12	n/a
1	DASH Alphabet Writing	0.03	0.06	n/a
2	Sound spelling	9.50*	4.34	4.28*
3	Writing onset latency	0.00	0.00	-2.66
	With autoregressor[b]			
1	WRMT-III phonological awareness (blending and deletion total)	0.53*	0.22	n/a
1	Age (in months)	-0.17	0.12	n/a
1	DASH Alphabet Writing	0.00	0.06	n/a
2	Grade 1 WRMT-III Word Identification	0.34**	0.11	17.23**
3	Sound spelling	4.57	3.95	0.34
4	Writing onset latency	0.00	0.00	-2.13

Note. Reported beta weights are from the final step in the model.
[a]Step 1: R^2 = 31.59%; $F_{(3, 78)} = 9.54$, $p < .001$.
Step 2: R^2 = 35.87%; $F_{(4, 77)} = 8.79$, $p < .001$.
Step 3: R^2 = 33.21%; $F_{(5, 74)} = 6.24$, $p < .001$.
[b]Step 1: 31.59%; $F_{(3, 78)} = 9.54$, $p < .001$.

Step 2: R^2 = 48.82%; $F_{(4, 77)}$ = 11.78, $p < .001$.
Step 3: R^2 = 49.16%; $F_{(5, 76)}$ = 10.21, $p < .001$.
Step 4: 47.03%; $F_{(6, 73)}$ = 7.79, $p < .001$.
*$p < .05$. **$p < .01$. ***$p \leq .001$.

Table 15

Hierarchical Linear Regression for Grade 2 WRMT-III Word Identification (Word Reading Accuracy) Using Mixed Scoring

Step	Variable	β	β SE	% ΔR^2
	Without autoregressor[a]			
1	WRMT-III phonological awareness (blending and deletion total)	0.71**	0.22	n/a
1	Age (in months)	-0.22	0.12	n/a
1	DASH Alphabet Writing	0.02	0.06	n/a
2	Mixed scoring	11.22*	4.28	7.62*
3	Writing onset latency	0.00	0.00	-2.10
	With autoregressor[b]			
1	WRMT-III phonological awareness (blending and deletion total)	0.53*	0.22	n/a
1	Age (in months)	-0.17	0.12	n/a
1	DASH Alphabet Writing	0.00	0.06	n/a
2	Grade 1 WRMT-III Word Identification	0.32**	0.12	17.23**
3	Mixed scoring	4.14	4.18	0.20
4	Writing onset latency	0.00	0.00	-2.22

Note. Reported beta weights are from the final step in the model.
[a]Step 1: R^2 = 31.59%; $F_{(3, 78)} = 9.54$, $p < .001$.
Step 2: R^2 = 39.21%; $F_{(4, 77)} = 9.46$, $p < .001$.
Step 3: R^2 = 37.11%; $F_{(5, 74)} = 6.87$, $p < .001$.
[b]Step 1: 31.59%; $F_{(3, 78)} = 9.54$, $p < .001$.

Step 2: R^2 = 48.82%; $F_{(4, 77)}$ = 11.78, $p < .001$.
Step 3: R^2 = 49.02%; $F_{(5, 76)}$ = 10.10, $p < .001$.
Step 4: 46.80%; $F_{(6, 73)}$ = 7.68, $p < .001$.
*$p < .05$. **$p < .01$. ***$p \leq .001$.

Table 16

Hierarchical Linear Regression for Grade 2 BAS Spelling (Word Spelling Accuracy) Using Writing Onset Latency

Step	Variable	β	β SE	% ΔR^2
1	WRMT-III phonological awareness (blending and deletion total)	0.54*	0.21	n/a
1	Age (in months)	-0.04	0.11	n/a
1[a]	DASH Alphabet Writing	-0.05	0.07	n/a
2[b]	Writing onset latency	0.00	0.00	-3.47

Note. Reported beta weights are from the final step in the model.
[a]Step 1: R^2 = 15.13%; $F_{(3, 78)} = 2.95$, $p < .05$
[b]Step 2: R^2 = 11.66%; $F_{(4, 75)} = 1.81$, $p = .14$
$p < .05$. **$p < .01$. ***$p \leq .001$.

Table 17

Hierarchical Linear Regression for Grade 2 BAS Spelling (Word Spelling Accuracy) Using Binary Spelling Accuracy

Step	Variable	β	β SE	% ΔR^2
1	WRMT-III phonological awareness (blending and deletion total)	0.39	0.21	n/a
1	Age (in months)	-0.04	0.11	n/a
1[a]	DASH Alphabet Writing	-0.08	-1.24	n/a
2[b]	Binary spelling accuracy	4.96*	2.17	9.27*
3[c]	Writing onset latency	0.00	0.00	-2.95

Note. Reported beta weights are from the final step in the model.
[a]Step 1: R^2 = 15.13%; $F_{(3, 78)} = 2.95$, $p < .05$
[b]Step 2: R^2 = 24.40%; $F_{(4, 77)} = 3.68$, $p < .01$
[c]Step 3: R^2 = 21.45%; $F_{(5, 74)} = 2.59$, $p < .05$
*$p < .05$. **$p < .01$. ***$p \leq .001$.

Table 18

Hierarchical Linear Regression for Grade 2 BAS Spelling (Word Spelling Accuracy) Using Letter Sequence

Step	Variable	β	β SE	% ΔR^2
1	WRMT-III phonological awareness (blending and deletion total)	0.33	0.21	n/a
1	Age (in months)	-0.04	0.11	n/a
1[a]	DASH Alphabet Writing	-0.08	-1.27	n/a
2[b]	Letter sequence	7.29*	3.07	8.28*
3[c]	Writing onset latency	0.00	0.00	-1.99

Note. Reported beta weights are from the final step in the model.
[a]Step 1: $R^2 = 15.13\%$; $F_{(3, 78)} = 2.95$, $p < .05$
[b]Step 2: $R^2 = 23.41\%$; $F_{(4, 77)} = 3.59$, $p < .05$
[c]Step 3: $R^2 = 21.42\%$; $F_{(5, 74)} = 2.64$, $p < .05$
*$p < .05$. **$p < .01$. ***$p \leq .001$.

Table 19

Hierarchical Linear Regression for Grade 2 BAS Spelling (Word Spelling Accuracy) Using Sound Spelling

Step	Variable	β	β SE	% ΔR^2
1	WRMT-III phonological awareness (blending and deletion total)	0.46*	0.21	n/a
1	Age (in months)	-0.05	0.11	n/a
1[a]	DASH Alphabet Writing	-0.07	-1.06	n/a
2[b]	Sound spelling	6.67	3.63	2.63
3[c]	Writing onset latency	0.00	0.00	-2.42

Note. Reported beta weights are from the final step in the model.
[a]Step 1: $R^2 = 15.13\%$; $F_{(3, 78)} = 2.95$, $p < .05$
[b]Step 2: $R^2 = 17.76\%$; $F_{(4, 77)} = 2.96$, $p < .05$
[c]Step 3: $R^2 = 15.34\%$; $F_{(5, 74)} = 2.07$, $p = .08$
*$p < .05$. **$p < .01$. ***$p \leq .001$.

Table 20

Hierarchical Linear Regression for Grade 2 BAS Spelling (Word Spelling Accuracy) Using Mixed Spelling

Step	Variable	β	B SE	% ΔR^2
1	WRMT-III phonological awareness (blending and deletion total)	0.37	0.21	n/a
1	Age (in months)	-0.05	0.11	n/a
1[a]	DASH Alphabet Writing	-0.08	-1.27	n/a
2[b]	Mixed spelling	9.16*	3.71	8.13*
3[c]	Writing onset latency	0.00	0.00	-2.08

Note. Reported beta weights are from the final step in the model.
[a]Step 1: R^2 = 15.13%; $F_{(3, 78)} = 2.95$, $p < .05$
[b]Step 2: R^2 = 23.26%; $F_{(4, 77)} = 3.66$, $p < .01$
[c]Step 3: R^2 = 21.18%; $F_{(5, 74)} = 2.67$, $p < .05$
*$p < .05$. **$p < .01$. ***$p \leq .001$.

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