SPELLING ACROSS ORTHOGRAPHIES

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SPELLING ACROSS ORTHOGRAPHIES

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Editorial: Spelling Across Orthographies

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Editorial on the Research Topic

Spelling Across Orthographies

The ability to spell words correctly is a cornerstone of literacy. Despite the substantial amount of research into this process, a large part of the empirical findings come from English-speaking populations. Given the distinctive features of the varying orthographic systems worldwide, more research into spelling across orthographies seems warranted. To stimulate this was the main goal of this Research Topic, which contains two review plus 14 research articles tapping 11 orthographies (viz., Arabic, Catalan, Chinese, English, French, Hebrew, Malay, Portuguese, Spanish, Tamil, and Welsh), from first graders to undergraduates. These articles were organized into three sections focusing on (1) the type of misspellings produced, (2) the role of non-phonological knowledge in spelling, and (3) the view of spelling as a basic writing process. Together, the findings from the studies included in the Research Topic showed that the type of misspellings produced is influenced by writing systems, writers' characteristics, and spelling tasks; that morphological, orthographic, morpho-orthographic, and syntactical knowledge are important sources of information to produce accurate spellings in varying orthographic systems; and that spelling is a fundamental writing process intertwined with handwriting. In sum, this Research Topic provides an up-to-date view on spelling across orthographies, which will contribute to increase our understanding of this process and instigate further research into it.

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EDITORIAL ON THE RESEARCH TOPIC: SPELLING ACROSS ORTHOGRAPHIES

Spelling—or the retrieval, assembling, and selection of orthographic symbols—is a fundamental process underlying reading and writing (Graham and Santangelo, 2014). Reflecting the central role of spelling in literacy, a large body of works having spelling as its central object of study has been built (Treiman, 2017). Still, the majority of conclusions emerging from this research is grounded on findings from English-speaking populations. Notwithstanding the importance of those results, a deeper understanding of spelling acquisition and development calls for a broader approach, capable of supporting inferences on the similarities and differences across orthographies. This acknowledgment was the motivating force to set up this collection of articles.

This Research Topic contains two review articles plus 14 articles reporting empirical studies, which targeted spelling across 11 orthographies (viz., Arabic, Catalan, Chinese, English, French, Hebrew, Malay, Portuguese, Spanish, Tamil, and Welsh). Together, these studies covered a large age span, from first-grade school children to undergraduate students. Articles are organized into three sections: section The Informative Nature of Misspellings looks into the type of misspellings produced by children and adolescents across orthographies and tasks; section Non-phonological Sources of Knowledge explores the non-phonological knowledge sources involved in spelling across varying writing systems; and section Spelling as a Basic Writing Process approaches spelling as a basic writing process, related to handwriting and important to produce good texts.

The Informative Nature of Misspellings

In the last decades, researchers have developed several spelling scoring methods, which are fine-grained alternatives to the traditional correct/incorrect scoring (Treiman et al., 2019). These methods provide detailed information about the challenges imposed by spelling in varying writing systems, different developmental points, or writing tasks with variable demands.

Five articles included in this section of the Research Topic focused on the types of misspellings produced by writers, among which three compared different orthographies. Joye et al. examined error types produced in dictation and composition by monolingual 9–10-year-olds with Developmental Language Disorder, speakers of French and English. Findings revealed more morphological errors in French than English in both tasks and more orthographic errors in English than French in the dictation task. Additionally, segmentation and contraction errors were more frequent in French, whereas morphological ending errors appeared more often in English. O'Brien et al. studied phonological, orthographic, and morphological errors across three language groups composed of bilingual children learning English plus an Asian alphabetic script (Malay), akshara script (Tamil), or hanzi script (Mandarin Chinese). Results showed that the Tamil group produced more overall errors and that the three groups differed in the proportions of phonological errors (more prevalent in Malay) and morphological errors (more prevalent in Malay and Chinese, albeit rare). In older, adult participants Martin et al. explored differences in spelling and phonological awareness between distinctive writing systems. Authors compared L1 English speakers with speakers of English as a second language (ESL) using different L1 writing systems: alphabet, abjad, and morphosyllabary. L1 English speakers performed better than all ESL groups, which differed in terms of their performance: the morphosyllabic L1 group showed the highest word spelling accuracy and very low pseudoword spelling accuracy; the alphabetic L1 group showed the lowest spelling and phonological awareness accuracy. The misspellings analysis revealed vowels to be more problematic than consonants, particularly in abjad L1 speakers.

Two other articles provided a comparison of error types between grades within the same orthographic system. Magalhães et al. examined Portuguese children's misspellings across grade (2, 4, and 6), type (phonetically inaccurate, phonetically accurate, and stress mark errors), and task (dictation and composition). Results showed a progressive decrease in all error types except stress mark errors, which were more frequent in Grade 4; and more misspellings in dictation than composing tasks. Spelling errors were found to be associated with texts of worse quality. Yassin et al. tested the impact of visual-orthographic features of the Arabic abjad on spelling errors produced by first, second, and fourth graders. Results showed a high rate of errors across all grades, with visual-orthographic spelling errors accounting for over one quarter of these. This category of errors was ranked the second most frequent one, below violations of spelling conventions and above phonological errors.

Non-phonological Sources of Knowledge

Despite the undeniable role of phonology in spelling, there is now a substantial amount of evidence showing that non-phonological sources of knowledge are used to spell words correctly from very early on (Treiman, 2017). Some of these sources are explored in this section, across six articles.

Salas looked into the non-phonological spelling strategies used by Catalan-speaking children in Grade 2 and 4, with exposure to Catalan outside school or not. Results were similar regardless of Catalan exposure and showed that strategies requiring morphophonological or orthographic knowledge were mastered before those requiring morphological or lexical knowledge. Moreover, all non-phonological strategies had a significant and unique contribution to conventional spelling. In a sample of Portuguese children, Vale and Perpétua also showed the reliance on non-phonological information from very early on, by examining the spelling of the schwa (/ə/)—a phonologically (or minimal) segment—absent in Portuguese first graders at two time points, with a 3-month gap. Despite the weak alphabet knowledge at the first assessment, children tended to represent schwa vowels mostly with the appropriate letter <e>. This representation increased over 3 months and, at both time points, was used more often in potentially orthographic illegal than legal phonological consonantal clusters.

Two additional articles present cross-sectional studies investigating morphological-related knowledge. Schiff et al. focused on the role of morpho-orthographic principles in homophonous affix letter spelling among Hebrew speaking students in Grades 2, 4, 7, and 10. Despite the increased accuracy across all affix letters, findings showed a differential application of morpho-orthographic principles throughout schooling. Younger spellers were mostly assisted by morpho-orthographic sites, morphological category frequency, and phonological transparency, whereas the spelling of older ones was more affected by morpho-orthographic prevalence. Mussar et al. explored morphological knowledge in a cross-sectional study with French-speaking children in Grades 1, 2, and 3. Results showed that children's performance on four morphological knowledge tasks improved across grades, even though they struggled more with explicit than implicit tasks. Moreover, those tasks converged into a single morphological knowledge factor that predicted children's ability to represent words with silent-letter endings, after controlling for grade, reading for pleasure, and general orthographic word recognition.

The definition of morphological spelling is however not consensual, as discussed in the review article of Weth, who proposes that syntactic markers (e.g., inflectional suffixes) should be distinguished from morphological spelling, which considers inflection only in relation to the orthographic word. On the contrary, syntactic markers seem a specific category that is part of the orthographic word but also indicate relational information on phrase and clause level. Highlighting the need to examining spelling by questioning the knowledge of grammatical categories required to choose the correct spelling, Van Reybroeck conducted a study in 9–12-year-old French-speaking children with dyslexia that aimed to understand their grammatical spelling difficulties. Compared to grammatical spelling and age-matched peers, children with dyslexia identified fewer subjects of different complex-structure sentences, suggesting a specific deficit in syntactic awareness.

Spelling as a Basic Writing Process

As proposed in many cognitive models of writing (e.g., Graham, 2018), the activity of producing text relies on the enactment of several processes. Together with handwriting (or typing), spelling constitutes a very basic writing process (i.e., transcription). The link between spelling and writing processes is addressed in this section.

Caravolas et al. compared the spelling and handwriting legibility of Welsh-English bilingual children in Grades 3–5 with same age and same spelling-ability English-monolingual peers. As expected, bilingual children displayed weaker spelling and handwriting skills than age-matched peers. A major finding was that handwriting legibility improved more with spelling ability than with handwriting practice emerging from years of schooling and maturation. Ding et al. investigated the links between handwriting fluency and spelling accuracy in a 2-year longitudinal study that followed children living in mainland China from the third to the fifth grade. Cross-lagged analysis showed a bidirectional predictive association between handwriting and spelling, after accounting for the well-established cognitive measures. Suárez-Coalla et al. investigated how the spelling deficits associated with dyslexia affect the dynamics of handwriting in 9–12-year-old native Spanish speakers. Compared to their chronological age-matched peers, children with dyslexia showed longer writing durations, a larger effect of word frequency in within-word pauses in articles and nouns, and a more prolonged phonology-to-orthography consistency effect in the pauses before the target word.

Providing a broader perspective on the role of spelling in literacy, Llauradó and Dockrell explored the relationships between handwriting, spelling, reading, and text production among second, fourth, and sixth graders speaking three different languages: Catalan, English, and Spanish. Spanish children produced fewer misspellings and spelling ability did not predict text quality. Though both English and Catalan children were challenged by spelling, their ability to spell correctly only influenced text quality in English. Evidence on the central role of spelling in the development of solid literacy skills has motivated the development of several instructional programs. Among these, technology-mediated ones have been gaining prominence, such as the GraphoLearn technology. This is reviewed by Lyytinen et al. with a focus on its effectiveness to the acquisition of basic spelling skills in different alphabetic writing systems, mainly in Occidental countries. The use of a game-based technology to support the teaching of reading and writing in Asia and Africa is also discussed.

CONCLUSION

This Research Topic gathered a collection of articles dealing with issues related to spelling in several orthographic systems. Our ultimate goal was to intensify discussions about the specific and universal underpinnings of spelling acquisition and development. Several insightful discussions had already taken place during the elaboration of this work. We do hope those reflections will continue and stimulate new research into spelling. This will deepen our knowledge about spelling and, ultimately, promote its acquisition, and development around the globe.

AUTHOR CONTRIBUTIONS

TL wrote a first draft of the manuscript. All authors reviewed and approved the manuscript.

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The Development of Morphological Knowledge and Spelling in French

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The Frenchorthographic system is particularly difficult to learn because nearly 30% of words in the lexicon end with a silent letter. One metalinguistic skill that has been identified to facilitate spelling acquisition in French is morphological knowledge. This cross-sectional study investigated the construct of morphological knowledge, its development and its role in building accurate orthographic representations in a sample of francophone elementary students. We proposed that morphological knowledge, a superordinate process, encompasses children's implicit use of morphemes in everyday language and their conscious, targeted manipulation of morphemes. In the present study, we assessed children's recognition of morphogrammes, the silent-letter endings (SLEs) of root words that become pronounced in suffixed forms (e.g., the silent t in chant/ʃɑ̃/ [song] → chanteur /ʃɑ̃tœʀ/ [singer]). When spelling root words, children may mark morphogrammes by recalling morphologically related words in which the morphogramme is not silent – thus, morphological knowledge was hypothesized to positively predict morphogramme spelling. One hundred and twenty-three children in grades 1–3 were assessed on four measures of morphological knowledge, two measures of spelling recognition and a dictation of pseudowords to explore their inclusion of silent-letter endings in novel words. As expected, morphological tasks that required explicit morphological manipulations were harder than implicit ones. Moreover, first graders struggled to complete explicit morphological tasks, while third graders were near ceiling performance on implicit tasks. Nevertheless, the four tasks converged on a single morphological knowledge construct as confirmed by a factor analysis. Importantly, morphological knowledge explained unique variance in children's accurate representation of silent-letter endings after controlling for grade, reading for pleasure and general orthographic recognition of words. Finally, children rarely used silent-letter endings when spelling pseudowords; however, when they did, they displayed sensitivity to the appropriate phonological context for the letter used. The findings are in accord with theoretical models suggesting that the representations of letters without phonological value are difficult to construct and may remain fuzzy.

Keywords: spelling, silent letters, morphology, development, grades 1–3

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INTRODUCTION

Written languages that use an alphabet mark the phonology of spoken languages. The degree of correspondence between phonology and orthography, however, varies across these languages. Some languages, like Italian, are described as transparent because of the high consistency between phonemes (i.e., spoken sound) and the corresponding graphemes (i.e., letters or group of letters). Other languages, like English and French, are described as opaque because of the low consistency in phoneme-grapheme correspondences. Consider that only 21% of French words can be spelled by sound alone (Ziegler et al., 1996). This lack of phoneme-grapheme consistency in the French orthographic lexicon is caused by at least two factors. First, inconsistency arises when a phoneme can be spelled in numerous ways (Véronis, 1986). For example, the French nasal vowel /ɛ̃/ can be spelled in eight different ways: in (*lapin* [rabbit]), im (*timbre* [stamp]), ain (*main* [hand]), aim (*faim* [hunger]), en (*examen* [exam]), ein (*peinture* [paint]), yn (*lynx*) or ym (*thym* [thyme]). The second factor is the presence of letters without phonological value, silent letters that frequently occur at the end of words (Jaffré and Fayol, 2006). For example, the final letter of each of these words is silent: *boue* /bu/ [mud], *chant* /ʃɑ̃/ [song], *chaud* /ʃo/ [hot], *gros* /gʁo/ [large] and *prix* /pʁi/ [price]. The present study investigated how young elementary-school children build accurate orthographic representations of French words that end with silent letters.

It is estimated that 56% of words present in children's school books in France contain silent-letter endings (SLEs) – endings that most often encode grammatical or semantic information (Lété et al., 2004; Gingras and Sénéchal, 2017). After removing inflected words (i.e., the silent plural and conjugated forms), Gingras and Sénéchal still found that 29% of words ended with a silent letter. In these remaining words, SLEs often become pronounced in morphological derivatives (e.g., chant /ʃɑ̃/ [song], chanter /ʃɑ̃te/ [to sing] and chanteur /ʃɑ̃tœʁ/ [singer]). In other cases, SLEs help distinguish homophones (e.g., sang [blood] and sans [without] are both pronounced /sɑ̃/), or they indicate an idiosyncratic spelling (léotard/leotaʁ/ [leotard]).

By virtue of their silent nature, SLEs cannot be easily conveyed through speech. This, in turn, makes it difficult for children to learn these endings. Even after 5 years of schooling, children still have more difficulty spelling words with silent letters as compared to those that do not (Gingras and Sénéchal, 2019). Conducting stringent analyses, Gingras and Sénéchal confirmed the detrimental effect of SLEs to spelling accuracy after controlling for well-established predictors such as word frequency, word length, phoneme-grapheme consistency and rime consistency. Given this particular difficulty, it becomes of interest to understand how children come to mark silent letters over and above rote memorization.

The nature of the French language is such that silent letters often convey morphological information. Lexical morphogrammes are silent letters at the end of root words that are pronounced in suffixed words of the same word family (Catach, 1995). In the previous example, the silent t in *chant* is pronounced in the derived *chanteur*. Given the frequency of occurrence of morphogrammes in French, researchers have investigated whether children's morphological knowledge would facilitate their spelling accuracy of SLEs. That is, if children think about words in terms of such morphological relations, then they may recall when a word contains an SLE and what that silent letter is. Previous findings have shown that children's understanding of morphemes contributes to their early spelling (Sénéchal et al., 2006; Desrochers et al., 2018). To better understand spelling acquisition, it therefore becomes important to understand the development of morphological knowledge.

Herein, morphological knowledge refers to the superordinate process encompassing children's morphological awareness and their morphological processing. Morphological awareness refers to the ability to consciously recognize and manipulate morphemes (Kuo and Anderson, 2006; Lam and Chen, 2017). This includes being able to recognize and segment the subcomponents of words and use these components to create novel words to fit a context. By contrast, morphological processing refers to the implicit ability to use morphemes for everyday language production (Kruk and Bergman, 2013; Nagy et al., 2013). For example, 4- and 5-year-old children, at an implicit level, recognize the relation between verbs and the agentive suffixes -er and -ist (Clark and Cohen, 1984). The child may even create new words using these suffixes. However, the child does not yet have explicit morphological awareness because they may not be able to explain the function of the suffix -er or -ist.

Although children do develop some morphological awareness prior to formal literacy instruction (Clark and Hecht, 1982; Casalis and Louis-Alexandre, 2000; Kim, 2011), it is not until they enter school that a substantial shift in children's morphological knowledge takes place. With sufficient exposure to print, children begin to recognize how certain words contain common and specific visual elements, in addition to common elements of sound and meaning (Sénéchal and Kearnan, 2007; Pacton and Deacon, 2008; Abbott et al., 2016). Children can then merge these three components, allowing for more complex morphemic analysis and decomposition of multimorphemic words; in turn, this may enable children to read more complex material, further increasing their exposure to novel words (Berninger et al., 2009; Goodwin and Ahn, 2010). In other words, even as they learn to associate oral vocabulary with written symbol sequences, they begin to recognize how certain smaller sequences provide unique meaning (Carlisle, 2010; Manolitsis et al., 2019). By first grade, children can explicitly derive transparent, high-frequency derivational suffixes (Anglin et al., 1993; Carlisle and Nomanbhoy, 1993). By second grade, children possess sufficient relational knowledge to explicitly identify how some words share phonological, orthographic and semantic components beyond simple grammatical features; they are also capable of synthesizing or segmenting common morphemes (Casalis and Louis-Alexandre, 2000). By third grade, children can, albeit with difficulty, use their understanding of affixes to compose morphologically appropriate non-words to fit a specific context (Duncan et al., 2009).

These rapid changes in young children's capabilities reveal the development of increasingly sophisticated and abstract cognitive processes. Consequently, when studying participants from different cohorts, multiple morphological measures may be needed to assess both the range of behaviours children can perform and the depth to which said behaviours can be performed. For example, relational judgement tasks, wherein participants are asked to determine if two phonologically similar words are semantically related, are generally considered easy, as they can ultimately be solved using implicit morphological processing (i.e., a "gut-feeling" that the two targets are related).

This type task is often considered appropriate for younger children as it requires little in the way of working memory or cognitive effort and no explicit morpheme manipulation on the part of the child (Colé et al., 2004; Duncan et al., 2009). However, older children may reach ceiling performance, limiting variability in their scores; for example, Duncan et al. (2009) observed grade 3 students complete this task with upwards of 80% accuracy. By contrast, a decomposition task requires children to successfully identify the root and affix of a word and then isolate said root or affix. This task relies on children's ability to explicitly manipulate morphemes, although implicit knowledge may also play a role, as children may be "primed" by hearing the root within the derived form. Analogy tasks are again more difficult, requiring children to recognize a morphological relation in one word pair, and apply this relation to complete a second word pair; for example, *haut* [high]: *hauteur* [height]∷ *gros* [large]: ______ *grosseur* [size]. In this task, the first item in the pair is a root with a silent morphogramme that becomes pronounced in the derived item. These tasks require both explicit morpheme production and a sophisticated level of reasoning – Sénéchal (2000) and Casalis et al. (2011) both found that grade 4 students only perform this task at approximately 65% accuracy. Though some argue that analogy tasks are inappropriate for younger children (see Kirby et al., 2012,) others have found some success with their implementation (e.g., Desrochers et al., 2018).

Current models of orthographic learning suggest that children begin to learn to spell by first associating individual letters with sounds, and through print exposure during reading, eventually refining their representations to whole word patterns (Ouellette, 2010; Sanchez et al., 2012; Conrad et al., 2013). The practice of spelling provides its own positive feedback loop – as children attend to each letter of the target word and the sound associated with it, their mental representation of the word strengthens (Ouellette, 2010). However, when a grapheme is phonologically underspecified, children's representations of it may be "fuzzy" (Sénéchal et al., 2016). Consequently, when faced with a phonologically underspecified grapheme, such as a silent letter, children may not accurately represent what that letter is, if they represent it at all (Sénéchal et al., 2016; Gingras and Sénéchal, 2019). In one study of children in grades 1–3, approximately 63% of children's SLE spelling errors in root words were the omission of the SLE, while the remainder were substitutions (Sénéchal et al., 2016). It is therefore of interest to understand how children overcome this difficulty. French maintains the principle of root consistency, meaning that the graphemes of root words are maintained in derivative forms. Though unpronounced (and underspecified) in the root, SLEs become salient in derived forms. Recalling derivatives forms of a root thus allows children to encode otherwise silent morphogrammes – for example, children can mark the silent "t" in *chant* [singing] by recalling its derivative *chanteur* [singer] (Sénéchal et al., 2006, 2016; Fejzo, 2016).

As an alternative to morphological awareness, it could be argued that words with large families benefit from orthographic redundancy, and that children recall SLEs based on orthographic relatedness. Support for a morphological explanation, rather than an orthographic one, was found in two studies. First, grade 4 children who reported using a morphological strategy (i.e., thinking of a derived word) spelled morphological root words with SLEs as accurately as did children who reported using retrieval, and morphological strategy users were more accurate than phonological strategy users (Sénéchal et al., 2006). Second, a study by Pacton et al. (2018) also provided evidence for the notion that it is morphology, not orthographic relatedness, that is the explanatory factor. In their research, grade 3 and 5 children were exposed to pseudowords with SLEs when reading texts that explained their meaning. In the morphological condition, the text also included two plausible derivatives that revealed the morphogrammes, whereas in the orthographic condition, the text included two orthographically related words that revealed the SLE but for which the suffix was implausible. In both conditions, the text included an opaque pseudoword that ended with a different SLE. Across conditions, children were matched on reading and spelling skills. Children in the morphological condition spelled more pseudowords accurately than opaque words, whereas children in the orthographic condition did not (also see, Pacton et al., 2013).

Correlational evidence also supports a significant role for morphological knowledge. Sénéchal (2000) showed, in 122 grade 2 and 4 children, that morphological knowledge accounted for unique variance in spelling roots with SLE morphogrammes after controlling for grade, general spelling, print exposure, oral vocabulary and phoneme awareness. This effect was specific to roots with SLE morphogrammes because morphological knowledge was not a significant contributor to spelling root words for which the SLEs were not morphogrammes (e.g., foulard /fulaʁ/ [scarf]). This specificity of the contribution of morphological knowledge to spelling SLE morphogrammes, as opposed to words with SLEs that are not morphogrammes, was replicated in a small sample of grade 4 children (Sénéchal et al., 2006). Fejzo (2016) provided further evidence of the specific role played by morphological knowledge in spelling French words. In this study, 75 children in grades 3 and 4 were asked to spell 31 complex words containing prefixes, bases with inconsistent graphemes, morphogrammes or suffixes. Children's spelling accuracy was assessed at the whole word level and at the level of individual morphemes. Morphological knowledge was assessed using real and pseudoword derivation tasks. Hierarchical regressions revealed that morphological knowledge predicted 4% of variance in spelling morphogrammes and 9% of variance spelling suffixes after controlling for grade, word identification, non-verbal intelligence and phonological awareness. By contrast, morphological knowledge did not predict whole word spelling once morpheme spelling was added to the model – thus, showing the specificity of the effect. In summary, the available evidence converges to a specific effect of morphological knowledge to spelling French word endings that contain morphological information.

The present study aimed to increase our understanding of the development of morphological knowledge and assess how morphological knowledge affects spell words with morphogrammes. There were three major goals for this study. The first goal was to thoroughly assess the construct of morphological knowledge by analysing the measures used to assess it in terms of the explicit morphological awareness needed to perform each of the measures. Having examined the nature of the construct, the second goal was to replicate previous findings showing that morphological knowledge predicts the accurate orthographic representation of morphogrammes. The final goal of the study was to explore whether children use SLEs in novel orthographic situations, and if so, under what circumstances thus providing a deeper understanding of how children adapt to a challenging aspect of French orthography.

The novelty of the present study was to assess, in a sample of children from grades 1 to 3, the broader construct of morphological knowledge by using multiple measures that were assumed to differ on the degree of explicit reasoning their required. Although some studies have used multiple concurrent assessments to quantify morphological knowledge (e.g., Casalis and Louis-Alexandre, 2000; Duncan et al., 2009), these studies only describe grade effects within each measure and do not report differences in grade performance across measures. The present study used four measures: a relational assessment task, two decomposition tasks and an analogy task. This array of measures, which require varying levels of implicit and explicit morphological reasoning, was thought to be particularly suitable for acquiring a comprehensive estimate of elementary children's morphological knowledge. Thus, even if young children struggle to perform highly explicit morphological tasks, such as analogy, they might still display their morphological skill in implicit tasks, such as relational judgements. It was hypothesized that task difficulty would increase as the amount of explicit morphological manipulation needed to solve said task increased. In other words, relatedness was hypothesized to be easier than decomposition, which was in turn hypothesized to be easier than analogy. The rank order of task difficulty was not expected to change across grades. Furthermore, although these four tasks were hypothesized to vary in the levels of implicit and explicit cognitive processing required, they were still considered to be part of one unifying construct, and that under factor analysis, they would load onto a single factor. Before discussing further goals of this study, however, it would be prudent to first address a controversy with the use of decomposition tasks.

Although widely used (Tyler and Nagy, 1989; Carlisle, 2000; Casalis and Louis-Alexandre, 2000; Fejzo, 2016), decomposition tasks have been criticized due to ambiguity as to whether children use morphological knowledge, phonological decoding or general vocabulary knowledge to complete them. Generally, the phonology of a root word is preserved to some degree within its derivative form – thus, we cannot know if a child successfully segments a word because they recognize the semantic relation between the root and derivative, or because they hear a "smaller word" within the derivative, or both. To address this, a novel decomposition task was developed. Unlike traditional decomposition tasks, which note only if the child identified the semantic root of a word, this new task also tracked if the child identified a phonologically "smaller" word – for example, the word *lire* [read] in *faiblir* /fɛbliʁ/ [weaken]. As an additional measure of phonological strategy use, some items of this task were unaffixed, meaning a smaller root could not be identified – for example, the word *pardon* /paʁdɔ̃/ [pardon]. If a child identified what they believed was a smaller word within this item – for example, *don* /dɔ̃/ [donation] – then they must have used a phonological strategy to do so. By accounting for children's proclivity to use phonological strategies to decompose words, it may be possible to partial out this variability, creating a more accurate measure of children's morphological reasoning. The efficacy of the new morphological-phonological decomposition task was assessed and compared to a more "traditional" decomposition task. While in general the morphological-phonological decomposition should be no more difficult than the traditional decomposition task, the items for which children must recognize that a semantically smaller word cannot be identified could prove more difficult, and thus, it was hypothesized that this task would be more difficult than the traditional decomposition task, though not so difficult as the analogy task.

Once the structure of morphological knowledge was established, it was possible to test whether it was statistically and significantly linked to children's accurate orthographic representations of SLEs in words. General experience (approximated by grade level), decoding skills and general orthographic representations of words were included as covariates in the model before adding morphological knowledge. Based on prior research, morphological knowledge was expected to provide a small but significant contribution to children's morphogramme spelling after accounting for other early literacy skills.

One final objective of this study was to examine whether children over-generalize SLEs when spelling novel words. Although the nature of spelling errors children make with morphogrammes is well documented (e.g., Sénéchal, 2000; Sénéchal et al., 2016; see also Bosse and Pacton, 2006; Quémart and Casalis, 2017), their general use of SLEs is not well understood. It is possible that, just as children go through a period of overgeneralizing morphemes (Carlisle, 2000), they may also go through a period of overgeneralizing morphogramme-like letter endings. A series of pseudowords, each with a rime that may elicit an SLE, were created to assess if children overgeneralized their use of SLEs. Pseudowords ensured that children's prior knowledge did not confound their spelling. If children did overgeneralize SLEs, it was expected that the letters *t* and *e* would be the most common, being the most and second most frequent SLEs, respectively (Gingras and Sénéchal, 2017). However, children in grade 1 were not expected to overgeneralize SLEs, as it seems unlikely that they would have sufficient experience with written language to begin forming and over using these sorts of schemas.

METHODS

Participants

One hundred and twenty-nine children between 5 and 8 years old were recruited from four francophone schools in Gatineau, Canada, in 2007. Three children withdrew from the study partway through testing, and an additional three children were omitted due to substantially incomplete data – the final sample size was 123. Children were recruited directly through the schools – a consent form was handed out by teachers to the children and signed by parents at home. Forty-six children were in grade 1 (M = 6.3 years, SD = 3.6 months; 25 boys), 51 in grade 2 (M = 7.4 years, SD = 4.1 months; 33 boys) and 26 in grade 3 (M = 8.5 years, SD = 3.5 months; 10 boys). All children spoke French, although many children spoke or were exposed to other languages in the home, including English (70.5%), Arabic (7.7%), Somali (3.1%), Greek (1.6%), Italian (1.6%), German (<1%), Russian (<1%), Creole (<1%), Spanish (<1%) and Berber (<1%).

MATERIALS

Children Reading Frequency

Parents reported on children's frequency weekly readings at bedtime and other times on a nine-point scale ranging from never to reading more than seven times a week. Parents also reported on the frequency with which their child read in French on a four-point Likert scale ranging from *never* = 0 to *very often* = 3.

Morphological Knowledge

Multiple morphological assessments were used to gain a comprehensive estimate of children's implicit and explicit morphological reasoning and consequently achieve a well-rounded estimate of morphological knowledge. The four tasks assessed children's understanding of the relationship between roots and derivatives, their ability to deconstruct multimorphemic words, the difference between children's phonological and morphological decoding of words and their ability to derive words through analogy. In all tasks, practice items with feedback were provided at the beginning to familiarize the child with the task; no feedback was provided for test items. Each task is described next, and task items are in **Appendix**. The internal consistency measure Cronbach's α was used to assess inter-reliability for all measures in this study. Generally, Cronbach's α is considered acceptable if it falls between 0.70 and 0.95 – any lower suggests that the scale has substantial measurement error, and any higher suggests redundancy between the items (Cortina, 1993; Tavakol and Dennick, 2011).

Relatedness

This spoken test was developed by Colé et al. (2004) and assessed children's ability to recognize whether two words were morphologically related. The task included 20-word pairs each consisting of a root word and a derived word, and all derivatives were suffixed. The suffixes (or pseudosuffixes) were phonologically transparent – this eased the difficulty of the task, as children find derivatives without phonological shifts easier to decompose than those with phonological shifts (Carlisle, 2003). Within each pair, one word was presented as a potential root and the other as a potential derivative. Ten pairs of words were morphologically related – for example, *amour* [love] and *amoureux* [amorous]; the remaining 10 pairs were orthographically and phonologically similar but did not share a sematic root – for example, *heure* [hour] and *heureux* [happy]. The assistant administering the task told the child that they would hear two words that sounded similar, and that the child should say whether the words were part of the same "family" or not. Children received one point for each correct answer. For this measure, inter-item reliability was acceptable (Cronbach's α = 0.69).

Decomposition

Children were orally presented 20 multimorphemic words (19 two-morpheme and 1 three-morpheme words) and asked to find the "smaller word", or root word, within each item – for example, a smaller word within *oreiller* [pillow] is *oreille* [ear]. All items were suffixed derivatives. Children received one point for each word they successfully segmented into its root form. Although it was also desired to analyse children's phonological decompositions – that is, when children identified a smaller word *via* the sound of the derived word, and not through analysing semantic relations – the archival nature of the data did not allow this. Inter-item reliability was good (Cronbach's α = 0.83).

Morphological-Phonological Decomposition (Morpho-Phono Decomposition)

Children were told that they would be presented with a series of words, some of which may contain a smaller word. The children were asked to identify if a smaller word existed, and if so, what it was. The task was developed for the present study and included 10 items that could be morphologically decomposed (with an approximately equal number of prefixed and suffixed words), and 10 items that were unaffixed (i.e., had no smaller root within them). Unlike the previous test, where children were assessed solely on their ability to identify the morphological root, this test assessed whether children provided a morphological decomposition of a word (for example, identifying *bond* [jump] within *rebond* [rebound]) or a phonological decomposition (*lire* within *faiblir*). Children's answers were scored as either morphological, phonological or other: a morphological answer indicated the child correctly identified the root of an affixed target word or correctly surmised that an unaffixed target word could not be morphologically decomposed; a phonological answer indicated the child used phonological decomposition to *incorrectly* identify a word other than the root of an affixed target or to identify a smaller word in an unaffixed target; other answers included non-responses, reporting only the first letter of the target word or saying there was no root in a word that could be morphologically decomposed. Inter-item reliability of the scale as a whole was poor (Cronbach's α = 0.64) with affixed items (Cronbach's α = 0.44) having lower reliability than unaffixed items (Cronbach's α = 0.53). Cronbach's α operates under the assumption of tau equivalence (Cortina, 1993) – that is, it assumes that item standard deviations are equivalent – and it underestimates reliability when this assumption is violated. Item analysis revealed substantial differences between item standard deviations, with the lowest being SD = 0.25 for the item *droitier* [right-handed person] and highest being SD = 0.83 for the item *faiblir* [weaken]. However, no appreciable increase in reliability was observed when removing individual items from the scale. Consequently, the scale was left whole for future analyses.

Analogy

This task was adapted from Sénéchal (2000) and designed to assess children's ability to form derivatives from root words using analogy. Children were orally presented two words that shared a morphological relation and were next provided the first item of a second pair. The children were then asked to deduce the missing item. For example, given the sequence "*gris* [grey (masc.)]: *grise* [grey (feminine form)] : : *blond* [blond (masc.)]: _______", the child would be expected to derive *blonde* [blond (feminine form)]. The morphological transformation was always suffixation. There were 20 items, and children were scored based on the number of items derived correctly. Inter-item reliability was good (Cronbach's $\alpha = 0.83$).

Representing Words With Silent-Letter Endings

The SLE orthographic recognition task was a written, classroom administered task assessed children's representation of silent-letter endings similar to the Orthographic Coding task developed by Olson (for a critical review, see Olson et al., 1994). Although this task involved a reading component, children had to access the orthographic representation of the silent-letter ending to answer correctly. Specifically, children were provided 30 sets of morphogramme words and asked to choose the correctly spelled word from three alternatives, all with an identical pronunciation. These alternatives included the word spelled with the correct SLE (e.g., *chocolat* [chocolate]), the word spelled with an incorrect letter ending (e.g., **chocolas*) and the word with the silent letter omitted (e.g., **chocola*). Children answered the items at their own pace and received one point for each correctly identified word. Inter-item reliability was acceptable (Cronbach's $\alpha = 0.70$). The items are in the **Appendix**.

General Orthographic Representations

The general orthographic recognition task, a classroom administered task, provided a more general view of children's orthographic representation. It is similar to Olson's Orthographic Coding task (for a critical review, see Olson et al., 1994). Children were presented with 30 pairs of words with an identical pronunciation but alternate spellings – for example, *jambe* (leg) and **jembe*. To answer correctly, children had to access the accurate orthographic representation of the ambiguously spelled phoneme. Children received one point for each correct answer. Inter-item reliability was acceptable (Cronbach's $\alpha = 0.72$). The items are in the **Appendix**.

Phonological Decoding

This written, classroom administered task presented children with 30 pairs of non-words (e.g., *fraze* and *traze*), one of which was phonetically identical to a real word (e.g., *phrase* [sentence]). The children were asked to identify which non-word was pronounced like a real word. They received one point for each correct answer. Inter-item reliability was poor (Cronbach's $\alpha = 0.63$). However, there were only modest differences between item standard deviations – the lowest was SD = 0.12 for the item *harmé* and the highest was 0.50 for the items *gam* and *eguiye*. There were no appreciable increases in reliability when removing individual items from the scale. As with the morpho-phono decomposition task, it was decided to keep the scale whole for future analyses. The items are in the **Appendix**.

Over-Extension of Silent Letters

The Silex database of French orthography (Gingras and Sénéchal, 2017) reports *e*, *t*, *d*, *s* and *x* to be the five most frequent silent-letter endings overall. However, the occurrence of any particular morphogramme is strongly conditional on the preceding phonological context. For example, many French words whose final syllable sounds as /aʀ/ end in a silent "*d*", as in *renard* [fox] and *canard* [duck]. Furthermore, children in grades 1–3 are sensitive to this context (Sénéchal et al., 2016). Eighteen two-syllable pseudowords, each designed to elicit a SLE, were developed to assess whether children would over-extend their use of SLEs. To elicit a breadth of SLEs, six different phonological endings were used: three oral vowel endings (/o/, /i/ and /a/), two /ʀ/ endings (/oʀ/ and /aʀ/) and one nasal vowel ending (/ɑ̃/). The task items, in order of presentation, were juti, fenar, pada, falo, renan, cajor, rajo, bivar, mouco, ciror, moufa, bonan, juna, cabi, ravor, cinan, mofi and dassar.

This task was administered by classroom and presented as a spelling task. Children were provided a sheet of paper on which to write their answers. Given that only the spelling of the words' endings was of interest, it was decided to ease the difficulty of the task by providing the children with the first syllable of the word and asking them to write the second syllable. The research assistant administering the task first explained that the children would be attempting to spell some "made up" words, and that children should try and provide an answer even if they are unsure of the proper spelling. The assistant dictated each pseudoword twice. An experimenter later totalled which of the five target SLEs, and how many, children used in their spelling. Inter-item reliability was good (Cronbach's $\alpha = 0.86$).

Procedure

The assessments were completed in school, during regular hours and at the teacher's convenience. All tasks were administered by a trained research assistant. After a brief period of time to acclimatize the students to the presence of the research assistant, testing began. Each child participated in a classroom wide session, during which the test for over-extension of silent letters, the SLE orthographic recognition, the general orthographic recognition and the phonological decoding tasks were administered in this fixed order – the session in its entirety took 30–40 min. Children were tested in early winter, and there was concern that grade 1 children would not yet have enough experience with reading on their own to complete the aforementioned tasks. It was decided to exempt grade 1 children from the decoding and the orthographic recognition tasks to exclude potential confounds with their reading ability. Children from all grades each participated in a one-on-one session with the research assistant, during which the four morphological knowledge assessments were administered in the following order: relatedness, decomposition, analogy and morpho-phono decomposition. The one-on-one session took place in a quiet space at the school, such as an empty classroom or library. These sessions took 10–15 min.

RESULTS

Preliminary Analyses

Preliminary analyses were conducted to assess the effects of missing data, outliers and child language. Because no variable was missing more than 5% of its data, missing data were imputed using multiple hot-deck imputation (Crammer et al., 2016). For each measure with missing data, potential information donors were identified by grade, gender and the remaining items in the measure. Given that missing data were minimal, the potential variance lost using this "simple" imputation method was trivial (Cranmer and Gill, 2013). Examination of distributions revealed the presence of minor outliers in the decomposition task, the morpho-phono decomposition task, the analogy task and the SLE orthographic recognition task. Most outliers represented a score that was low for the sample. However, given that the deviation from the expected range of scores was fairly minimal, with outliers often being only one or two points below the lowest expected score, it was decided that they would not pose a significant threat to the distribution of the data, and they were left unchanged. Finally, given the high percentage of multilingual children in the sample, correlations were drawn between all measures and children's status as a French monolingual or multilingual student to identify potential differences between these groups. All correlations were non-significant (largest correlation was $r = 0.14$, $p = 0.13$); thus, child language is not discussed further.

Morphological Knowledge

Morphological Versus Phonological Strategies During Decomposition

The morpho-phono decomposition task was designed to provide an insight into children's use of phonological rather than morphological strategies when decomposing words. As such, the distribution of answer types was analysed with two goals in mind – to assess if the morpho-phono task did indeed capture children's use of phonological answers, and if so, how best to account for them in future analyses. Recall that morphological answers were those wherein the child successfully identified the root of an affixed word, or correctly surmised that an unaffixed word had no internal root (i.e., it is, in and of itself, the root). Phonological answers were those wherein a child phonologically decomposed a word to identify the "smaller word". Other answers included no responses, child answered with a non-word or child said that they did not know. The mean number of morphological, phonological and other responses is presented in **Table 1**. All values are significantly greater than zero (ts > 3.39, $p < 0.0027$), indicating that at all grades, children produced a significant number of morphological, phonological and other responses.

Examination of morphological strategy use in **Table 1** revealed that children found decomposing affixed words easier than stating that an unaffixed word could not be decomposed. The examination of phonological strategies revealed a different pattern altogether. Children seldom used a phonological strategy for affixed words, whereas they often decomposed unaffixed words. Furthermore, this pattern of response generally held constant for all affixed and unaffixed items – that is to say, no one affixed or unaffixed item received substantially higher quantities of morphological or phonological decompositions.

The contrast between strategy use for affixed and unaffixed words is instructive because it suggests that, in some circumstances, children's performance in decomposition tasks might be influenced by their propensity to use phonology to decompose words. Given this propensity and the novelty of the task, we examined whether to adjust children's scores for subsequent correlational analyses. To do so, we examined the pattern of correlations on this task. We found that children's morphological responses on the affixed items were not associated with those on unaffixed items ($r = 0.08$ after controlling for grade). Given this pattern, it is children's morphological responses on affixed items that were used in the subsequent correlational analyses. We also conducted an additional verification as to whether adjusting these scores by subtracting the number of phonological responses from the morphological responses to affixed items would alter findings, and it did not. Consequently, the unadjusted morphological responses on the affixed items were used in the subsequent analyses.

TABLE 1 | Mean responses (and standard deviation) on the morpho-phono decomposition task as a function of response type and grade.

	Affixed words (max. 10)			Unaffixed words (max. 10)		
	Grade 1	Grade 2	Grade 3	Grade 1	Grade 2	Grade 3
Morphological	4.8 (2.2)	6.2 (2.1)	7.3 (1.6)	2.4 (1.6)	3.0 (1.7)	3.7 (1.7)
Phonological	1.2 (1.0)	0.8 (1.0)	0.6 (0.9)	4.6 (1.6)	5.5 (1.6)	5.0 (1.7)
Other	4.0 (2.1)	3.0 (2.0)	2.0 (1.3)	3.6 (1.7)	2.0 (2.0)	1.7 (0.9)

Morphological answers were the (1) successful identification of the root of affixed words or (2) correct judgement that unaffixed words could not be decomposed. Phonological answers were the (1) inaccurate identification of a smaller word other than the root in affixed words or (2) inaccurate identification of a smaller word in unaffixed words.

Growth in Morphological Knowledge

Descriptive statistics for the four morphological knowledge tasks are found in **Table 2**. Performance on the morphological relatedness task was significantly better than the expected 50% chance of success for all grades [smallest was $t_{\text{Grade 1}}(45) = 6.55$, $p < 0.001$], although children in grade 1 did not perform above chance for unrelated word pairs (t [45] = −0.41, $p = 0.69$).

A MANOVA analysis on the four morphological tasks revealed a significant main effect of grade (Pillai's = 0.521, $p < 0.001$). This was followed by a 3 (Grade: 1 vs. 2 vs. 3) × 4 (Task: relatedness vs. decomposition vs. morpho-phono decomposition vs. analogy) mixed-design ANOVA, with grade as the between-subjects factor and task as the within-subjects factor. These analyses were conducted to test the hypothesis that tasks that can be solved through implicit morphological processing are easier than those requiring explicit morphological awareness. The use of a repeated-measures ANOVA to assess mean differences among morphological tasks was justified by conceptualizing the tasks as four different treatment levels varying in explicit cognitive requirements. The task order, from easiest to hardest, was hypothesized to be relatedness, decomposition, morpho-phono decomposition and analogy. The analysis revealed a significant main effect of grade, $F(2, 120) = 49.58$, MSE = 0.01, $p < 0.001$, and task, $F(3, 360) = 281.79$, MSE = 0.02, $p < 0.001$, but the interaction was not significant, $F(6, 360) = 1.01$, MSE = 0.02, $p = 0.42$. **Figure 1** illustrates the similarity across grades in task difficulty. Repeated contrasts indicated that, as expected, performance improved from grades 1 to 2, $F = 51.71$, $p < 0.001$, and from grades 2 to 3, $F = 13.54$, $p < 0.001$. Within-subjects contrasts revealed no mean difference in children's performance on the relatedness and traditional decomposition tasks, $F(1, 120) < 1$, ns; however, morpho-phono decomposition was harder than the traditional decomposition, $F(1, 120) = 38.78$, MSE = 0.04, $p < 0.001$, and analogy was harder than morpho-phono decomposition, $F(1, 120) = 255.51$, MSE = 0.05, $p < 0.001$. All significant contrasts exceeded the Bonferroni correction of $p < 0.008$. In general, this pattern of results provides support for the hypothesis that tasks that rely on explicit morphological awareness are more difficult than those that can be solved using implicit processing.

TABLE 2 | Mean performance (and standard deviation) on morphological tasks as a function of grade.

	Grade 1	Grade 2	Grade 3
	n = 46	*n* = 51	*n* = 26
Relatedness (20)	12.57 (2.66)	14.98 (2.60)	16.19 (2.59)
Related word pairs (10)	7.74 (1.87)	8.06 (1.21)	8.30 (1.22)
Unrelated word pairs (10)	4.83 (2.91)	6.92 (2.37)	7.92 (2.19)
Decomposition (20)	11.72 (3.96)	15.00 (2.40)	17.35 (1.62)
Morpho-phono decomposition (20)[a]	7.54 (2.86)	9.82 (3.05)	11.65 (2.38)
Analogy (20)	2.94 (2.09)	6.37 (2.73)	7.96 (2.78)

The maximum score is presented in parentheses following each measure. [a]For mean correct responses on the affixed and unaffixed items, see morphological responses in ***Table 1****.*

The Structure of Morphological Knowledge

The correlations among the morphological measures ranged from 0.43 to 0.53. These coefficients were significant, positive and moderate in strength, indicating that children who scored high on any one measure of morphological knowledge tended to score high on others as well. An exploratory factor analysis was conducted to assess the hypothesized factor structure representing morphological knowledge. The classic eigenvalues greater than one criterion were used to determine the number of factors to retain (Matsunaga, 2015). The first eigenvalue at 2.45 was the only eigenvalue to exceed one. It accounted for 61% of the observed variance – thus, a one factor solution was considered appropriate. Factor loadings, ranging from 0.64 to 0.73, and communalities, ranging from 0.42 to 0.57, were reasonably strong. The measures are well represented in this factor space, and no one measure accounted for a substantially larger amount of variance. This confirms the hypothesis that, despite the measures assessing different levels of implicit or explicit morphological reasoning, they all assess a unified construct. The factor scores from this analysis were used as the measures of morphological knowledge in all subsequent analyses.

Reading Behaviours at Home and Literacy Skills

As shown in **Table 3**, parents reported, on average, that children read in French very often and read frequently on a daily basis. As shown in the table, there was little variation across grades in the children's experiences. Indeed, grade was not a significant factor in a MANOVA that included the three questions.

The descriptive statistics for the literacy measures are also shown in **Table 3**. Mean performance on phonological decoding, general orthographic recognition and SLE orthographic recognition each exceeded their respective chance performance levels ($ts_{\text{Grade 2}}$ = 16.74, 10.85, 9.78, $ps < 0.001$). Children in both grades performed equally well on the decoding task. Children's performance on the two orthographic recognition tasks was analysed with a 2 (grade: 2 vs. 3) × 2 (task: general vs. SLE orthographic recognition) mixed-design ANOVA. The analysis revealed a significant main effect of grade, $F(1, 75) = 18.03$, MSE = 29.34, $p < 0.001$, and task, $F(3, 360) = 65.93$, MSE = 510.22, $p < 0.001$, but the interaction was not significant, $p = 0.13$. Although children's performance improved across grades, children in both grades had more difficulty identifying the correct spelling of words ending with a silent letter (SLEs) as compared to the correct spelling of words in general (i.e., without SLEs).

Morphological Knowledge and Representing Silent Letters

In order to assess the central hypothesis that morphological knowledge is positively and robustly associated with children's ability to represent silent letters correctly, it was necessary to also examine their relations with other measures. As shown in **Table 4**, representing silent letters accurately and morphological

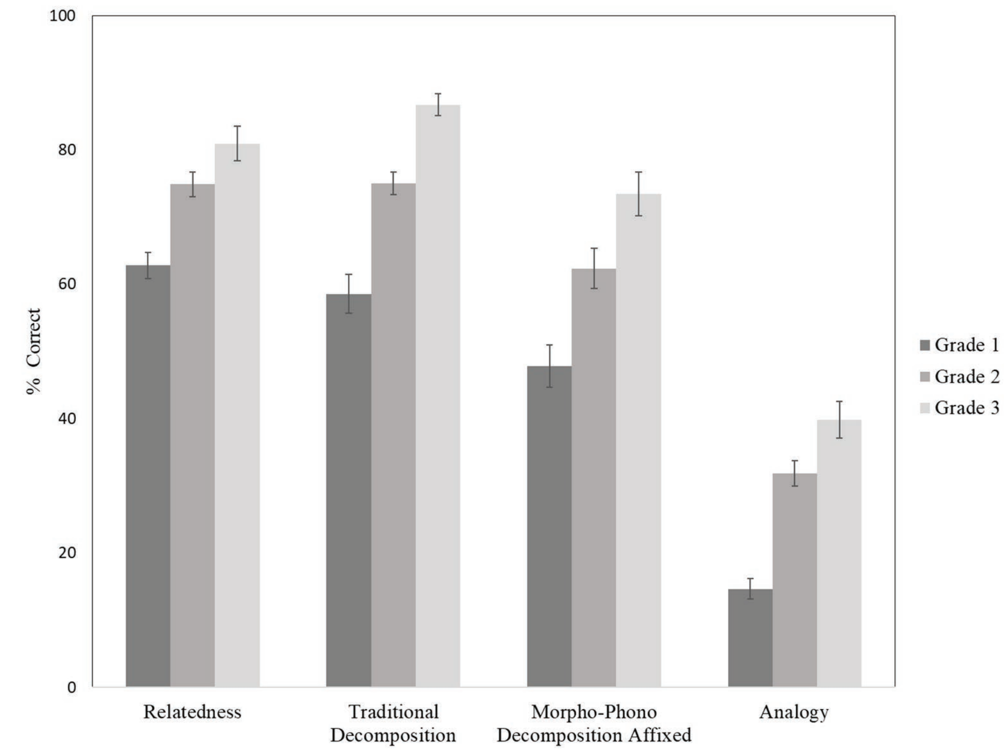

FIGURE 1 | Mean per cent correct (and SEMs) on four morphological tasks as a function of grade.

TABLE 3 | Mean performance (and standard deviation) on reading behaviours and literacy skills.

	Grade 1	Grade 2	Grade 3
Reading at home			
Reading at bedtime[a]	4.87 (2.25)	4.43 (2.53)	3.72 (2.23)
Reading at other times[a]	4.45 (2.04)	3.85 (2.61)	4.09 (2.75)
Child reads in French[b]	1.98 (0.80)	2.02 (0.77)	1.76 (0.97)
Literacy skills[c]			
Decoding	–	23.43 (3.60)	23.46 (3.20)
General orthographic rec.	–	20.88 (3.87)	24.12 (3.58)
SLE orthographic rec.	–	16.59 (4.81)	20.88 (3.87)

Literacy tasks were not administered in Grade 1. rec. = recognition; SLE = silent-letter ending; [a]0 = never; 1 = once a week; 2 = twice a week; …; 7 = seven times a week; 8 = more than seven times a week; [b]0 = never; 1 = rarely; 2 = often; 3 = very often; [c]There are 30 items in each literacy task.

knowledge were significantly correlated, and both were also associated with general orthographic recognition, the frequency of children's independent reading and grade level. General orthographic recognition was positively associated with reading behaviours and grade. Children's decoding skills, however, were not associated with any measure.

A fixed-order regression analysis was used to test whether morphological knowledge remained associated with children's representation of SLEs after controlling for key predictors. The order of entry of the control variables was determined according to their theoretical proximity to SLE representation, from the farthest removed to the closest. As shown in **Table 5**, grade level accounted for a significant 18% of variance, the two reading frequency measures added 7%, while general orthographic recognition contributed 26.7% more variance. As predicted, morphological knowledge entered last in the equation accounted for 2.5% unique variance in children's ability to recognize SLEs correctly.

Do Young Children Overgeneralize the Spelling of Silent-Letter Endings?

Included in this study was a dictation of pseudowords with endings that are often followed by as silent consonant in French. To assess whether children overgeneralized their use of SLEs, their proportional use of SLEs following pseudowords with various rimes was tabulated – the results are presented in **Table 6**. Overall, children rarely use SLEs when spelling unfamiliar words, although their proportion of usage does increase slightly with age – only 8% of grade 1 children's answers included any kind of SLE, while 21% of grade 3 children's answers included an SLE. Furthermore, there was some variability based on the phonological rime – while between 1 and 5% of children provided an SLE following the rime /o/, 17–41% provided an SLE following /aʀ/. When SLEs were used, the letter *e* was most common across all ages and phonological contexts, though particularly following the oral vowel /i/ and words ending in an /ʀ/. Strikingly, children in grades 2 and 3 seemed to have some sensitivity to the letter "d" in specific contexts. Specifically, they used a terminal *d* following /aʀ/, as in *fenar,* or /oʀ/, as in *travor*.

TABLE 4 | Pearson correlations among key variables for children in grades 2 and 3.

	1	2	3	4	5	6
1. SLE orthographic rec.	–					
2. Morph. knowledge	0.439**	–				
3. General orthographic rec.	0.696**	0.365**	–			
4. Decoding	0.149	0.237	0.049	–		
5. Reading frequency	0.244*	0.250*	0.352**	0.091	–	
6. Reads in French	0.154	0.224*	0.355**	0.127	0.727**	–
7. Grade	0.427**	0.406**	0.379**	0.004	–0.051	–0.149

*SLE, Silent-letter endings; orthogr. rec., orthographic recognition; Morph., morphological. *p < 0.05; **p < 0.01.*

TABLE 5 | Fixed-order hierarchical regression for the orthographic recognition of silent-letter endings.

Variable order	R^2	ΔR^2	*F* change	Final			95% CIs	
				B	SE	β^a	Lower	Upper
1. Grade	0.182	0.182	16.69***	1.01	1.057	0.101	–1.017	3.98
2. Reading frequency	0.255	0.073	3.58*	0.128	0.138	0.109	–0.147	0.403
3. Reads in French				–1.025	0.755	–0.166	–2.531	0.482
4. General ortho. rec.	0.524	0.269	40.73***	0.774	0.124	0.611	0.528	1.021
5. Morph. knowledge	0.550	0.025	3.99*	1.397	0.699	0.186	0.004	2.790

*Ortho. rec., orthographic recognition; Morph., morphological. *p = 0.05; ***p = 0.001; [a]Final β s are statistically significant when the CI range excludes zero.*

TABLE 6 | Proportion of children's silent-letter endings during pseudoword dictation as a function of phonological rime and grade.

Rime	Grade	*e*	*t*	*d*	*s*	*x*	Omission
/a/	1	0.01	–	–	–	–	0.99
	2	0.03	0.01	–	–	–	0.96
	3	0.03	–	0.01	–	0.01	0.95
/i/	1	0.04	–	–	0.01	–	0.96
	2	0.10	–	–	–	–	0.90
	3	0.24	0.01	–	–	–	0.74
/o/	1	0.01	–	–	–	–	0.99
	2	0.01	–	–	–	–	0.99
	3	0.03	–	0.01	0.01	–	0.95
/oʀ/	1	0.21	–	–	–	–	0.79
	2	0.30	–	0.05	–	–	0.65
	3	0.18	0.05	0.13	–	0.01	0.63
/aʀ/	1	0.17	–	–	–	–	0.83
	2	0.16	0.01	0.10	–	–	0.72
	3	0.06	0.06	0.28	–	–	0.59
/ã/	1	0.04	–	–	–	–	0.96
	2	0.05	0.02	–	0.01	–	0.93
	3	0.03	0.04	0.03	–	0.01	0.90
Average	1	0.08	–	–	–	–	0.92
	2	0.11	0.01	0.03	–	–	0.86
	3	0.09	0.03	0.08	–	0.01	0.79

Furthermore, within /aʀ/ words, there existed a proportional decrease in the use of *e* over *d* as children entered grade 3, as a χ^2 test of homogeneity found that the distribution of SLE responses within this rime was not equivalent across grades [χ^2 (4) = 39.4, $p < 0.001$]. This provides some evidence that, by this age, children restrict the context in which they use silent-letter endings to the most appropriate letter. However, children's use of the silent letters *t*, *s* and *x* is almost non-existent.

DISCUSSION

The present study documented the growth of children's morphological knowledge across grades 1–3. Although children's performance on four morphological knowledge tasks improved across grades, tasks that required more explicit morphological processing were harder than those relying on implicit knowledge. Yet, all tasks loaded on a single morphological knowledge factor and this factor explained additional unique variance in children's accurate spelling of morphogrammes – silent-letter endings (SLEs) that are pronounced in derived members of a word family. Finally, a pseudoword spelling task revealed some evidence that, with experience, the phonological rime might prime the use of SLEs. Each of these findings is discussed in turn.

Morphological Knowledge

Prior research suggests that children's capacity for explicit morphological manipulation is unstable in young elementary students, particularly among first graders (Casalis and Louis-Alexandre, 2000; Kuo and Anderson, 2006). Several studies have used multiple morphological measures to gain a more complete understanding of children capabilities (e.g., Casalis and Louis-Alexandre, 2000; Berninger et al., 2009; Duncan et al., 2009; Desrochers et al., 2018); however, these studies only report between-grade differences in children's performance on disparate measures. Without examining within-grade differences, it remains unclear how measure selection influences the structure of the final morphological construct. In the present study, four tasks were chosen – relatedness, traditional decomposition, morpho-phono decomposition and analogy – each assumed to require progressively more explicit morphological manipulation. In general, tasks believed to require more explicit cognitive effort were more difficult – analogy was significantly harder than morpho-phono decomposition, which was in turn more difficult than traditional decomposition and relatedness.

Examination of the mean scores of each grade across tasks illustrated the importance of choosing appropriate measures for a particular age range. Although Sénéchal (2000) and Desrochers et al. (2018) report that analogy tasks are appropriate for children beginning grade 2, in this study the grade 1 children tested in the middle of the school year struggled markedly, answering on average just two of 20 questions correctly. By contrast, children in grade 3 performed near ceiling level on the more implicit relatedness and traditional decomposition tasks. In other words, tasks requiring marked explicit manipulation appeared to be almost too difficult for first graders, but tasks which required very little appeared too easy for third graders. Clearly, due to the wide variation in skill level across this population, no one task registered a suitable breadth of variance – only by using multiple measures targeting different skill levels was it possible to gain a comprehensive view of morphological knowledge across these three grades. That said, and in spite of the range of difficulties presented by these measures, they all loaded on a single factor, indicating they assessed a unified construct. Ours is not the first factor analysis performed to assess the dimensionality of morphological knowledge – in a sample of fourth graders, Spencer et al. (2015) found that a one factor solution performed adequately in comparison to two-factor solutions based on oral versus written measure administration and oral versus written child response; by contrast, Tighe and Schatschneider (2015) confirmed a two-factor solution composed of real-word tasks and pseudoword tasks in a sample of adult basic education students. To our knowledge, however, no other factor analysis has been performed to assess the structure of morphological knowledge on the dimensions of implicit versus explicit reasoning, nor has one been performed in so young a cohort. Unfortunately, due to limited sample size, we were unable to examine whether the factor structure of morphological knowledge changes across age groups. Given how rapidly children's morphological reasoning evolves after beginning school (Anglin et al., 1993; Carlisle and Nomanbhoy, 1993; Casalis and Louis-Alexandre, 2000; Duncan et al., 2009), the morphological structure of elementary school children may differ from middle to high school children – for example, perhaps a two-factor solution presents in older children once sufficient experience in explicit morphological reasoning is achieved. Future research may wish to examine how the structure of morphological knowledge evolves with children's exposure to reading and writing in school.

Theoretical concerns have been voiced that traditional decomposition tasks can be solved with phonological strategies rather than morphological ones, inflating children's apparent morphological skill. The morpho-phono decomposition task was developed to explore this possibility by first using items that may elicit phonological decompositions, and noting when children use an alternate decomposition strategy. At all grades, children were observed to make a significant number of phonological decompositions when presented with unaffixed words, despite accurately decomposing affixed words. There are at least two interpretations of this finding. First, young elementary-school children may indeed use a phonological strategy when decomposing words, and this suggests the need to adjust children's performance accordingly as well as including other types of morphological measures as was done in the present study. Second, it is possible that the instructions of finding a smaller word might have biased children answers. Studies of child response bias have determined that children are often reluctant to say that they do not know the answer (Earhart et al., 2014), and that this bias is exasperated in closed-ending type questions (Waterman et al., 2001). One study found that, despite high accuracy in identifying nonsensical or unanswerable questions, children still attempted to answer more than 70% of nonsense question (Waterman et al., 2010). It is possible that children, being primed to look for smaller words (i.e., roots) and reluctant to provide no answer, instead utilized phonological decomposition to achieve a response. Nevertheless, the morpho-phono decomposition task provided a method of quantifying children's proclivity for phonological decomposition, by recording children's use of phonological decomposition when answering affixed words, as opposed to traditional decomposition tasks, which merely report whether children provide the correct answer. Furthermore, acquiring this information about children's phonological decomposition came at a paltry increase in time and effort on the part of the researchers, making the morpho-phono decomposition task an economical way to quantify both children's morphological knowledge and their reliance on phonology. Although correcting or not for children's phonological decomposition on the affixed words yielded identical findings in the present study, future research is needed to understand better why children are likely to use phonological strategies on unaffixed words.

Orthographic Representations of Morphogrammes

Having exhaustively examined the morphological construct, the next goal of the present study was to add to a small body of research assessing the contributions of morphological knowledge to spelling in general (for reviews, see Sénéchal and Kearnan, 2007; Pacton and Deacon, 2008; Abbott et al., 2016), as well as morphogramme spelling in particular (Casalis et al., 2011). Indeed, after controlling for grade, print exposure and general orthographic representations, morphological knowledge explained an additional 3% unique variance in morphogramme recognition, a result comparable to the 2% reported in the study of Sénéchal (2000) and the 4% reported in the study of Fejzo (2016). Furthermore, unlike in the study of Sénéchal (2000), our analogy to print exposure – reading at home – was a significant predictor of morphogramme recognition (when entered after grade), and yet morphological knowledge continued to explain additional variance. Print exposure predicates orthographic redundancy, as greater exposure provides more opportunities for a child to encode members of the same word family (Ouellette, 2010; Conrad et al., 2013). The fact that morphological knowledge predicted morphogramme recognition in spite of this indicates that the advantage morphological knowledge provides to the orthographic representation of SLEs goes beyond the benefits provided by orthographic redundancy in large-word families. This adds to a body of research showing that morphological knowledge provides a unique benefit to children's early spelling, presumably by bolstering the recollection of phonologically underspecified letters and, therefore, fostering the formation of complete orthographic representations. Importantly, the benefits afforded by morphological knowledge cannot be readily explained by the orthographic redundancy between roots and their silent-letter revealing derivatives (Pacton et al., 2018). Notwithstanding the beneficial effects of morphological knowledge, recent evidence has also shown learning effects due to the frequency of occurrence of the silent-letter themselves (Sénéchal et al., 2016; Gingras and Sénéchal, 2019). As such, children seem to harness multiple learning mechanisms when acquiring their orthographic lexicon.

Overgeneralization of Silent-Letter Endings

Silent-letter endings present great difficulty to children's spelling, with children omitting the SLE in 52–66% of instances (Sénéchal, 2000; Sénéchal et al., 2016). In the present study, children of all grades rarely used SLEs when spelling to dictation the rime of pseudowords containing terminal phonemes warranting SLEs. While first graders, being novice readers, were not expected to have the experience necessary to understand the important of SLEs in French orthography, it was expected that older children would use more SLEs when writing pseudowords, given that they have more established representations of these letters (Gingras and Sénéchal, 2019). However, there was a small trend for older children to use more SLEs than younger ones. It is possible that, given the long period it takes for children to master spelling SLEs (Québec Ministère de l'Éducation et de l'Enseignement supèrieur, 2009; Gingras and Sénéchal, 2019), the expected overgeneralization does not occur until a later age.

The five most common SLEs in French are *t*, *e*, *s*, *x* and *d* (Gingras and Sénéchal, 2017) In the present study, the most common letter used by children was *e*. Though it is possible that sheer frequency influenced *e*'s prevalence, the most common SLE overall, *t*, was almost never used. Furthermore, the letter *d* is the least frequent SLE among the five represented in this study – however, it was the second most used by this cohort of children. Thus, the frequency of the SLE in French orthography does not seem to drive children's acquisition of the SLE. The use of *e* could tentatively be explained through its involvement with the French process of feminization. All nouns in French possess a grammatical gender, and many have male and female variants, which change their orthography and phonology (Jaffré and Fayol, 2006). A terminal letter *e* often denotes a feminine form of a word (e.g., *bavard* (masc.) vs. *bavarde* (fem.) [chatterbox]). Children recognize grammatical gender from infancy (Van Heugten and Shi, 2009), and the process of feminization is explicitly taught in early grades in Québec schools (Québec Ministère de l'Éducation et de l'Enseignement supèrieur, 2009). It is possible, then, that the association of *e* to this common and explicitly taught inflectional process makes it particularly salient – thus, *e* may become a "go to" SLE for novel words.

By contrast, the letter *d* is not a common SLE in French orthography, although it occurs regularly in words ending with /ʀ/ (Gingras and Sénéchal, 2017). In the present study, children used the SLE *d* almost exclusively following the rimes /aʀ/ and /oʀ/. Anecdotal evidence suggested a grade effect – in grade 1, 17% of SLE responses to the /aʀ/ rime were *e*, and 0% was *d*, but by grade 3, only 6% of SLE responses were *e*, while 28% was *d*. Perhaps the letter *d* was easier to acquire because it has a very narrow phonological domain, to which it is strongly associated. Children displayed sensitivity to the phonological context of *e* as well, using it in phonological contexts appropriate for the SLE (e.g., /i/, /oʀ/, /aʀ/) and omitting it from contexts where it occurs infrequently (e.g., /a/, /o/) or cannot occur at all (e.g., /ñ/). One avenue for future research may be to assess how the combination of frequency and phonological rime specificity affect children's acquisition or overgeneralization of SLEs.

Additional Limitations and Implications

Two additional overarching limitations impacted this study. The first was the study's small and unequal sample size across grades, which impacted both the choice of statistical analyses and the generalizability of results. Many analyses, including ANOVA and regression, lose power when samples are small and uneven (Tabachnick and Fidell, 2014), although they remain fairly robust if other assumptions, such as normality and homogeneity of variance, hold true. Yet, we observed increases in performance between each grade, and the observed pattern of task difficulty across grades, shown in **Figure 1**, suggests more similarity than differences with increased experience. It is possible also that the smaller sample size of the grade 3 cohort means that the results of the factor analysis may be less applicable to this group, as they are underrepresented in the data. Thus, these analyses may be considered a starting point for future studies, in need of replication before findings can be confirmed.

The second overarching limitation of this study was children's multilingualism. In this study, multilingualism did not account for differences in their early literacy skills. However, multilingualism is known to affect the development of morphological awareness (see Chen and Schwartz, 2018). It may further have an effect on the orthographic redundancy within the child's vocabulary. For example, English was the most common second language in the present sample of children. Although English shares several morphological properties with French, such as root consistency and affixation, English seldom has SLEs. Notably, cross-language vocabulary exposure can illuminate silent letters – for example, the SLEs in *lézard* [lizard], *chocolat* [chocolate] and *confort* [comfort] are all revealed in their English equivalents. A recent study, however, showed that this beneficial effect is temporary. Jubenville et al. (2014) found, in a sample of monolingual and bilingual children schooled in French, different effects during oral vocabulary learning of the incidental presence of the printed word-to-be learned. In this study, the printed words were non-words that were consistent or not, with the inconsistency due to the presence of a SLE (e.g., pocra vs. pocrat). During learning, the incidental presence of an SLE was detrimental to monolinguals but had a facilitative effect on oral vocabulary learning for bilinguals, but these effects were no longer significant 1 day later. Notwithstanding this advantage, both groups stumbled similarly on SLEs when asked to spell the non-words the next day because omissions and substitutions of the SLE accounted for 95 and 93% of spelling errors, respectively. The latter findings, along with those of the present study, suggest that even for multilingual children, constructing orthographic representations of SLEs is difficult. Future research should continue to explore how the relations among oral language, morphological knowledge and spelling might differ between mono- and multilingual children.

CONCLUSION

French abounds with silent-letter endings, presenting a substantial challenge for children learning to spell. However, when the SLE contains morphological information, as morphogrammes do, then children's morphological knowledge may provide recourse, as they can consider derived members of a word family when recalling the root word's ending. The present study replicated prior findings that morphological knowledge provides unique benefits to children's morphogramme spelling, as well as provided a thorough examination of the construct of morphological knowledge. Furthermore, the present study explored an avenue for new research into children's overgeneralization of SLEs. Overall, the present study expands upon our understanding of morphological knowledge and SLE spelling in young elementary children and highlights the importance of including multiple measures when the construct of interest, such as morphological knowledge, is sensitive to developmental change.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Carleton University's Research Ethics Boards. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

RM planned and conducted the analyses, and she wrote the first draft of the manuscript. MS and VR initiated the study. VR designed the morpho-phono decomposition task, commented on the penultimate version and approved the final version. MS designed the remaining tasks, supervised the data collection and edited all subsequent versions of the manuscript.

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APPENDIX

Decomposition Task (and Correct Answer)

Training items: amical (ami); serpentin (serpent); chocolatier (chocolat).

Test items: villageois (village; ville); cuisinier (cuisine); écriture (écrit); horloger (horloge); érablière (érable); oreiller (oreille); animalerie (animale); pommier (pomme); naturel (nature); chevalier (cheval); épicier (épice); droitier (droit); marchandise (marchand); juteux (jus); lentement (lent); bavarder (bavard); lignée (ligne); bouffonnerie (bouffon); porcherie (porc); fabricant (fabrique).

Morpho-Phono Decomposition Task (Phonological Answer; Morphological Answer)

Training items: dentier (et; dent); requin (no smaller word = nsw).

Suffixed test items: droitier (roi, et; droit), faiblir (lire; faible), fermier (fer, et; ferme), griffure (gris; griffe), impropre (un; propre), impure (un, pue; pure), planchette (plan; planche), plombier (et; plomb), rebond (on; bond), rebord (or; bord).

Unaffixed test items: achat (a, chat; nsw), bouteille (bout; nsw), café (fée; nsw), canon (cane, non; nsw), caverne (cave, ver, verre; nsw), cochon (on, coche; nsw), coquille (coq, quillet; nsw), jurer (jus; nsw), pardon (par, don; nsw), profil (pro, prof, fil; nsw).

Analogy (and Correct Answer)

Training items: chien: chienne; chat: (chatte); content: contente; joyeux: (joyeuse); deux: deuxième; trois: (troisième).

Test items: gris: grise; blond: (blonde); parfait: parfaitement; heureux: (heureusement); retard retarder; souhait: (souhaiter); méchant: méchante; doux: (douce); jaloux: jalouse; délicat: (délicate); défait: défaite; compris: (comprise); canard: canardeau; souris: (souriceau); grand: grandeur; lent: (lenteur); drap: draperie; tapis: (tapisserie); laid: laideur; épais: (épaisseur); surpris: surprise; parfait: (parfaite); blanc: blanche; froid: (froide); content: contente; bavard: (bavarde); étroit: étroite; sourd: (sourde); haut: hauteur; gros: (grosseur); dent: dentier; dos: (dossier); chaud: chaudement; gratuit: (gratuitement); regard: regarder; aliment: (alimenter); renard: renardeau; éléphant: (éléphanteau); ment: menteur; vend: (vendeur).

Silent-Letter Ending Orthographic Recognition Task (Correct Answers in Italic)

1.	*chocolat*	chocolas	chocola	11.	repo	repot	*repos*	21.	habid	*habit*	habi
2.	matela	*matelas*	matelat	12.	argumend	*argument*	argumen	22.	*ragoût*	ragoûx	ragoû
3.	tapi	*tapis*	tapit	13.	diaman	diamand	*diamant*	23.	charios	chario	*chariot*
4.	*retard*	retar	retart	14.	*canot*	cano	canop	24.	transpord	*transport*	transpor
5.	ran	*rang*	rant	15.	spor	spord	*sport*	25.	torren	*torrent*	torrend
6.	combas	*combat*	comba	16.	plon	*plomb*	plont	26.	*milliard*	milliar	milliart
7.	*biscuit*	biscuis	biscui	17.	galot	galo	*galop*	27.	fusit	fusi	*fusil*
8.	aimand	aiman	*aimant*	18.	*serpent*	serpen	serpend	28.	*avocat*	avocas	avoca
9.	sabo	sabop	*sabot*	19.	*confort*	conford	confor	29.	dra	*drap*	drat
10.	*lézard*	lézar	lézart	20.	documen	documend	*document*	30.	*outil*	outit	outi

General Orthographic Recognition Task (Correct Answers in Italic)

1.	*graisse*	graice	11.	*jambe*	jembe	21.	baucal	*bocal*
2.	orteille	*orteil*	12.	fain	*faim*	22.	painture	*peinture*
3.	bombon	*bonbon*	13.	*sauce*	sausse	23.	jirafe	*girafe*
4.	*quille*	qille	14.	cinture	*ceinture*	24.	*brosse*	broce
5.	*garder*	guarder	15.	*menton*	manton	25.	*baleine*	balaine
6.	tanbour	*tambour*	16.	sommeille	*sommeil*	26.	flaucon	*flocon*
7.	*frein*	frain	17.	guardienne	*gardienne*	27.	*japper*	japer
8.	guarderie	*garderie*	18.	*magasin*	magazin	28.	trein	*train*
9.	naige	*neige*	19.	*trésor*	trézor	29.	bule	*bulle*
10.	*frapper*	fraper	20.	*rappel*	rapel	30.	*reine*	raine

Decoding Task (Correct Answers in Italic)

1.	*fraze*	traze	11.	umin	*ubin*	21.	*geamès*	geomès
2.	*phrès*	drès	12.	*amphant*	amdant	22.	daremps	*paremps*
3.	harfé	*harmé*	13.	loce	*lèce*	23.	*hinoscent*	binoscent
4.	*kuillaire*	tuillaire	14.	*geois*	geoif	24.	*genvié*	genrié
5.	réamp	*jéamp*	15.	aksidont	*aksidant*	25.	cefrait	*cekrait*
6.	liot	*liom*	16.	mahibe	*mahisse*	26.	açanfeur	*açanceur*
7.	*rekin*	tekin	17.	fainke	*sainke*	27.	*geardaim*	gearlaim
8.	*éguiye*	éguipe	18.	*rèzon*	rèton	28.	*rèzim*	rèmin
9.	sate	*saje*	19.	mévrié	*phévrié*	29.	muque	*duque*
10.	*movet*	mopet	20.	*seinje*	feinje	30.	katé	*karé*

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Dynamics of Sentence Handwriting in Dyslexia: The Impact of Frequency and Consistency

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Previous literature has indicated that linguistic and motor processes influence each other during written sentence production, and that the scope of this influence varies according to spelling ability or cognitive resources available. This study investigated how the spelling deficits associated with dyslexia affect the dynamics of the interaction between central and peripheral processes and the level of anticipation that can be observed in word spelling in the context of a sentence to dictation task. Children 9–12-year-olds with and without dyslexia wrote sentences to dictation in which the lexical frequency and phonology-to-orthography consistency of the last word (target) were manipulated. Analyses of kinematic measures (writing durations, in-air pen duration, and peaks of speed) revealed that children with dyslexia showed lexical frequency effects evident in within-word pauses (in-air pen) in the article and noun production. In addition, both children with and without dyslexia showed a phonology-to-orthography consistency effect in the pause before the target word. This effect tended to continue affecting the execution of the syllable prior to the inconsistency only in the group with dyslexia. Results support the influence of linguistic processes on motor execution. In addition, the study provides evidence of the impact of spelling deficits on the dynamics of handwriting in children with dyslexia.

Keywords: dyslexia, handwriting, sentence, orthographic consistency, lexical frequency, Spanish

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INTRODUCTION

Writing words involves both spelling processes (i.e., central processes) and graphomotor execution (i.e., peripheral processes). The nature of the spelling-motor interaction is still an unresolved issue. In fact, results from previous investigations are not consistent, in large part because varying tasks, orthographic systems, and/or measures have been employed (Søvik et al., 1994; Delattre et al., 2006; Lambert et al., 2011; Afonso et al., 2015a,b, 2018; Kandel and Perret, 2015a). However, accumulating evidence suggests that there is a complex relationship between both central and peripheral processes when writing and that this relationship may change with age, spelling and graphomotor skills (Olive and Kellogg, 2002; Sausset et al., 2012; Afonso et al., 2015a; Kandel and Perret, 2015b). It is well-documented that children and adults with dyslexia have persistent difficulties with accurate spelling (Wimmer and Mayringer, 2002; Lyon et al., 2003; Tops et al., 2012; Suárez-Coalla et al., 2016) that constrain handwriting production (Sumner et al., 2013, 2014; Afonso et al., 2015b). However, how the interaction between linguistic and motor processes is affected in children with dyslexia is still unknown, especially during the production of written words embedded in sentences, a very frequent task at school.

Although different mechanisms may be proposed to explain how linguistic processes affect motor processes (Afonso and Álvarez, 2019), a widely accepted explanation is that described by Olive (2014) in his model of cascade sentence writing. According to this account, different processes may be active in parallel during written production. Information processed at a certain level could flow (or "cascade") from higher-levels of processing to affect lower-level processes, allowing higher-level modules to deal with forthcoming linguistic units while motor processes are engaged in the production of preceding segments. This would lead to concurrent activation of different writing processes, which would be engaged with different parts of a sentence. Thus, when words must be produced successively (like in a sentence), some characteristics or dimensions of words could be planned during the writing of previous words, while others would be handled after starting the motor execution of the word (Bonin et al., 2006; Lambert et al., 2011; Fayol and Lété, 2012; Maggio et al., 2012, 2015).

Support for this point of view has been obtained in several studies that have analyzed the kinematics of the written response. Lambert et al. (2011) explored how lexical frequency and phonology-to-orthography regularity affect the time-course of handwriting during a four-words copying task. Undergraduates had to write a sequence of four words, where the target word (of varying lexical frequency and regularity) was placed in third position. The authors tried to test whether the spelling of the target word takes place during graphomotor execution of the previous word, which would mean an effect of anticipation or, in contrast, whether the spelling occurs during the pause right before the target word. Results proved that adult writers are able to retrieve the spelling of a word during the graphomotor execution of the previous word, showing a clear anticipation effect. In the same vein, Maggio et al. (2015) performed a written denomination task, where French adults wrote words for which frequency, orthographic consistency, and length were manipulated and that were preceded or not by a determiner. Results indicated that the speed of noun production decreased in the condition without the determiner, as the intra noun pauses was longer in that condition. Moreover, retrieval of the noun's spelling seemed to start before the determiner and continue during writing production. The frequency effect impacted on latencies and noun writing rate both with and without determiner; and the consistency effect was evident in the determiner writing rate, suggesting that some spelling features were being retrieved before or during the determiner production. Thus, the few works carried out so far with sentence writing about this issue indicate that there is a clear parallel processing and some anticipation effect when adults write successive words.

Crucially, according to Olive's (2014) model if sufficient cognitive resources are not available, information may cease to flow leading to serial processing of the different units of the message (Alamargot et al., 2007, 2010; Lambert et al., 2011). Support for this notion has been found in different populations and using a range of tasks. Sausset et al. (2012) found that adults were able to process all the syllables of a word in parallel before they started producing a word if they were asked to write in lower-case print letters (i.e., a condition with low graphomotor constraints). However, syllabic processing became more serial (with each syllable being prepared at the corresponding inter-syllabic interval) if graphomotor constraints imposed by the task increased by asking the participants to write in a less familiar condition (e.g., large upper-case print without visual feedback).

Due to the high demands of both handwriting and spelling processes during early writing acquisition, it is reasonably to think that age may play an important role in the level of parallel processing and the time-course of anticipation during writing. This issue has been mostly analyzed in studies investigating the written production of isolated words (Bonin and Fayol, 2002; Delattre et al., 2006; Lambert et al., 2011; Sausset et al., 2012; Afonso et al., 2018; Suárez-Coalla et al., 2018). Evidence obtained has shown that the impact of some linguistic factors on handwriting dynamics is different for different age groups. Kandel and Perret (2015a) found that phonology-to-orthography consistency affected the writing durations produced by French children between 8 and 10 years of age, but that the effect was larger for the younger children. Regarding word frequency, it has been found that this variable affects written latencies in both children and adults (Delattre et al., 2006; Lambert et al., 2011; Afonso et al., 2018), but its influence on writing durations seems to depend on the age of the writer (Søvik et al., 1994; Kandel and Perret, 2015b; Afonso et al., 2018; Suárez-Coalla et al., 2018). Afonso et al. (2018) reported that the effect of lexical frequency in Spanish children strongly affected the writing durations of 8-year-olds, but this effect decreased to disappear by 11 years of age.

Research investigating how the effects of the influence of linguistic processes on handwriting movements are affected by developmental dyslexia is still rather limited. Nonetheless, the few studies addressing this issue have consistently found that spelling difficulties experienced by individuals with dyslexia modify the scope of the influence that lexical and sublexical processes have on writing durations. French children with dyslexia exhibited larger effects of phonology-to-orthography regularity and lexicality on writing durations than peers without dyslexia in a word copying task (Kandel et al., 2017). Interestingly, in a study conducted in Spanish, children with dyslexia showed larger effects of consistency and lexical frequency in written latencies than typical readers, but a reduced effect of word frequency on writing durations in spelling to-dictation than in copying (Afonso et al., 2019). This pattern of results may be reflecting a reduced ability to engage in parallel processing when spelling words to dictation in younger children compared to older children and in children with dyslexia than in their peers without dyslexia.

To sum up, research devoted to written production of isolated words (Delattre et al., 2006; Álvarez et al., 2009; Lambert et al., 2011; Sausset et al., 2012; Kandel et al., 2013, 2014; Roux et al., 2013; Buchwald and Falconer, 2014; Afonso et al., 2015b) supports the hypothesis that central and peripheral processes interact during writing and that this interaction varies as a function of age and spelling ability (Lambert et al., 2011; Sausset et al., 2012; Afonso et al., 2015b). Specifically, spelling difficulties experienced by individuals with dyslexia seem to affect the extent to which linguistic processes affect word writing (Kandel et al., 2017; Afonso et al., 2019). According to the assumptions made by Olive's (2014) model, potential difficulties associated with the ability to parallel processing during writing should be more apparent when cognitive demands of the tasks are higher, like in a sentence production task or during text composition. The few studies that have investigated the effect of spelling difficulties associated with dyslexia on the production of linguistic units larger than a single word suggest that this may be the case (Berninger and Swanson, 1994; Sumner et al., 2013, 2014). In a study conducted with 9-year-olds, Sumner et al. (2013) observed that children with dyslexia produced a similar amount of letters per minute than their peers without dyslexia in an alphabet-writing task (a task with low cognitive demands), but they produced fewer words during text composition (a task with high cognitive demands). Children with dyslexia have also been reported to pause more often than peers in a sentence-copying task (Sumner et al., 2014), even if this task does not require generating ideas or retrieving the correct spelling of words. It seems that sentence-copying exerts sufficient cognitive demands to detect the effect of spelling difficulties on the handwriting movements produced by English-speaking children with dyslexia.

Spelling to dictation is a more cognitively demanding task than copying in at least two aspects. Firstly, during dictation writers must generate the spelling of the target words, while in copying the orthographic form is provided in the input. This may be a crucial point for individuals with spelling difficulties and may explain the reduced evidence for parallel processing observed in spelling to dictation when compared to copying in children with dyslexia (Afonso et al., 2019). Secondly, dictation requires maintaining the linguistic message in memory, while in a copying task this is usually available during the production of the response. This difference is more pronounced in sentence production than in single-word production tasks, since the linguistic message is substantially longer. Thus, differently from text composition tasks, writing sentences to dictation removes the demands related to idea generation but exerts specific demands on spelling processes. This makes this task especially interesting for the study of the dynamics of the relationship between spelling difficulties and handwriting performance. Surprisingly, no studies have approached the writing-to-dictation of words embedded in sentences.

Therefore, the main purpose of this study was to address the dynamics of handwriting in children with and without dyslexia, when they face a spelling-to-dictation of words embedded in sentences task. This task makes possible to explore the effects of spelling on handwriting, but eliminating the cognitive demands associated with planning or reading. The sentence structure was: article^1 + noun^1 + verb + preposition + article^2 + noun^2. The noun^2 was the target word, where lexical frequency and orthographic consistency were manipulated. The last word in the sentence was chosen as the target position based on previous findings that demonstrate that in the spelling tasks writers start writing as soon as they identify the first sounds of the auditory input (Afonso et al., 2018, 2019). We aimed to make sure that participants would not be able to actually produce the word before the end of the stimulus or shortly after, which would reduce the possibility of observing effects related to increased cognitive load. As spelling difficulties seem to constrain the writing flow and the dictation task implies some cognitive load, it was expected that significant differences between children with and without dyslexia in the temporal characteristics of handwriting processing would be found. Specifically, larger frequency and consistency effects in children with dyslexia than in children without dyslexia were expected. In addition, and in line with previous literature, differences between the impact of lexical frequency and inconsistency on handwriting dynamics are expected, with consistency having a greater impact on writing durations. We predicted that if children with dyslexia will not be able to solve the inconsistency before they start handwriting, then spelling will overrun the pause between article^2 and noun^2 (target), and as a consequence, the graphomotor execution of the first syllable (before the inconsistency) will slow down.

MATERIALS AND METHODS

Participants

A total of 36 children between 9 and 12 years of age (mean age 10 years; 8 months; $SD = 0.9$) participated in this study: eighteen with diagnosis of dyslexia (DYS) and 18 age-matched children without reading problems who served as controls (CON). Both groups consisted of 10 boys and 8 girls. They were also matched by socioeconomic status and type of handwriting (print letter or cursive writing). Participants with dyslexia were recruited from several primary schools, the Association of Dyslexia and certain Speech Therapy Centers of Asturias (Spain). They had previously received the diagnosis of dyslexia and they were receiving therapy in order to overcome or reduce their literacy difficulties. Participants without dyslexia were recruited from several primary schools in Asturias (Spain).

All of the participants were native Spanish speakers and had no known motor or perceptual disorders. They had an intelligence quotient (IQ) of 85 or higher according to the Wechsler Intelligence Scale for Children (Wechsler, 2001). Before performing the experimental tasks, a reading battery, PROLEC-R (Cuetos et al., 2014), was administered to all participants in order to assess reading performance and confirm reading difficulties in children with dyslexia. PROLEC-R yields scores (accuracy and total reading times) for word and pseudoword reading. The word section consists of 40 Spanish words, both high and low frequency. For each half, 10 words are short words and 10 are long words. The pseudoword section includes 40 pseudowords, half of them short and the other half long. Children with dyslexia (included in the DYS group) scored 1.5 to 2 standard deviations below the age norms provided by PROLEC-R in both accuracy and reading speed. Children without dyslexia (included in the CON group) had an age appropriate score in both sections. Means, standard deviations and p values for demographic characteristics and scores obtained in reading assessment tests are provided in **Table 1**.

In addition, we collected data about spelling ability from children with dyslexia, using the spelling battery PROESC

TABLE 1 | Means and standard deviations (in parenthesis) for demographic characteristics and reading scores of children with dyslexia (DYS) and chronological age-matched controls (CON).

	DYS *M* (*SD*)	CON *M* (*SD*)	*p*-value
Age (years)	10.8 (0.9)	10.7 (0.8)	$p = 0.66$
Education (years)	8.2 (0.8)	8.2 (0.8)	$p = 1$
Reading			
Words			
Accuracy (out of 40)	35.88 (2.72)	39.66 (0.59)	$p < 0.001$
Speed (s)	58.61 (21.25)	22.22 (3.35)	$p < 0.001$
Pseudowords			
Accuracy (out of 40)	32.00 (4.49)	38.61 (0.91)	$p < 0.001$
Speed (s)	78.50 (24.84)	41.55 (8.35)	$p < 0.001$

(Cuetos et al., 2002). This battery includes 25 inconsistent words, 25 ruled words and 25 pseudowords. The inconsistent words include at least two spelling options for one of its phonemes. The correct spelling of these words requires lexical knowledge and it is not enough to know the phoneme-grapheme conversion rules to spell them properly (e.g., "bolsa" [bag]). The ruled words includes some special orthographic rules (e.g., verbs ending in "-bir" must be written with "b" instead of "v," as in "recibir" [receive]). Finally, the correct spelling of pseudowords must be derived from the phoneme-grapheme conversion rules, as we do not have an orthographic representation for them (e.g., "sirulo"). Children with dyslexia showed a very low performance in the spelling battery. Specifically, they scored a $M = 14.55$, $SD = 3.95$ for the inconsistent words (while the average for their age, according to battery norms, is between 21 and 23), $M = 16.38$, $SD = 3.66$ for the ruled words (the average for their age is between 23 and 24); and $M = 17.72$, $SD = 2.19$ for the pseudowords (the average for their age is between 24 and 25).

Regarding the number of participants, *post hoc* computations conducted with G*Power 3.1.9.4 (Faul et al., 2009) of the achieved power showed that, given an $\alpha = 0.05$ and a total sample size of 36, the power achieved in this study to detect a significant effect with an effect size $\eta^2{}_p = 0.12$ in a within-between interaction in a repeated measures ANOVA was $1 - \beta = 0.99$. The effect size selected was that obtained in a significant interaction between the variable group (dyslexia versus typically-developing readers) and word frequency on the written latencies of adults of Spanish speakers (Afonso et al., 2015b).

Materials

The experimental task consisted of a writing-sentence-to-dictation-task, where twenty-four sentences, six words each, were employed. The sentence structure was: article^1 + noun^1 + verb + preposition + article^2 + noun^2 (target word); and the sentences were classified in four conditions (six sentences in each condition), where the lexical frequency and orthographic consistency were manipulated for the noun^2 of the sentences. On the other hand, the first syllable, the number of syllables, the number of letters number, the neighborhood size and the identity of the preposition and the article previous to the noun^2 were controlled across the conditions. Consequently, considering the noun^2 we had the following type of sentences: (1) high frequency and consistent words HFC - e.g., La gata descansa en el regazo [The cat rests in the lap], (2) low frequency and consistent words LFC - e.g., El marinero participa en la regata [The sailor participates in the regatta], (3) high frequency and inconsistent words HFI – e.g., La paisana pasea con el rebaño [The countrywoman walks with the flock], (4) low frequency and inconsistent words LFI – e.g., La tendera insiste en la rebaja [The shopkeeper insists on the rebate]. In addition, lexical frequency, orthographic consistency and length (syllable and letter number) were controlled for the noun^1 and the verb.

For the lexical frequency manipulation, we used the values provided by ONESC (Martínez and García, 2008). This database (for orthographic neighbors and including lexical frequency) was created from the cumulative dictionary of the six grades offered in Martínez and García (2004), a dictionary of frequencies for written language in children 6–12 years of age. In the dictionary of Martínez and García (2004), authors tried to make a quasi-absolute database of the words, considering the words a group of children found in their reading. The number of words (and also the number of children) to create this database was small. However, we consider this database is suitable for this study. As the age range in the groups tested is considerable (9–12 years of age) it is very important for the present study to ensure that word frequency values used to select material are applicable to children attending a range of different grades. The lexical frequency for the HF words was $M = 71.08$ ($SD = 78.05$), and for the LF ones $M = 5.15$ ($SD = 5.43$).

The selection of the inconsistent words was based on the P-G rules of the first phoneme of the second syllable. In this case, all of the inconsistent words had, at the beginning of the second syllable, a phoneme with two alternative spellings. For example, the word no-**V**e-la ([no**'b**ela], novel) is inconsistent because the second syllable (-Ve-) starts with the phoneme/β/, which in Spanish could be spelled as V or B (e.g., novela -correct- vs. nobela -incorrect-). Words in which spelling decisions of the second syllable are context-dependent have been excluded (e.g., c, z). By contrary, the consistent words were selected when the first phoneme of the second syllable only included phonemes with unambiguous spellings, for example, no-**T**a-rio, [no'**t**ario], notary), where the phoneme/t/is represented by only one grapheme "t." The full set of sentences with the values for manipulated and controlled variables is given in **Supplementary Material Appendix A**. For each sentence, an auditory stimulus was created for the spelling-to-dictation task.

Procedure

Sentence presentation and digital recording of the responses were controlled by Ductus (Guinet and Kandel, 2010). The experiment was run on an HP Mini laptop. A WACOM Intuos 5 graphic tablet connected to the computer and an Intuos Inking Pen were used to register the participants' responses. Auditory stimuli were recorded by a female speaker with a Plantronics microphone and edited with Audacity. The experimental sessions were carried out for each participant individually in a quiet room in the children school or private speech therapist center.

In the task, each trial started with the simultaneous presentation of an auditory signal and a 500-millisecond fixation point. The auditory stimulus was presented 500 milliseconds after offset of the fixation point. Participants had to listen to the auditory stimuli twice and then write the sentence in lower case, but with the first letter capitalized (as they typically do in the classroom), on a lined sheet of paper placed over the digitizer as quickly and as accurately as possible. When they finished the sentence, participants were asked to hold the pen over the next line of the response sheet, but without making any contact with the paper. In this moment, the experimenter clicked the left button of the mouse to start a new stimulus. The experimental session lasted around 20 minutes.

The research design was approved by the Ethics Committee for Research of the Principality of Asturias, Spain. The study was developed in accordance with the Declaration of Helsinki and the Spanish Law of Personal Data Protection (15/1999 and 3/2018) principles, and the data collection was covered by a written informed parental consent, obtained for all participants.

Statistical Analysis

For the statistical analyses, in addition to accuracy, we considered several critical segments: the pause between the preposition and the article[2] [e.g., La gata descansa EN ↔EL regazo], the article[2] previous to the noun[2] [e.g., La gata descansa en EL regazo], the pause between the article[2] and the noun[2] [e.g., La gata descansa en EL↔REGAZO] and the first syllable of the noun[2] [e.g., La gata descansa en el REgazo]. The trajectory and tangential velocity were used to isolate the syllable, using geometric (cuspids and curvature maxima) and kinematic (velocity minima) criteria when necessary, as proposed by Kandel and Valdois (2006). In order to distinguish between increased cognitive load emerging during parallel processing and during serial processing, the total duration of a word was divided in on-paper writing duration (in which the pen is in contact with the paper) and in-air pen duration (the total time within a word that the pen did not make contact with the tablet). Thus, the considered measures were the writing durations (after excluding the in-air pen duration), the in-air pen durations (within the word or syllable and between-words pause), and the number of peaks of speed. As only correct responses for the noun[2] were included in these analyses, responses with misspellings, self-corrections or missing data were removed from these analyses (in total, 19.33% of data were removed; 11.9% for the DYS group and 7.4% for the CON group). Besides, data above and below 2 standard deviations from the mean by participant and word were also excluded from the analysis (3.91%). For writing duration and in-air pen duration, ANOVAs were performed with mixed-effects analyses (Baayen, 2008) using R-software (RStudio, R Studio Team, 2015) with participants and items as random-effect variables and group, word frequency, and orthographic consistency as fixed factors. The most complex adjustment model (adjustment on the by-participants and by-item intercepts and by-participant slopes) was included in all the analyses (Barr et al., 2013). Stepwise model comparisons were conducted, from the most complex to the simplest model, and the one with the most complex adjustment but the smallest Bayesian information criterion (BIC) and significant χ^2 test for the log-likelihood was retained (Schwarz, 1978). *F* values from the ANOVAs of type III, with Satterthwaite approximation for degrees of freedom, are reported for fixed-effects. If interactions were significant, *t*-tests were performed and the *p*-values were adjusted via the Holm-Bonferroni method. For the analyses of errors, we used a generalized mixed-effect model with a binomial distribution. A *p*-value < 0.05 was adopted as a level of significance.

RESULTS

Writing Durations, In-Air Pen Durations, Peaks of Speed and Accuracy

Writing durations (in milliseconds) were considered as the time the pen was in contact with the tablet within a given word, so the in air-pen duration was excluded. In air-pen duration (in milliseconds) refers to the total time the pen is not in contact with the tablet for a given word. The number of peaks of speed or movement fluency involved the number of absolute velocity peaks in the velocity profile for each segment.

Writing durations, in-air pen durations, and number of peaks of speed were collected for the article[2] and the first syllable of noun[2]. In addition, in-air pen durations were considered for the pause between the preposition and the article[2] and between the article[2] and the noun[2].

In addition, the number of correct answers was analyzed.

Pauses (In-Air Pen Duration)

Between the Preposition and the Article[2]

The orthographic consistency factor had a marginally significant effect in the analysis conducted on in-air pen duration (or pause) between the preposition and the article[2], $F(1,18.313) = 3.28$, $p = 0.08$ (*Estimate* = 24.39, *SE* = 18.31). The time of the pencil in the air was longer when the noun[2] contained an inconsistent grapheme than when it did not have it.

Between the Article[2] and the Noun[2]

The main effect of orthographic consistency was significant in the analysis conducted on in-air pen duration (or pause) between the article and the noun[2], $F(1,21.13) = 4.39$, $p < 0.05$ (*Estimate* = 43.080, *SE* = 18.82). Longer pauses were observed before the production of nouns including an inconsistent segment.

Article

The main effect of lexical frequency was significant in the analysis conducted on in-air pen duration (or pause) during the article handwriting, $F(1,23.28) = 5.69$; $p < 0.05$ (*Estimate* = 13.09, *SE* = 5.48); and the lexical frequency by group interaction was also significant $F(1,591.03) = 3.70$; $p < 0.05$. Pairwise comparisons showed that only the DYS group showed a significant effect of lexical frequency in-air pen durations, $t(70) = 2.90$, $p < 0.05$ (*Estimate* = 21.40, *SE* = 7.36). See **Table 2**.

TABLE 2 | Writing duration and in-air pen duration for article and first syllable of children with dyslexia (DYS) and control group (CON).

	Article		First syllable			
	In-air pen		In-air pen		Writing duration	
	HF (*SE*)	LF (*SE*)	HF (*SE*)	LF (*SE*)	Consist (*SE*)	Incons (*SE*)
CON	30.43 (11.35)	39.51 (11.77)	45.54 (12.21)	44.36 (12.23)	549.93 (40.02)	548.08 (40.24)
DYS	35.21 (11.42)	60.91 (11.70)	43.11 (12.44)	58.55 (12.39)	593.34 (40.25)	650.74 (40.61)

HF, high frequency; LF, low frequency; Consist, orthographic consistent words; Incons, orthographic inconsistent word; SE, standard error.

First Syllable of the Noun[2]

In addition, lexical frequency significantly affected in-air pen duration (or pause) during the first syllable handwriting, $F(1,571.45) = 3.80$, $p < 0.05$, (*Estimate* = 7.13, *SE* = 3.65); the interaction between lexical frequency and group was also significant, $F(1,571.45) = 5.16$; $p < 0.05$. Pairwise comparisons showed that only the DYS group showed a significant effect of lexical frequency, $t(572) = 2.81$, $p < 0.05$, (*Estimate* = 15.43, *SE* = 5.49). See **Table 2**.

Writing Durations

Article[2]

The main effect of group was significant in the analysis conducted on writing durations, $F(1,33.8) = 4.257$, $p < 0.05$ (*Estimate* = 82.97, *SE* = 40.21). Children in the DYS group produced longer writing durations than children in the CON group.

First Syllable of the Noun[2]

A significant interaction between orthographic consistency and group was found on the writing durations analysis, $F(1,547.33) = 11.69$; $p < 0.001$. Pairwise comparison showed that orthographic consistency did not affect the CON group and affected marginally the DYS group $t(31) = 2.55$, $p = 0.07$ (*Estimate* = 57.39, *SE* = 22.47).

Number of Peaks of Speed

The variable group only affected the number of peaks of speed in the article[2] $F(1,33.81) = 4.26$, $p < 0.05$, (Estimate = 0.27, *SE* = 0.28), the DYS group showed more peaks of speed than the CON group.

Target Noun Spelling Accuracy

Table 3 shows the mean percentage of correct responses and standard deviations in each condition for both groups. Considering the 19.33% of misspellings, self-corrections and missing data, we found 15.29% of misspellings (9.32% for the DYS group, and 5.97% for the CON group), 2.19% of self-corrections (1.73% for the DYS group, and 0.46% for the CON group), and 1.85% of missing data (only for the DYS group). We found different type of mistakes: (1) grapheme substitution that implies a phonologically plausible mistake [e.g., "ca**b**erna" instead of "ca**v**erna"]; (2) grapheme substitution that implies a phonologically non-plausible mistake, resulting in a pseudoword [e.g., "necano" instead of "decano"]; (3) semantic substitution [e.g., "lavabo" instead of "lavadero"]; (4) grapheme omission [e.g., "decan" instead of "decano"]; (5) mixed mistakes [e.g., "**reb**oto" instead of "**dev**oto"].

The analysis showed an orthographic consistency effect ($p < 0.01$; Estimate = 1.56, *SE* = 0.57; *OR* = 0.21), and orthographic consistency by group interaction ($p < 0.05$, Estimate = 1.09, *SE* = 0.45; *OR* = 0.33), *post hoc* analysis revealed that the differences between groups was only significant for the inconsistent words ($p < 0.001$, Estimate = 1.08, *SE* = 0.26); in addition the consistency effect was larger for the DYS group ($p < 0.001$, Estimate = 2.64, *SE* = 0.57) than for the CON group ($p < 0.05$, Estimate = 1.55, *SE* = 0.58).

Summary of the Results

In comparison to typically developing peers, children with dyslexia produced longer writing durations and more peaks of speed in the article preceding the target word. They also showed a larger effect of word frequency in the in-air pen durations produced within the article and the first syllable of the target noun. Moreover, the duration of the pause previous to the target word was similarly affected by orthographic consistency in both the group with dyslexia and the group without dyslexia. However, this effect lasted for longer in the group with dyslexia, also affecting writing durations during the production of the target word.

DISCUSSION

The goal of this study was to better characterize the dynamics of handwriting processes of children with DYS when they spell to dictation words embedded in a sentence. To achieve this objective, the time-course of sentence handwriting was considered. In this task, Spanish children with DYS wrote on a digitizer 24 sentences with the same structure, but in which the orthographic consistency and lexical frequency of the last word was manipulated. We compared their performance with that of chronological-age matched children without literacy problems. Writing durations, in-air pen durations, peaks of speed, and accuracy were analyzed.

Results revealed interesting information about handwritten words in the context of a dictated sentence. Differences between groups were evident, supporting the idea that spelling difficulties impact on accuracy and handwriting execution. Children with DYS made more errors than the CON group in the inconsistent words and they showed a larger lexical frequency effect than

TABLE 3 | Mean percentage of correct responses and standard deviations (in parenthesis) in each condition for both groups.

	% HF Consist	% LF Consist	% HF Incons	% LF Incons
CON	96.29 (9.14)	90.74 (8.52)	82.40 (16.64)	71.29 (12.53)
DYS	96.07 (7.29)	90.74 (11.74)	62.96 (20.25)	54.63 (18.79)

HF Consist, high frequency and orthographic consistent words; LF Consist, low frequency and orthographic consistent words; HF Incons, high frequency and orthographic consistent words; LF Incons, low frequency and orthographic consistent words.

CON children on in-air pen duration during the article and first syllable production. The orthographic consistency effect seems to marginally continue impacting the production of the first syllable in DYS children. The effects of both frequency and consistency variables had different time courses during handwriting production.

The lexical frequency effect appeared in the article[2] (before the target word) for children with DYS and continued along the first syllable of the noun[2]. Specifically, DYS children spent more time with the pen in the air (for both the article[2] and the first syllable of the noun[2]) when they had to deal with LF words than when HF words were concerned. On the contrary, the CON group did not show a lexical frequency effect. In this study, where words were embedded in a sentence, DYS children showed an anticipation effect, as the frequency of a word had an effect on the production of the previous article[2]. These results confirm the difficulty for the DYS group accessing or processing low frequency words (Rüsseler et al., 2003; Afonso et al., 2015b, 2019), considering the small reading exposure they have. The extent to which this effect may be related to reduced exposure to written language in the group with dyslexia and thus, to differences between groups in the frequency with which words are actually encountered, is an issue that requires further investigation.

Similar to the effect found here in the previous article, Lambert et al. (2011) also reported anticipation of the word frequency effect in adult writers, as the spelling of one word seemed to be processed during the handwriting of the previous word. They considered that the graphomotor execution in adults implies a low cognitive load, and because of that, writers are able to process the spelling of the following word. In our case, we only found this anticipation effect for DYS children when they deal with LF words. Discrepancies could be due to several factors. First, they may be due to differences between the tasks used. While in our study we used a sentence-to-dictation task (with 6 words) and where the sentence was pronounced twice, the task used by Lambert et al. (2011) consisted of a four-words copying task, with the target word in third position. In this sense, it may be that the semantic context provided by the sentence in our study had contributed to a facilitation of the lexical selection process (Bonin et al., 2015) in the control group, leading to little difference between high-frequency and low-frequency words.

In previous research, the impact of lexical frequency on hand movements (e.g., writing durations) have yielded mixed results. In general, studies conducted with children have reported some effects of lexical frequency on writing durations (Søvik et al., 1994; Kandel and Perret, 2015a; Afonso et al., 2019), but not those carried out with adults (Delattre et al., 2006; Lambert et al., 2011). According to this, it seems that the influence of lexical frequency on writing durations may depend on the age or the spelling ability of the writer (Kandel and Perret, 2015a; Afonso et al., 2018, 2019). Previously reported results support the idea that lexical frequency modulates motor execution during writing acquisition (Afonso et al., 2018) and in children with dyslexia (Kandel et al., 2017), which is in line with our results. Interestingly, the frequency effect observed for the group with dyslexia affected the in-air pen durations produced within-words (namely, within the article and the first syllable of the target noun) rather than on-paper writing durations. This pattern may reflect a reduced ability to process in parallel the spelling of the word and the concurrent handwriting movements in the group with dyslexia. For children with dyslexia, information may cease to flow due to the cognitive demands exerted by the spelling to dictation task, leading to serial processing of central and peripheral processes (Olive, 2014). Accordingly, lexical access could only take place in pauses between periods of execution of writing movements.

Although this explanation seems to fit previous evidence (Alamargot et al., 2007, 2010; Lambert et al., 2011; Kandel et al., 2017) and widely accepted theoretical proposals developed in the field of writing (Olive, 2014), it is important to note that a strictly serial model could also accommodate the findings reported here. It has been suggested that individuals with dyslexia may experience difficulties accessing phonological or visual representations only when particularly high demands are imposed on short-term memory or when the task is especially challenging (Ramus and Szenkovits, 2008). In these cases, a processing bottleneck may occur for difficult stimuli, such as low-frequency words or inconsistent words. This bottleneck would lead to a postponement of the central processing for forthcoming units (Ferreira and Pashler, 2002), with the effects produced by the processing of previous units lasting more for students with dyslexia. This may also explain the word frequency effect in the present study. In any case, our findings clearly establish that the dynamics of the interaction between central and peripheral processes are altered in the handwriting production of Spanish children with dyslexia when compared to that of typically readers of the same age.

Alternatively, Spanish is a language with a more transparent orthography than French, so it is not impossible that our participants had relied more on the application of phonology-to-orthography conversion procedures than on lexical processes. This latter explanation may find support on the fact that our control group did show significant effects of orthographic consistency. Finally, it is also possible that the differences between high-frequency and low-frequency words are small in this group and that resources are enough to process low-frequency words without producing a significant impact on writing durations. In any case, more research is necessary in order to know more about the variables that affect the impact of word frequency in different tasks and populations.

Contrary to lexical frequency effect, orthographic consistency affected the pause between the preposition and the article[2] (marginally), and the pause between the article[2] and the noun[2] in both DYS and CON children. However, this effect tended to last longer in the DYS group, affecting also (marginally) the writing durations of the first syllable of the noun[2] in DYS children. As reported several times in studies using single words, orthographic consistency and regularity increases written latencies in adult and children (Bonin et al., 2001; Kandel and Valdois, 2005; Delattre et al., 2006; Roux et al., 2013; Afonso et al., 2015a,b; Suárez-Coalla et al., 2018). Crucially, the consistency and regularity effects seem to spread to affect the production of hand movements, indicating that inconsistencies are not fully resolved before writing starts (Roux et al., 2013; Afonso et al., 2015a, 2018, 2019; Kandel et al., 2017; Suárez-Coalla et al., 2018).

Moreover, this effect has been reported to depend on the position of the inconsistency (Roux et al., 2013; Suárez-Coalla et al., 2018) and on spelling ability (Afonso et al., 2015b). Recently, Kandel et al. (2017) found that irregularity increased writing duration and dysfluency in both children with and without dyslexia (ages 10–11), but the impact of regularity was larger for the group with dyslexia. In relation to our data, one may consider that CON children solve the inconsistency before they start the motor execution, during the previous pause.

However, the spelling processes were marginally active when DYS children were writing. According to this, and in accordance with accuracy results, difficulties with inconsistent words were more evident in DYS children than in CON ones. The absence of the effect of consistency in children without dyslexia may seem striking, but perhaps the semantic context provided by the sentence and the repeated presentation of the stimuli may have facilitated the resolution of the inconsistency before writing starts, thus favoring the disappearance of this effect on writing durations in this group of children.

Taken together the effects of orthographic consistency and lexical frequency, we observed that these variables produce different movement patterns in DYS children. The lexical frequency implied larger effects in in-air pen duration, while orthographic consistency impacted movement production. Similar results were reported by Kandel et al. (2017), suggesting that orthographic irregularities could have a stronger link with handwriting movements than lexical frequency. Further research addressing why these variables seem to have a different relationship with peripheral processes would surely provide valuable information to better understand the time-course of the different spelling routes.

In conclusion, our study provides evidence of the impact of linguistics variables on the peripheral processes during a sentence handwriting task, where DYS and CON children received words embedded in a sentence by dictation. Namely, we observed that the spelling deficit had an impact on the dynamics of sentence handwriting in dyslexia, as some differences between groups were found. Specifically, DYS children showed a word frequency effect evident in the article and the noun production. This frequency effect was manifested in within-word pauses (in-air pen), which is consistent with the idea of parallel processing of lexical and peripheral processes in individuals with dyslexia. In addition, both children with and without dyslexia showed a phonology-to-orthography consistency effect in the pause before the target word, but this effect continued to marginally affect the execution of the syllable prior to the inconsistency only in the group with dyslexia. This pattern supports the hypothesis that spelling impairment causes differences between children with dyslexia and age-matched peers in the dynamics of their writing, even when the planning and reading demands of the task are eliminated or reduced to a minimum.

Definitely, this study offers the opportunity to think over the spelling-motor interaction in children with and without spelling difficulties, as we tried to reach the impact of linguistic variables on graphomotor execution. Moreover, an effort was made to understand this interaction in the context of a sentence to dictation task, a very common classroom activity, but not very often used in research. This task seems to be suitable to achieve the effect of spelling difficulties on the handwriting movements, where information is not available during the response production (copying task) and generation of ideas is not necessary (text production). From our results, apart from the possible interpretations, it is clear that there are differences between Spanish children with and without dyslexia, in the dynamics of the spelling-motor interaction in the handwriting production.

The findings reported here have several implications for teachers of children with dyslexia. Accordingly, DYS children will need more time to successfully perform any written task including low frequency and inconsistent words. In this sense, adaptations may need to be considered at schools in order to facilitate the work of these children and avoid frustration. In addition, it should be important to help them to achieve writing accuracy.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee for Research of the Principality of Asturias, Spain. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

PS-C and OA developed the study concept and design. CM-G performed testing and data collection. PS-C and OA analyzed the data. PS-C, OA, and FC drafted the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2020.00319/full#supplementary-material

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Spelling Performance of Portuguese Children: Comparison Between Grade Level, Misspelling Type, and Assessment Task

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There is consensus among researchers that misspellings are something to avoid. However, misspellings also convey relevant information for researchers and educators. The present study is a first effort toward the analysis of misspellings produced by Portuguese children. Specifically, we aimed to examine the association between misspellings in dictation and composing tasks; compare misspellings across grade, type, and task; and test the contribution of different misspellings produced in dictation and in composition to text quality. For that, 933 Portuguese pupils in Grade 2 (n = 297), Grade 4 (n = 302), and Grade 6 (n = 334) performed a spelling-to-dictation task and wrote an opinion essay. Misspellings were categorized into phonetically inaccurate, phonetically accurate, and stress mark errors. Results showed correlations between the same type of misspellings across tasks for phonetically inaccurate errors in Grades 2 and 4, and phonetically accurate errors in Grade 2. Moreover, pupils produced more misspellings in dictation than composing tasks, and there was a progressive decrease in phonetically inaccurate and phonetically accurate misspellings across schooling, though stress mark errors were more frequent in Grade 4 than in other grades. Finally, spelling errors predicted text quality, particularly in younger children. Overall, these findings are aligned with extant results on spelling development and support current voices claiming for fine-grained analyses of misspellings. As they may vary across grade and task, and impact text quality differently, a detailed approach to spelling errors can provide valuable information on the development of this skill.

Keywords: Portuguese, spelling, misspellings type, grade comparison, assessment task

INTRODUCTION

The importance of producing accurate spellings is undeniable. Problems with word spelling hamper readers' comprehension, denote poor writing ability, and divert writers' attention from other processes (Graham and Santangelo, 2014). In alphabetic writing systems, accurate spellings rely on a solid knowledge of phoneme-to-grapheme and orthographic conventions[1]

[1]Children learning alphabetic scripts need to master phoneme-to-grapheme (spelling) and grapheme-to-phoneme (reading) correspondences, which are undoubtably related (Shankweiler and Lundquist, 1993). However, since spelling is the main topic of this brief report, for the sake of concision, only phoneme-to-grapheme correspondences are addressed.

(Treiman and Bourassa, 2000). Good spellers need to be able to match speech sounds in a language (phonemes) with their accurate representation in written form (graphemes). Moreover, they need to master the orthographic constraints imposed by the orthographic depth of the language, which comprises the complexity and unpredictability of phoneme-grapheme correspondences (Schmalz et al., 2015). Orthographic depth varies along a continuum from shallow orthographies – with simple and consistent phoneme-grapheme relations – to deep orthographies – with complex and inconsistent sound-letter mappings (Katz and Frost, 1992). Concerning the orthographic depth of sound-to-print correspondences, European Portuguese has several phonemes with multiple representations (Lurdes de Castro, 2000), such as the phoneme /z/ that can be spelled ⟨z⟩, ⟨s⟩ or ⟨x⟩. These multiple correspondences make the learning of spelling challenging as reflected in the amount of misspellings produced by beginning writers (Mesquita et al., 2020). However, few studies examined the type of spelling errors produced by speakers of European Portuguese. The present study conducted an analysis of Portuguese children's misspellings in order to increase understanding about failures in implementing basic word spelling procedures at different developmental stages; and to test whether such failures may be influenced by the spelling task and have impact on composing text.

According to a dual-route model (Barry, 1994), there are two procedures to spell a word: a phonological route that relies on sound-to-spelling conversions (assembled spelling) and a lexical route that retrieves known words from memory (addressed spelling). Grounded on this model, developmental theories proposed that the two routes are acquired successively, with children progressing from a partial-to-full *alphabetic phase* largely characterized by assembled spelling, to an *orthographic phase* that starts using addressed spelling (e.g., Ehri, 1986). Raising some objections to these theories, researchers recommended an approach to spelling development "as consisting of the predominant use of a particular process or strategy at different points in time, but not to the complete exclusion of others" (Treiman and Bourassa, 2000, p. 4). Beginning spellers may prioritize sound-based information, but they already rely on some orthographic knowledge; however, it is only with experience, that they become able to use multiple strategies to spell complex words (Cassar and Treiman, 1997). These claims have been supported by research examining spelling correctness of words with varying orthographic constraints (Defior et al., 2009). A study with Portuguese children found high accuracy rates in spelling words with unambiguous and context-dependent phoneme-grapheme mappings in Grade 2 (90 and 82%), though these latter were only mastered in Grade 4 (Mesquita et al., 2020). Similar findings were observed in Brazilian children (Pinheiro, 1995).

Common to many categorization systems of misspellings is the assumption that spelling is phonologically mediated (Treiman et al., 2019). Based on the dual-route model, a valuable classification of spelling errors, which was used in this study, is phonetically inaccurate vs. phonetically accurate (Treiman and Bourassa, 2000). In phonetically inaccurate errors, there is a mismatch between the spelling of the word and how it sounds [spelling the word ⟨ca**s**a⟩ (*house*) /ˈka.zɐ/ as ⟨ca**ss**a⟩/ˈka.sɐ/ results in a pronunciation that does not match the intended word]. In phonetically accurate errors, the phonological structure of the word is preserved, but an inappropriate orthographic interpretation is used (spelling ⟨ca**s**a⟩ or ⟨ca**z**a⟩ results in the same pronunciation /ˈka.zɐ/, but the second form is orthographically incorrect). These errors may signal difficulties in using the spelling routes. Phonetically inaccurate errors indicate that spellers are not successfully using sound-based strategies, whereas phonetically accurate errors suggest a correct use of the assembled route, but a failure in using a lexical-based orthographic procedure. From a developmental stand, it is thus not surprising that phonetically inaccurate errors decrease throughout schooling and that the bulk of misspellings are phonetically accurate (Bahr et al., 2012; Protopapas et al., 2013).

This dichotomic classification of misspellings is, however, not without limitations (Moats, 1993; Bosman and Van Orden, 1997). Among others, it is not sensitive to specific complexities of some orthographic codes, such as the use of marks to indicate stress. Though related to phonology, their use is not governed by phoneme-to-grapheme correspondences, but rather by orthographic rules and lexical-level prosodic knowledge (Defior et al., 2012; Gutiérrez-Palma et al., 2019). In European Portuguese, there are three stress marks (acute accent /´/; circumflex accent /^/; and tilde /∼/); for example, children learn that a stressed antepenultimate syllable requires an acute or circumflex accent to open or close the vowel, respectively (⟨p**ê**ndulo⟩ [*pendulum*] /ˈpẽ.du.lu/). Stress marks pose difficulties to Portuguese (Mesquita et al., 2020) as well as Spanish (Defior et al., 2009) and Greek (Protopapas et al., 2013) learners. Still, little is known about its incorrect use, including additions (⟨c**ô**xo⟩ for ⟨c**o**xo⟩ [*lame*] /ˈko.ʃu/), omissions (⟨j**u**ri⟩ for ⟨j**ú**ri⟩ [*jury*] /ˈʒu.ɾi/), or substitutions (⟨c**á**o⟩ for ⟨c**ã**o⟩ [*dog*] /ˈkɐ̃w/). This may be linked to their underrepresentation in current theoretical models, largely based on English spelling, which do not include diacritics. Therefore, following Gutiérrez-Palma et al. (2019), this study addressed stress mark errors as an independent type of misspellings with the goal of providing preliminary empirical evidence on their prevalence in Portuguese children's writing and contribute to refine explanatory approaches to word spelling.

Another understudied aspect is the extent to which spelling is task dependent. Typically, spelling abilities are assessed in dictation or composing tasks that challenge spellers differently. In dictation tasks, participants are asked to spell pre-defined items chosen to assess specific features of the spelling system; in composing tasks, participants are asked to write a text in response to a specific prompt and they are free to choose the words to write, including to avoid those features. Moreover, in dictation tasks, participants' only job is to retrieve, assemble, and select the word's orthographic representation and write it down; in composing tasks, they also need to enact many other processes, such as ideation, translation, and reconceptualization (Graham, 2018). A handful of studies reported correlations between dictation and composing misspellings, from 0.25 in American to 0.71

in Italian pupils (Graham et al., 1997; Limpo and Alves, 2013; Bigozzi et al., 2016), indicating an overlap between tasks. Nonetheless, no information about the impact of the assessment task on the type of misspellings was provided.

Because of the many processes competing for writers' attention during composition, being able to spell accurately is a valuable asset for young learners (Alves et al., 2018). Research showed that spelling skills constrain text quality (Graham et al., 1997; Abbott et al., 2010; Limpo and Alves, 2013), used as an indicator of writers' ability to create texts with good and coherently organized ideas, conveyed through well-crafted sentences and interesting vocabulary (Cooper, 1997). As claimed by recent cognitive writing models (Graham, 2018), due to spelling difficulties during composition, poor spellers have limited resources for other processes (e.g., idea generation, language formulation). In spite of this claim, no study tested whether text quality is more affected by pupils' difficulties with sound-based conversions (phonetically inaccurate errors), orthographic and/or lexical knowledge (phonetically accurate errors), or word stressing (stress mark errors).

PRESENT STUDY

Grounded on the dual-route model (Barry, 1994), we aimed to examine the success of Portuguese pupils in implementing sound- and orthographic-based spelling strategies. For that, we categorized misspellings into phonetically inaccurate or phonetically accurate errors (please see section "Procedure and Tasks"). A third category of errors was considered – stress marks – to examine whether word stressing was problematic for learners, as suggested before (Defior et al., 2009). Misspellings were compared across Grades, 2, 4, and 6 to study the evolution of each error type. Because stage theories (Ehri, 1986) suggest a progression from sound- to orthographic-based strategies, we expected more phonetically inaccurate errors in younger pupils, and an overall higher percentage of phonetically accurate and stress mark errors (Bahr et al., 2012). To test the premise that spelling skill is task dependent, we also compared the type of misspellings across two tasks with varying constraints (dictation vs. composing). Besides moderate between-tasks correlations (Limpo and Alves, 2013; Bigozzi et al., 2016), we anticipated that, despite the greater demands of composing, this task would elicit less errors, by allowing participants to choose the words to write (Graham et al., 1997; Limpo and Alves, 2013; Bigozzi et al., 2016). Finally, we aimed to deepen past findings showing contributions of spelling to writing (Graham et al., 1997; Abbott et al., 2010; Limpo and Alves, 2013) by identifying the type of misspellings with the strongest impact on text quality. We hypothesized that phonetically inaccurate errors, as markers of a failure in the basic mechanism to spell words (assembled spelling; Barry, 1994), would have the most damaging impact on writing. Together, these findings may improve our understanding of spelling development and provide useful hints to inform assessment and instructional spelling practices.

METHOD

Participants

Participants were 933 Portuguese native speakers in Grades 2, 4, and 6, who came from 50 classes from five public clusters of schools, holding collaboration protocols with authors' University. All pupils attending school in the data collection day and without special education needs were included. The sample comprised 297 second graders (M_{age} = 7.68 years, SD = 0.37; 44% girls), 302 fourth graders (M_{age} = 9.72 years, SD = 0.39; 52% girls), and 334 sixth graders (M_{age} = 11.66 years, SD = 0.43; 55% girls). For characterization purposes, we surveyed pupils' grades in core subjects (Portuguese and Mathematics) and mothers' educational level. Overall, our sample presented values slightly above the general population, as detailed in **Supplementary Table S1**.

Instructional Setting

Spelling has a central role in the Portuguese primary writing curriculum (Buesco et al., 2015). In Grades 1–2, spelling instruction is greatly focused on conveying basic phonological and orthographic knowledge. Children learn sound-to-print correspondences and consistent orthographic features (e.g., digraphs and context-dependent mappings). From Grade 3 onward, explicit spelling instruction is reduced, with the focus of writing instruction being on composing situations, where children should consolidate difficult orthographic complexities (e.g., inconsistencies or diacritics).

Procedure and Tasks

In one 30-min session, classroom groups with 20–25 pupils composed an opinion essay and spelt 16 words dictated at 10-s intervals.[2]

The procedure for the composing task was similar across grades. Pupils had 10 min to write the text, and they were notified 5 min and 1 min before the end of the time limit. Essay topics were: "Do you think children should eat candies whenever they want?" for Grade 2, "Do you think pupils' should have more field trips?" for Grade 4, and "Do you think teachers should give pupils homework every days?" for Grade 6. These prompts were previously identified by primary- and middle-grade schoolteachers as appropriate for pupils of the respective grades in terms of difficulty and interest value, thereby maximizing task engagement and productivity.

The 16-word list comprised four words from four orthographic complexity categories of the Portuguese spelling system, namely, consonant clusters (e.g., ⟨te**cl**ado⟩ *keyboard* /tɛ.ˈkla.du/), stress marks (e.g., ⟨j**uì**ri⟩ *jury* /ˈʒu.ɾi/), inconsistencies (e.g., ⟨**g**ema⟩ *yolk* /ˈʒe.mɐ/), and silent ⟨h⟩ (e.g., ⟨hino⟩ *anthem* /ˈi.nu/). These words were selected from a 56-word test used in previous research (Limpo and Alves, 2013;

[2] With the initial purpose of testing the contribution of misspellings to text quality above and beyond handwriting skill (i.e., ability to produce fast and accurate handwriting), pupils were also asked to perform two handwriting fluency tasks. However, introducing handwriting into the regression models led to the exact same results (see section "Contribution of Misspellings to Text Quality"). Thus, for the sake of parsimony, this variable was not included in any analysis and therefore not addressed in the manuscript.

Alves and Limpo, 2015; Mesquita et al., 2020), which time-related reasons prevented us to use here. The 16 words were selected by excluding complexity categories with high accuracy rates in Grade 2 and words less sensitive to grade level. Based on non-published data from Alves and Limpo (2015), performance in the 56- and 16-word list was strongly correlated (r = 0.84). The list here used includes bi- and trisyllable words of 4-to-7 letters, roughly half of them of high frequency and the other half of low-to-medium frequency (more information on the 16 words appears in **Supplementary Table S2**, and the 56-word test is described in Mesquita et al., 2020).

Measures

Spelling Errors

The number and type of spelling errors was examined in the dictation and composing tasks. Misspellings were counted and categorized into three types: phonetically inaccurate (e.g., spelling ⟨gema⟩ /ʹʒe.mɐ/as ⟨**x**ema⟩ /ʹʃe.mɐ/), phonetically accurate (e.g., spelling ⟨gema⟩ as ⟨**j**ema⟩, both forms accurately sound as /ʹʃe.mɐ/), and stress mark (surplus, omission, or substitution of diacritics; e.g., spelling ⟨gema⟩ as ⟨g**ê**ma⟩). Due to lack of legibility, the spelling correctness of 1% if the words could not be discerned. Given the reduced percentage, these words were not considered in further analyses. The final score for both tasks was the percentage of each error type, computed by dividing number of errors by number of words dictated or written in the essay. By using percentages, we accounted for differences in the amount of words produced in the compositions: 41 (SD = 28), 52 (SD = 29), and 54 (SD = 29) in Grades 2, 4, and 6, respectively. To allow the computation of percentage in reference to total words, for words with several errors only one was counted, following a hierarchy of error severity from readers viewpoint, being in decreasing order phonetically inaccurate, phonetically accurate, and stress mark.

Text Quality

The quality of opinion essays was rated by two trained graduate research assistants with an holistic scale (based on Cooper, 1997). Raters gave a single value to each text from 1 (*low quality*) to 7 (*high quality*), taking ideas quality, organization, sentence structure, and vocabulary into account (Limpo and Alves, 2013). To control for expected grade differences, texts were grouped and rated separately by grade. Judges were then provided with representative examples of low-, medium-, and high-quality texts within each grade level (for a similar procedure see Graham et al., 1997; Alves and Limpo, 2015). To avoid biased judgments, all texts were typed and corrected for misspellings (Berninger and Swanson, 1994). The final score was the average across judges.

Reliability

Spelling measures from 80 pupils per grade (25–30%) were rescored by a second judge. Interrater agreement measured with the intraclass correlation coefficient (ICC) for single measures and separately by grade was above 0.82 and 0.92 for misspellings in composing and dictation, respectively. Because text quality of all participants was double scored, we computed average measures ICC, which was above 0.92.

RESULTS

Characterization of Pupils' Misspellings

To characterize misspellings, we conducted a preliminary examination of descriptive statistics (**Table 1**) and correlations (**Table 2**) for misspellings by grade. Noteworthy findings were: correlations between the same type of misspellings in dictation and composition were observed for phonetically inaccurate errors in Grade 2 (r = 0.33) and Grade 4 (r = 0.25), and for phonetically accurate errors in Grade 2 (r = 0.25); correlations between different types of misspellings in dictation (namely, between phonetically inaccurate and phonetically accurate, between phonetically inaccurate and stress marks, and between phonetically accurate and stress marks errors) were evident mainly in Grade 2 ($-0.18 < rs < -0.52$), whereas correlations between different types of misspellings in composition were stronger in Grade 4 ($0.27 < rs < 0.30$); poorer texts were generally associated with more misspellings, particularly in second graders ($-0.11 < rs < -0.26$).

Comparison of Misspellings Across Grade, Type, and Task

We conducted a 3 (Grade [Grade 2, Grade 4, Grade 6]) x 3 (Misspelling type [phonetically inaccurate, phonetically accurate, stress mark]) x 2 (Task [composing, dictation]) ANOVA with repeated measures on the last factors. Results revealed three main effects: Grade, $F(2,930) = 440.70$, $p < 0.001$, $\eta_p^2 = 0.49$; Misspelling type, $F(2,929) = 649.27$, $p < 0.001$, $\eta_p^2 = 0.58$; and Task, $F(1,930) = 5385.38$, $p < 0.001$, $\eta_p^2 = 0.85$; and three 2-way interactions: Grade x Misspelling type, $F(4,1860) = 111.29$, $p < 0.001$, $\eta_p^2 = 0.19$; Grade x Task, $F(2,930) = 204.60$, $p < 0.001$, $\eta_p^2 = 0.31$; and Misspelling type x Task, $F(2,929) = 555.74$, $p < 0.001$, $\eta_p^2 = 0.55$. We also found a significant 3-way interaction, $F(4,1860) = 64.17$, $p < 0.001$, $\eta_p^2 = 0.12$, illustrated on **Figure 1** and decomposed with simple effects analyses described below.

Differences Between Grade Levels

We found grade differences for all error types in both tasks, $Fs(2,930) > 17.55$, $ps < 0.001$, $\eta_p^2 > 0.04$. Pairwise comparisons showed that the percentage of phonetically inaccurate and phonetically accurate errors in both tasks was significantly different among the three grades ($ps < 0.001$, except for differences in the percentage of phonetically inaccurate errors in the dictation task between Grade 4 and 6, $p = 0.20$), with second graders displaying more errors and sixth graders displaying less errors. The pattern of findings was different for stress mark errors: in composition, fourth graders produced more errors than second graders, who in turn produced more errors than sixth graders ($ps < 0.001$); in dictation, fourth graders produced more errors than both second and sixth graders ($ps < 0.001$), who did not differ one another ($p = 0.78$).

Differences Between Misspelling Types

Except for Grade 6 in the composing task, where the percentage of misspellings did not vary across error type ($p = 0.22$), we found differences in error types for both tasks and in the

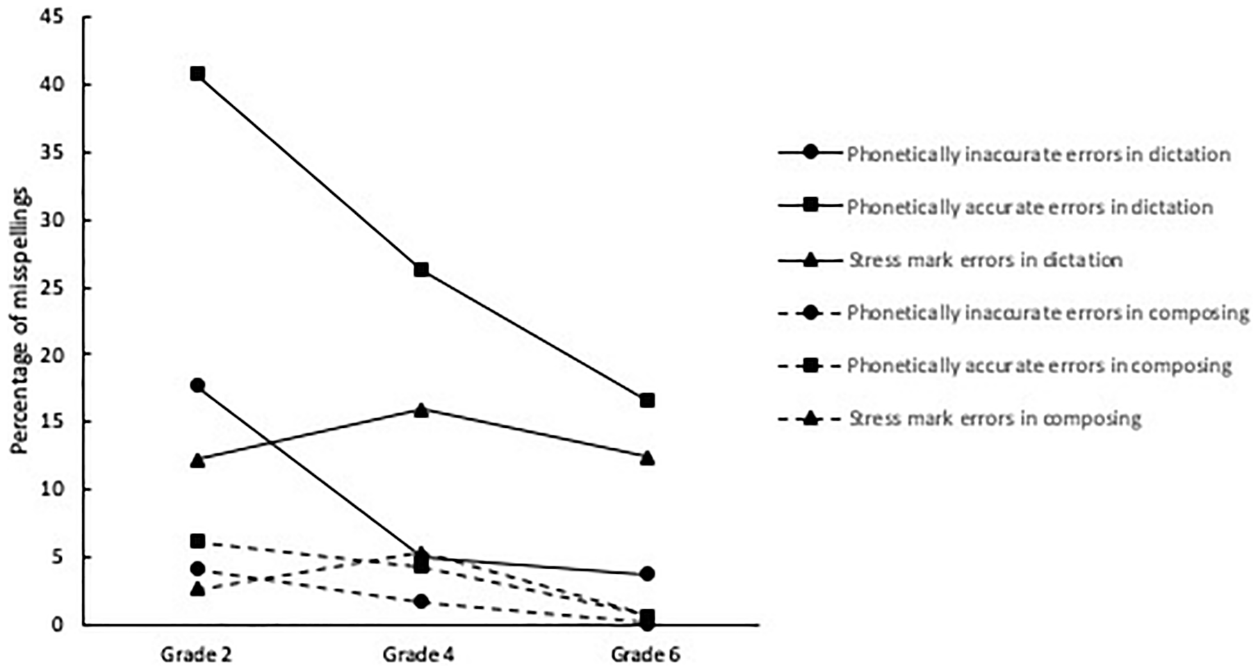

FIGURE 1 | Illustration of the Grade × Error Type X Spelling Task interaction.

three grades, $Fs(2, 929) > 33.43$, $ps < 0.001$, $\eta_p^2 > 0.07$. For the composing task, the percentage of errors in decreasing order was phonetically accurate, phonetically inaccurate, and stress mark in Grade 2, and stress mark, phonetically accurate, and phonetically inaccurate in Grade 4; for the dictation task, the percentage of errors in decreasing order was phonetically accurate, phonetically inaccurate, and stress mark in Grade 2, and phonetically accurate, stress mark, and phonetically inaccurate in Grades 4 and 6 ($ps < 0.02$).

Differences Between Spelling Tasks

We found task differences for all error types in the three grades, $Fs(1, 930) > 23.33$, $ps < 0.001$, $\eta_p^2 > 0.02$, with consistently more errors in dictation than composition.

Contribution of Misspellings to Text Quality

To examine the contribution of misspellings to text quality, we conducted regression analyses for each grade (**Table 3**). In Grade 2, misspellings explained 12% of the variability in text quality, $R = 0.35$, $F(6, 290) = 6.76$, $p < 001$. Significant predictors were phonetically inaccurate errors in the dictation task ($b = -0.16$) and phonetically inaccurate ($b = -0.21$) and stress mark ($b = -0.13$) errors in the composing task. In Grade 4, misspellings explained 11% of the variability in text quality, $R = 0.33$, $F(6,295) = 9.50$, $p < 001$. Significant predictors were stress mark errors in the dictation task ($b = 0.12$) and phonetically inaccurate ($b = -0.12$), phonetically accurate ($b = -0.14$), and stress mark ($b = -0.13$) errors in the composing task. In Grade 6, misspellings explained 4% of the variability in text quality, $R = 0.20$, $F(327,6) = 2.22$, $p = 0.04$, with phonetically inaccurate errors in dictation ($b = -0.15$) being the unique predictor.

DISCUSSION

This study aimed to examine the types of misspellings in spelling-to-dictation and composing tasks produced by second-, fourth-, and sixth-grade Portuguese pupils.

An examination of the correlations between the same type of misspellings in dictation and composition showed that

TABLE 1 | Means and standard deviations of the misspellings produced in the dictation and composing tasks by grade.

	Grade 2		Grade 4		Grade 6	
	(*n* = 297)		(*n* = 302)		(*n* = 334)	
Measures	***M***	***SD***	***M***	***SD***	***M***	***SD***
Percentage of spelling errors in dictation (total)	72.85	16.77	47.25	15.96	33.31	14.15
Phonetically inaccurate	17.68	18.69	4.95	8.81	3.71	6.17
Phonetically accurate	40.80	14.01	26.26	11.03	16.60	6.12
Stress mark	12.23	8.65	15.94	8.25	12.43	9.14
Percentage of spelling errors in text (total)	13.05	10.96	11.31	16.40	1.73	5.92
Phonetically inaccurate	4.12	6.35	1.69	4.08	0.11	0.65
Phonetically accurate	6.18	6.68	4.25	8.57	0.64	1.62
Stress mark	2.63	3.86	5.29	9.41	0.67	1.67
Text quality (1–7)	3.10	1.38	3.24	1.32	3.54	1.00

TABLE 2 | Correlations among misspellings in the dictation and composing tasks by grade.

	Total		Phonetically inaccurate		Phonetically accurate		Stress mark		Text
	Dictation	**Composing**	**Dictation**	**Composing**	**Dictation**	**Composing**	**Dictation**	**Composing**	**Quality**
Grade 2									
Total									
Dictation		0.23	0.73	0.28	0.30	0.14	−0.41	−0.04	−0.21
Composing			0.15	0.64	0.17	0.74	−0.16	0.45	−0.30
Phonetically inaccurate									
Dictation				0.33	−0.18	0.02	−0.52	−0.14	−0.18
Composing					−0.08	0.09	−0.21	0.01	−0.26
Phonetically accurate									
Dictation						0.25	−0.26	0.18	−0.11
Composing							−0.10	0.16	−0.16
Stress mark									
Dictation								−0.06	0.14
Composing									−0.14
Grade 4									
Total									
Dictation		0.22	0.58	0.27	0.71	0.15	0.34	0.12	−0.07
Composing			0.20	0.57	0.07	0.75	0.09	0.80	−0.29
Phonetically inaccurate									
Dictation				0.25	0.14	0.17	−0.17	0.08	−0.15
Composing					0.17	0.27	0.02	0.30	−0.22
Phonetically accurate									
Dictation						0.04	−0.11	0.02	−0.06
Composing							0.04	0.28	−0.22
Stress mark									
Dictation								0.12	0.10
Composing									−0.20
Grade 6									
Total									
Dictation		0.09	0.57	0.09	0.55	0.17	0.73	0.22	−0.18
Composing		0.02	0.11	0.12	0.27		0.04	−0.26	−0.14
Phonetically inaccurate									
Dictation				0.07	0.12	0.06	0.09	0.11	−0.16
Composing					0.05	0.08	0.07	−0.06	−0.03
Phonetically accurate									
Dictation						0.06	0.11	−0.12	−0.03
Composing							0.18	0.03	−0.07
Stress mark									
Dictation								0.19	−0.11
Composing									−0.03

Correlations of 0.12 or above for Grades 2 and 4, and of 0.11 or above for Grade 6 are significant at an alpha level of 0.05.

the percentage of phonetically inaccurate errors in Grades 2 and 4, and of phonetically accurate errors in Grade 2 which were produced in dictation was associated with that produced in composition. This finding partially agrees with other studies showing correlations between misspellings in dictation and composing tasks (e.g., Graham et al., 1997; Limpo and Alves, 2013; Bigozzi et al., 2016). However, the low correlations in Grades 2 and 4 (<0.33) and general lack of correlation in Grade 6 (<0.19) seem to reflect the different conditions under which spelling is measured. In dictation, pupils' major task is to spell isolated words, whereas in composition, processes other than these compete for writers' attention (e.g., idea generation; Graham, 2018). Additionally, in the dictation task, participants were forced to spell a set of pre-defined words, some of them with very low frequency of occurrence and representing difficult orthographic features of the Portuguese spelling system (e.g., consonant cluster, stress marks, and phoneme-grapheme inconsistencies). In the composing task, children were free to choose the words they wanted to write.

TABLE 3 | Parameter estimates for models regressing text quality onto misspellings by grade.

Predictors	B	SE	b	t	p
Grade 2					
Misspellings in dictation					
Phonetically inaccurate	−0.01	0.01	−0.16	−2.30	0.02
Phonetically accurate	−0.01	0.01	−0.12	−1.81	0.07
Stress mark	<0.001	0.01	−0.03	−0.35	0.07
Misspellings in composing					
Phonetically inaccurate	−0.05	0.01	−0.21	−3.62	<0.001
Phonetically accurate	−0.02	0.01	−0.08	−1.33	0.19
Stress mark	−0.05	0.02	−0.13	−2.29	0.02
Grade 4					
Misspellings in dictation					
Phonetically inaccurate	−0.01	0.01	0.07	−1.17	0.24
Phonetically accurate	<0.001	0.01	<0.001	−0.07	0.95
Stress mark	0.02	0.01	0.12	2.05	0.04
Misspellings in composing					
Phonetically inaccurate	−0.04	0.02	−0.12	−1.99	0.05
Phonetically accurate	−0.03	0.01	−0.14	−2.38	0.02
Stress mark	−0.02	0.01	−0.13	−2.23	0.03
Grade 6					
Misspellings in dictation					
Phonetically inaccurate	−0.02	0.01	−0.15	−2.71	0.02
Phonetically accurate	0.00	0.01	<0.001	−0.04	0.97
Stress mark	−0.01	0.01	−0.10	−1.83	0.07
Misspellings in composing					
Phonetically inaccurate	<0.001	0.09	<0.001	0.00	1.00
Phonetically accurate	−0.03	0.04	−0.04	−0.67	0.50
Stress mark	0.04	0.03	−0.06	1.10	0.27

These differences between the dictation and composing tasks can also explain the finding that, consistently across grades and types of misspellings, the dictation task resulted in more spelling errors than the composing task. This finding was not surprising. Given the low percentage of misspellings (average of 8% for the whole sample), children seemed very effective in selecting words they knew how to spell (Graham and Santangelo, 2014). Actually, in Grade 6, the percentage of misspellings in composition was below 2%, suggesting that pupils become increasingly strategic throughout schooling. However, this finding also indicates that composing tasks might not be a sensitive indicator of older pupils' spelling skill. Composition-based measures may mask spelling' difficulties and provide a biased picture of writers' abilities.

It should additionally be noted that because of the forced vs. free selection of words that characterizes dictation and composing tasks, the type of misspelled words compared was probably different. This may be another factor contributing to the above-discussed inter-task differences concerning correlational patterns and percentage of misspellings. For example, can the same word spelled in dictation and composing tasks be similarly misspelled? For a stringent test to the effects of assessment task on misspellings, future research should manipulate dictation and composing tasks to elicit comparable words. This could be achieved by using lists composed of words either closer to those that children produce and are exposed to in school, or in line with the topic of composition.

In general, pupils in higher grades produced less phonetically inaccurate and phonetically accurate misspellings than those in lower grades. With experience and instruction, children acquire new strategies and knowledge that allows them to produce less and less misspellings (Treiman and Bourassa, 2000). This developmental pattern is not new (Bahr et al., 2012; Alves and Limpo, 2015), but it provides relevant practical indications. Despite the decrease, sixth graders failed to correctly spell 33% of the words dictated. Indeed, though explicit spelling instruction in Portuguese schools seems to occur only in primary years, pupils show evidence of not having mastered the complexities of the Portuguese spelling system during that period. This skill should perhaps be explicitly taught and systematically practice until difficult orthographic features are fully learned. For a deeper understanding of the specific features that are a struggle for pupils at different grades, future studies should include fine-grained analyses of misspellings at the stimulus level.

The decreasing trend observed for phonetically inaccurate and phonetically accurate misspellings was, however, not observed for stress mark errors, which were more frequent in Grade 4. Unexpectedly, the more frequent these errors were in the dictation task, the better the quality of fourth graders compositions. The present study does not provide compelling explanations for these findings. Though they may represent a sample artifact, they may also be linked to the way stress marks were taught to the children observed here. The relationship between instructional practices and pupils' performance, particularly in terms of stress assignment, should receive further research attention. Past studies already indicated that children struggle with the learning of this spelling feature in particular (e.g., Defior et al., 2009). Stress mark errors may signal poor knowledge of lexical stress and difficulties in mapping orthography and prosody (Defior et al., 2012; Gutiérrez-Palma et al., 2019). A question still to be answered is how this information is being taught in primary grades. At least for Portuguese spellers there are no evidence-based practices that teachers can use to foster pupils' knowledge about the appropriate placement of stress marks in words.

Considering all pupils together, stress mark and phonetically accurate errors represented the majority of misspellings produced in both tasks (cf. Bahr et al., 2012). In comparison, phonetically inaccurate errors were less frequent, confirming that the learning of sound-based spelling strategies occurs in the earliest phases of spelling development (Ehri, 1986; Treiman and Bourassa, 2000). In dictation, phonetically accurate errors were consistently higher than phonetically inaccurate errors, suggesting an overall success in using the assembled route to spell words, but a less-than-desirable ability in using the orthographic-based procedure. From an applied viewpoint, this means that spelling instruction is not being entirely successful in fostering addressed spelling. Past research already showed the differential benefits of varying training methods to improve spelling accuracy (Berninger et al., 1998; Van Leerdam et al., 1998). Future research should complement these findings by looking at the effectiveness of those methods to suppress specific types of misspellings, in particular those resulting from failures in the orthographic processing system.

We found an effect of spelling on text quality that supports theoretical claims (Berninger and Winn, 2006; Graham, 2018) and replicates past findings (Abbott et al., 2010; Limpo and Alves, 2013; Limpo et al., 2017). Misspellings explained 12, 11, and 4% of the variance in text quality in Grades 2, 4, and 6, respectively. This low percentage was not unexpected. It aligns with writing models proposing that spelling is a key writing process (Graham, 2018), alongside many others not here examined (e.g., idea generation, language formulation, reviewing, executive functions). Furthermore, older pupils' spelling seemed to play a smaller role in writing, supporting the claim that throughout schooling as spelling gets more automatic and interferes less with composing quality (Graham et al., 1997; Berninger, 1999; Abbott et al., 2010).

This study also showed the specificity of the misspellings' effects on text quality. We found that poorer texts were associated with (a) phonetically inaccurate errors in dictation and composition, and stress mark errors composition in Grade 2; (b) stress mark errors dictation and all types of errors in composition in Grade 4; (c) phonetically inaccurate errors in dictation in Grade 6. As already anticipated from the correlation analyses, it seems that neither all types of misspellings interfered with text quality nor to the same degree, suggesting the involvement of varying levels of attentional resources in different word spelling processes. At least here, the most consistent predictors were phonology-based misspellings. These errors may indicate lack of automaticity in sound-to-print conversions, which may need extra attentional resources that are diverted from other processes underlying good writing. Pupils did not produce this type of errors very often – though it represented 18% of the second graders' misspellings in dictation – but those who did it, seem at a clear disadvantage. Teachers should be sensitive to their occurrence in any grade and implement either preventive or remediating practices to eliminate them.

Moreover, the finding that phonetically accurate errors were generally unrelated to text quality may indicate that pupils do not seem to struggle with the addressed spelling route, even when disrupted. For example, little interference in writing is expected if pupils are not aware of an orthographic rule and believe to be spelling correctly (which is reinforced by the fact that the misspelled word sounds as the intended word). It is worth noticing that the holistic measure of text quality prevented us to ascertain the specific text features (e.g., discourse, sentence, word) affected (or not) by different types of misspellings, which can be done by employing analytic measures. These findings also imply that depending on children's grade, some tasks maybe more appropriate than others to uncover the link between spelling and text quality. Composing tasks seem useful to assess spelling skills and examine its predictive value in younger pupils; whereas they seem less valuable in older pupils, who may act strategically as previously noted.

CONCLUSION

There is no question that misspellings are something to avoid. However, as suggested by current and other findings (e.g., Treiman et al., 2019), misspellings also convey key information for researchers and educators. Despite the proved value of looking into spelling accuracy (Abbott et al., 2010), examining the type of misspellings provides fine-grained data that may not only deepen researchers' knowledge about learning to spell and its role on writers' ability to produce text, but also inform educators about the most suitable instructional practices to fulfill pupils' writing needs.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Faculty of Psychology and Educational Sciences of the University of Porto. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

TL and SC designed the study. SM, AM, MF, and AV collected and coded the data. TL analyzed and interpreted the data. All authors wrote and reviewed the manuscript and approved its final version.

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SUPPLEMENTARY MATERIAL

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The Reciprocal Relationship Between Handwriting Fluency and Spelling Accuracy in Chinese: A Longitudinal Study

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Mastering transcription skills is an important goal in the development of children's written language abilities, and handwriting fluency and spelling accuracy are crucial indicators of transcription ability. The current study was a two-year longitudinal study to investigate the reciprocal relationship of handwriting fluency and spelling accuracy. Participants included 123 students living in mainland China, who were tracked from third to fifth grade, and were administered a comprehensive battery of tests including assessments for non-verbal intelligence, phonological awareness, rapid automatized naming, and copying and dictation of Chinese characters. The results showed that: (1) previous handwriting fluency predicted subsequent spelling accuracy; and (2) previous spelling accuracy predicted subsequent handwriting fluency. These findings indicated there is a bidirectional relationship between handwriting fluency and spelling accuracy in Chinese. This implies spelling accuracy should not be unilaterally emphasized when teaching children new vocabulary, but attention should also be given to the cultivation of handwriting fluency in daily pedagogical practice.

Keywords: reciprocal relationship, handwriting fluency, spelling accuracy, Chinese children, longitudinal study

INTRODUCTION

Transcription is the ability to transform linguistic representations in working memory into written texts, and incorporates both handwriting and spelling skills (Berninger, 1999). According to the simple view of writing (Berninger et al., 2002; Bisschop et al., 2016), transcription, as one of its vital related skills, supports the complex writing processes performed within working memory. However, while the simple view of writing emphasizes the importance of transcription skills, it fails to indicate the relationship between handwriting and spelling, the two essential skills needed for transcription. Compared to the considerable amount of research regarding transcription and writing (Limpo and Alves, 2013; Kent et al., 2014), the interaction between handwriting and spelling skills have not attracted much attention in the literacy acquisition process (Medwell and Wray, 2010). The widespread use of mobile phones and computers makes individuals gradually become used to typing over writing by hand, which seriously weakens writing skills and results in having problems writing characters (Hu, 2019). Nevertheless, both handwriting and spelling skills are vital for individuals to learn, especially children. It is estimated that 30–60% of a child's school day is spent performing written work (Marr et al., 2001). Children should be able to master certain levels of handwriting and spelling skills so they can adeptly use them as tools to improve their learning in school (Limpo et al., 2017). Thus, fluent handwriting and accurate spelling can help to minimize restrictions on students' writing and facilitate their acquisition of basic writing skills (Graham and Santangelo, 2014), even enabling students to achieve maximum success in the classroom throughout their academic careers (Eames and Loewenthal, 1990; Graham et al., 2000).

Handwriting is a complex activity requiring an intricate blend of cognitive, kinesthetic, and perceptual-motor components (Rosenblum et al., 2003), and it is influenced by children's visual motor integration, fine motor dexterity, and other skills. Each of these is considered the foundational skill required for adequate handwriting (Maeland, 1992). The more automatized this process of integration is, the more cognitive resources are available, and handwriting becomes smoother under a lower cognitive load (Bourdin and Fayol, 1994). Hence, whether English (Berninger et al., 1992; Lambert et al., 2011) or Chinese studies (McBride-Chang et al., 2011; Yeung et al., 2016), handwriting skills, especially handwriting fluency, has always been a major focus in research on children's writing development. In the handwriting practice, children are required to write as fast as possible, and their handwriting fluency are assessed by counting the number of correct letters written during the task (Berninger et al., 1992). During this process, children who want to write quickly need to build and strengthen their visual-spatial representation skills and orthographic characterization of words. The integration of this ability is directly related to the level of automation, thus affecting the speed of children's output. Moreover, the automatization of this process means that children have high levels of handwriting fluency (Santangelo and Graham, 2016).

Furthermore, spelling is also an important component of transcription (Berninger et al., 1992). Spelling refers to the ability to recognize, recall, and reconstruct the correct order of letters for a word in spoken or written form (Graham and Miller, 1979). Children are often required to understand and apply phonetic and morphological rules to establish orthographic representations of words (Critten et al., 2016). Moreover, spelling is a complex cognitive process that emphasizes accuracy. Spelling accuracy is a core indicator of children's spelling abilities, and dictation has been conventionally adopted to test spelling accuracy in alphabetic languages (Lam and McBride, 2018) and morphosyllabic languages (Li et al., 2017)]. In the process of dictation, when children hear a spoken word, they need to spell out this word, with the help of grapheme-phoneme correspondence and complex orthographic rules (Brown and Ellis, 1994). Correct spelling in dictation indicates that a child has a firm grasp of words and good spelling accuracy (Morris, 1983).

Understanding the bidirectional relationship between handwriting fluency and spelling accuracy is significant for educational researchers when attempting to improve these skills. In contrast to the substantial amount of research examining the direct effects of handwriting fluency and spelling accuracy on writing and reading performance (Graham et al., 1997; Graham and Harris, 2000; Limpo and Alves, 2013), there are only a handful of studies investigating the underlying mechanism of the relationship between handwriting and spelling. By analyzing the influencing factors of spelling accuracy in children in the third grade, researchers (Cheng-Lai et al., 2013) concluded that the degree of difficulty in performing Chinese word dictation co-varies with handwriting fluency. However, from a developmental perspective, the bidirectional relationship between handwriting fluency and spelling accuracy remains unclear. Given that cognitive skills, such as visual-orthographic coding, required for handwriting fluency overlap with spelling skills (McBride-Chang et al., 2011), it is reasonable to assume that there is a mutually reinforcing relationship between handwriting fluency and spelling accuracy.

The Role of Handwriting Fluency in Spelling Accuracy

Automatic information processing (LaBerge and Samuels, 1974) refers to the theory that repetition can gradually allow the brain to use fewer resources to focus on details, making a behavior easier to perform. Therefore, it requires repeated practice to improve the automatization of information processing and task quality. This theory seems to apply equally to handwriting. The perceptual and kinesthetic aspects of handwriting are integrated with the language network in the brain, and this connection can become increasingly close, even automatic, which frees up more attention resources and further improves spelling accuracy. Hence, handwriting fluency may be potentially crucial for children's later development of spelling skills.

In a prior study about Chinese language (McBride-Chang et al., 2011), Hong Kong children in the third and fourth grades, with and without dyslexia, were administrated tasks of copying unfamiliar prints and dictation. The results showed that the correlation coefficient between handwriting fluency and spelling accuracy was between 0.37 and 0.58, and handwriting fluency explained 3% of the unique variance in spelling accuracy. Consistent with findings from McBride-Chang et al. (2011), Lam and McBride (2018) surveyed 141 kindergartners in Hong Kong schools to explore the important role of handwriting skills in how children learn to spell Chinese words, and found that handwriting altogether significantly explained 10% of the variance in spelling accuracy, even after statistically controlling for the effects of age, non-verbal IQ, vocabulary knowledge, morphological awareness, orthographic awareness, and phonological awareness. Similar results were also seen in studies by Bosga-Stork et al. (2016) and Afonso et al. (2018), however, they further found that the effect only lasted until the third grade and disappeared in upper grades. Thus, they believed handwriting to be independent of spelling by the third grade. On the contrary, practical teaching experience showed that a vast majority of primary school teachers generally train students' mastery of words by means of handwriting practice, and teachers believed that for students who are fluent in handwriting, they often spell more accurate words in spelling assignment (Graham et al., 2008). As a result, it is unclear whether handwriting and spelling develop independently in upper grade levels. Additionally, the above studies generally adopted the cross-sectional design to explore correlations between variables, so it's hard to examine whether the previous variable would affect subsequent variable. Longitudinal studies may be better able to examine causal relationships between variables over time, thus, whether previous handwriting fluency has an impact on later spelling accuracy in upper primary school grades needs to be studied further.

The Role of Spelling Accuracy in Handwriting Fluency

The lexical quality hypothesis (Perfetti and Hart, 2002) posits that the quality of lexical representation depends on three dimensions: phonology, orthography, and semantics. All three are indispensable, as without them, the overall effect of lexical representation would be impacted, such as the accuracy and efficiency of lexical recognition. Furthermore, proficiency in literacy skills depends on the utilization frequency of an individual's high-quality lexical representations. In other words, once an individual has a good grasp of the depth of the vocabulary, the refinement of lexical information processing can effectively form abundant network connections in the brain. As a result, automatic lexical representation is gradually formed, and, accordingly, the retrieval of vocabulary is more efficient. Therefore, investigating spelling accuracy could help increase understanding of the development of children's handwriting fluency.

There have been studies on the effects of spelling accuracy on handwriting fluency; however, most have been conducted using children with dyslexia, and relatively few examined children without dyslexia. As evidenced by an empirical study analyzing the spelling errors of 10-year-old children with dyslexia, Martlew (1992) discovered that spelling accuracy affects handwriting fluency and pause times. Similarly, Sumner et al. (2014) investigated children with dyslexia, and the findings showed that spelling accuracy significantly accounted for 53% of the variances in their handwriting fluency, which indicated that poor spelling in children with dyslexia could limit the rate of handwriting production. The effect is particularly pronounced in children with dyslexia; however, whether it can be extended to children without dyslexia remains unclear. Abbott et al. (2010) followed non-dyslexic English-speaking children in the first through seventh grades, and found that the longitudinal path from spelling accuracy to handwriting fluency was significant across adjacent grades, from fourth to fifth. After all, the above studies are based on alphabetic languages, and the clues of correspondence between letters and phonemes can be used (Jiang, 2001). However, in Chinese, there are many homophones, grapheme-phoneme correspondence is arbitrary, and phonetic clues are unreliable (Shu et al., 2003). Given the different characteristics between Chinese characters and the English alphabet, it is unclear how much present spelling accuracy would affect later handwriting fluency for non-dyslexic Chinese-speaking children.

Chinese Writing

Different from the English alphabet, which is composed of 26 letters, Chinese writing uses square script and morphosyllabic characters. Chinese characters can be broken down into radicals and strokes. Although about 80% of the phonetic radicals in modern Chinese characters provide clues for their pronunciation (Shu et al., 2003), the grapheme-phoneme correspondence can be arbitrary. Therefore, retrieving the correct character from short-term memory can be difficult for children. Furthermore, Chinese characters have rich visual-spatial properties (Kao et al., 2004). Through the mapping of Chinese characters' cognitive images, effective handwriting practice could help children become familiar with the visual-spatial properties of the characters and facilitate children's orthographic awareness and establishment of long-term motor memory (Tan et al., 2005). Thus, there is an alternative possibility that children may develop spelling accuracy through handwriting fluency. On the other hand, familiar with the strokes and radicals of Chinese characters may also help children to maintain the continuous output of character, which in turn promotes the development of handwriting fluency. Therefore, there may be a reciprocal relationship between handwriting fluency and spelling accuracy in Chinese.

This Study

Previous research has provided preliminary evidence for a potential relationship between handwriting fluency and spelling accuracy. The primary aim of the current longitudinal study (two-year follow up) was to evaluate the mutual causality between handwriting fluency and spelling accuracy in upper primary school grades. On the basis of the above-mentioned theoretical concepts and empirical results, we hypothesized that a bidirectional relationship exists between handwriting fluency and spelling accuracy. Previous studies found that non-verbal IQ is a powerful predictor of handwriting and spelling skills (Sampson et al., 2003). Further, phonological awareness and rapid automatized naming also play important roles in word recognition and production (Savage et al., 2008; Alloway and Alloway, 2010). Therefore, non-verbal IQ, phonological awareness, and rapid automatized naming were the control variables in the current study.

METHODS

Participants

The study was approved by the Research Ethics Committee of Beijing Normal University. The sample consisted of 136 children, who are selected by cluster sampling from two primary schools in the Shanxi province in mainland China. Thirteen participants (9% attrition rate) were eliminated due to transferring to other schools. The final sample size was 123 children (62 boys and 61 girls), with no significant differences in intelligence $[t_{(123)} = -1.24, p = 0.22]$ or gender $[\chi^2(1) = 1.67, p = 0.25]$ between children included in the sample and those who had withdrawn from the study. School principals, classroom teachers, and parents supported our study, were informed of its purpose, and provided written informed consent.

Measures

Handwriting Fluency

We adopted a prior digit copying fluency task (Yan et al., 2012) and a sentence copying fluency task (Guan et al., 2013) to assess children's handwriting fluency. In the digit copying fluency task, children were required to copy in 1 min, repeatedly and as quickly as possible, a string of digits line by line (e.g., 一二三四五六七八九十; one, two, three, four, five, six, seven, eight, nine, and ten). The test was scored by the total number of words copied. The test-retest reliability coefficient for the fourth and fifth grade tests was 0.78. In the sentence copying fluency task, children were asked to copy a sentence (e.g., 敏捷的棕狐狸跳越懒狗; the quick brown fox jumps over the lazy dog). This sentence uses complicated words which contained almost the full range of single strokes (see sample items in **Appendix**). Before the test, children were required to be familiar with the sentence, so as to ensure the children knew its meaning. Thus, the influence of syntactic skills on children's copying speed could be reduced as much as possible. For the task, children were asked to repeatedly copy the sentence as quickly as possible within 1 min. The total score on the test was the correct number of words copied in sequence. The test-retest reliability coefficient of this task for the fourth and fifth grade tests was 0.71. The participants were then given the same test in the fourth and fifth grades.

Spelling Accuracy

Regarding Chinese character dictation tasks (Li et al., 2017), easy-items and difficult-items dictation tasks were used to examine spelling accuracy. Children were asked to dictate a target word in disyllabic words, such as "读" /du2/ [read] in "读书" /du2 shu1/ [read books]. Twelve easy items were selected from Chinese textbooks for their current grade level, and twelve difficult items were selected from Chinese textbooks of participants' next grade level. Compared with the terms of current grade level, the terms of next grade level is more difficult for participants. The 12 difficult items were the low-frequency words, and the frequency is about 0.001% (Modern Chinese Frequency Dictionary, 1986). The participants were asked to write down each target word, which was repeated twice on the recording, first in isolation and then embedded in a two-character word (sample items appear in **Appendix**). Children were encouraged to write as many words as possible. Correctly writing a word was scored as 1 point. The participants were given different dictation tasks in the fourth and fifth grades. Cronbach's α coefficients for easy items of the fourth and fifth grade tests were 0.70 and 0.74, respectively. And Cronbach's α coefficients for difficult items of the fourth and fifth grade tests were 0.72 and 0.77, respectively.

Rapid Automatized Naming

Rapid digit naming task contained five numbers, 1, 3, 4, 5, and 8, presented in a 5 × 5 matrix on a single sheet of paper, and was used to determine child's ability to quickly pronounce the numbers. There was only 1 trial, children were required to read the digit matrix aloud twice, as quickly and accurately as possible each time. The average score of the two tests was used as the final score. The experimenter timed the tests with a stopwatch, which was accurate to 0.01 s. The test-retest reliability coefficient for this task was 0.83.

Phonological Awareness

The phoneme deletion task (Shu et al., 2006) was used to determine children's perceptual and operational capability of phonology. For this task, the children were asked to produce a new syllable by taking away the target phoneme from a monosyllabic Chinese word, including deletion of the initial, middle, and last phonemes of target syllables, respectively. This task comprised 6 practice items and 12 test items. A correct response received 1 point, for 12 points possible in total. Cronbach's α coefficient for this task was 0.74.

Nonverbal IQ

Using the standardized Chinese version of Raven's Progressive Matrices (Zhang and Wang, 1985), children were asked to select the most appropriate choice from six to eight choices to complete the target pattern. There were 60 items, and Cronbach's α coefficient for this task was 0.93.

Procedure

As part of longitudinal research on the literacy development of Chinese children, the current study evaluated children's handwriting fluency and spelling accuracy development over 2 years. The experimenter, with the assistance of a class teacher, administered Raven's Progressive Matrices and the Chinese character dictation tasks to participants. These tasks were taken by classes as a unit (45 students), and three classes were tested. Other tests were carried out individually, including the phoneme deletion task, rapid automatized naming tasks, digit copying fluency task and sentence copying fluency task. The duration of each session was 40 min in total. The whole study consisted of four time points. **Table 1** shows the tests and procedures. Control variables were measured at the first two time points, i.e., participants' non-verbal IQs in the autumn semester of first grade (T0), phonological awareness and rapid automatized naming abilities in the autumn semester of third grade (T1). The handwriting fluency and spelling accuracy tests were conducted in the participants' autumn semester of fourth grade (T2) and re-assessed in fifth grade (T3).

RESULTS

Descriptive Results of Each Variable

Table 2 presents means and standard deviations computed for all measurements of this study. Children's handwriting fluency improved with the increase of grade levels (digit copying task: $F_{(1, 122)} = 68.79$, $p < 0.001$; sentence copying task: $F_{(1, 122)} = 151.66$, $p < 0.001$). Due to the different tests used for fourth and fifth grade, the comparison of spelling accuracy could not be carried out.

Table 3 displays correlations between the variables for all time points. The results showed that, rapid automatized naming at T1 had significant correlation with all observed variables about handwriting and spelling at T2 and T3, except for sentence copying at T3. Handwriting fluency at T3 was significantly correlated with spelling accuracy at T3; however, only sentence copying at T2 was significantly correlated with spelling accuracy at T2. Previous handwriting fluency and spelling accuracy at

TABLE 1 | Tests and procedures.

Test time	Variables	Task
First grade (T0)	Intelligence	Raven's progressive matrices
Third grade (T1)	Phonological awareness	Phoneme deletion task
	Rapid automatized naming	Rapid automatized naming tasks
Fourth grade (T2)	Handwriting fluency	Digit copying fluency task
		Sentence copying fluency task
	Spelling accuracy	Easy items dictation task
		Difficult items dictation task
Fifth grade (T3)	Handwriting fluency	Digit copying fluency task
		Sentence copying fluency task
	Spelling accuracy	Easy items dictation task
		Difficult items dictation task

TABLE 2 | Descriptive statistics for all variables at all time points (M ± SD).

	T0	T1	T2	T3
IQ	27.40 ± 8.74	–	–	–
PA	–	9.20 ± 2.31	–	–
RAN	–	9.15 ± 2.16	–	–
DC	–	–	49.41 ± 10.18	58.12 ± 10.76
SC	–	–	13.75 ± 2.86	17.07 ± 2.69
EI	–	–	10.25 ± 1.68	9.81 ± 2.29
DI	–	–	7.86 ± 2.65	7.42 ± 2.79

IQ, Raven's Standard Progressive Matrices; PA, Phonological awareness; RAN, Rapid automatized naming; DC, Digit copying fluency task; SC, Sentence copying fluency task; EI, Easy items; DI, Difficult items; T0, Time 0; T1, Time 1; T2, Time 2; T3, Time 3.

TABLE 3 | Correlation coefficients for all variables.

	1	2	3	4	5	6	7	8	9	10
IQ T0	–									
PA T1	0.13									
RAN T1	−0.02	−0.26**								
DC T2	0.03	0.04	−0.24**							
SC T2	0.09	0.02	−0.18*	0.64***						
EI T2	0.04	0.11	−0.25**	0.07	0.31***					
DI T2	0.20*	0.26**	−0.34***	0.13	0.28**	0.70***				
DC T3	0.32***	0.11	−0.23*	0.38***	0.38***	0.21*	0.31***			
SC T3	0.22*	0.03	−0.14	0.27**	0.42***	0.19*	0.22*	0.67***		
EI T3	0.25**	0.23*	−0.23**	0.19*	0.35***	0.66***	0.68***	0.33***	0.20*	
DI T3	0.27**	0.20*	−0.28**	0.16	0.27**	0.49***	0.55***	0.40***	0.32***	0.74***

*IQ, Raven's Standard Progressive Matrices; PA, Phonological awareness; RAN, Rapid automatized naming; DC, Digit copying fluency task; SC, Sentence copying fluency task; EI, Easy items dictation task; DI, Difficult items dictation task; T0, Time 0; T1, Time 1; T2, Time 2; T3, Time 3. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.*

T2 were significantly correlated with later handwriting fluency and spelling accuracy at T3, respectively. Spelling accuracy at T2 was significantly correlated with handwriting fluency at T3; similarly, handwriting fluency at T2 was significantly correlated with spelling accuracy at T3, except for the difficult-items dictation at T3.

Model Analysis

Controlling for the three influencing variables, a two-wave cross-lagged model was used to explore the reciprocal relationship between handwriting fluency and spelling accuracy. A structural equation model was created for data analyses using Amos 22.0 statistical software. Handwriting fluency was a latent variable extracted by two measures (digit copying and sentence copying) as indicators. Spelling accuracy was a latent variable which was extracted by two measures (easy items and difficult items) as indicators. **Figure 1** shows the model of the reciprocal relationship between handwriting fluency and spelling accuracy, controlling for non-verbal IQ, phonological awareness, and rapid automatized naming. The model fit index was $\chi^2 = 68.51$, $df = 32$, root mean square error of approximation (RMSEA) = 0.09, comparative fit index (CFI) = 0.93, incremental fit index (IFI) = 0.93, and Tucker-Lewis index (TLI) = 0.89. According to previous recommendations for good fit indices (Hu and Bentler, 1998), the ratio of χ^2 to df should be smaller than 2; CFI, IFI, and TLI values should be larger than 0.90; and RMSEA values should be smaller than 0.08. In this model, the fit index of TLI was lower and the RMSEA value was larger. According to the modified index model, sentence copying at T2 was correlated with digit copying at T3. When this variable was allowed to correlate with its corresponding variables in the modified model, the fit indices of the modified model were better: $\chi^2 = 58.19$, $df = 31$, RMSEA = 0.07, CFI = 0.95, IFI = 0.95, and TLI = 0.92. Thus, the modified model was ultimately adopted. The results of structural equation modeling showed a significant positive correlation between handwriting fluency and spelling accuracy in fourth grade, with a correlation coefficient of 0.23. There was no significant correlation between handwriting fluency and spelling accuracy in fifth grade. Moreover, handwriting fluency at T2 predicted subsequent spelling accuracy at T3, and spelling accuracy at T2 predicted subsequent handwriting fluency at T3.

DISCUSSION

This 2-year longitudinal study assessed the bidirectional relationship between handwriting fluency and spelling accuracy. These findings, extending the research of Lam and McBride (2018), confirmed a bidirectional predictive relationship between handwriting fluency and spelling accuracy in upper grade primary school students, even after considering well-established cognitive measures, including non-verbal intelligence, phonological awareness, and rapid automatized naming. However, inconsistent with previous research (Bosga-Stork et al., 2016), this study indicated that handwriting fluency and spelling accuracy in Chinese are still interdependent in the upper grades of primary school, and provided further clarification regarding the extent to which the two predict and facilitate each other.

Effects of Handwriting Fluency on Spelling Accuracy

Supporting the hypothesis, the current study showed that handwriting fluency in fourth grade significantly predicted

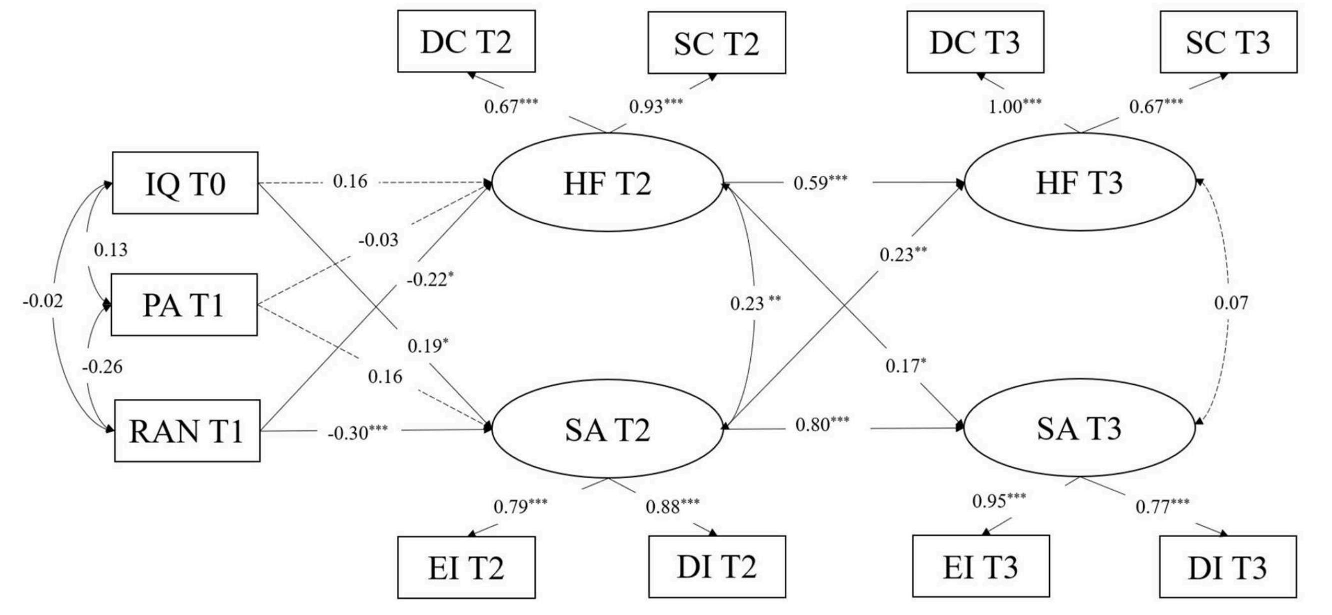

FIGURE 1 | The cross-lagged analysis for handwriting fluency (HF) and spelling accuracy (SA). IQ, Raven's Standard Progressive Matrices; PA, Phonological awareness; RAN, Rapid automatized naming; DC, Digit copying fluency task; SC, Sentence copying fluency task; EI, Easy items dictation task; DI, Difficult items dictation task; T0, Time 0; T1, Time 1; T2, Time 2; T3, Time 3. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

subsequent spelling accuracy in fifth grade, which is consistent with previous findings (McBride-Chang et al., 2011; Lam and McBride, 2018). This suggested that previous proficient handwriting fluency could improve later spelling accuracy for both Chinese and alphabetic characters, even after third grade. This could be due to a few possible reasons, discussed below.

First, handwriting improves visual-motor integration, which further develops spelling accuracy. Frith (1982) argued that some children's poor spelling may be the result of a lack of attention to details for letter-by-letter sequencing. Handwriting uses a visual-motor integration process involving perceiving a visual form and responding with hand movements (Lai and Leung, 2012). This facilitates the formulation of children's strategies for analyzing and reproducing different types of Chinese characters, and allows children to mentally code and store characters in a systematic way. Additionally, it could help children develop and shape their own corresponding motor programs, which could achieve the effect of memory consolidation by practice. Practicing handwriting-based movements could help children form basic sensory impressions about the structure type and stroke order of Chinese characters. In this process, the integration of vision and movement is constantly strengthened, and the stroke order is gradually stored in the motor program. When spelling words, subsequent stroke trends are already preformed in the mental lexicon with the help of kinesthetic cues, ensuring the output of correct character for children with consistent strokes. Thus, it is possible for children to improve their spelling accuracy by maintaining consistent handwriting. This is also applicable for upper grade primary school students who are still learning vocabulary.

Second, as was shown in the research of Yan et al. (2012), handwriting may refine word processes, increase orthographic depth, and make meaning representation of characters more precise. A prior study (Cheng-Lai et al., 2013) demonstrated that the lexical knowledge of Chinese characters plays an important role in individual differences in word dictation performance. Therefore, spelling accuracy is, to some extent, dependent on existing knowledge of vocabulary. Spelling accuracy can be achieved with the acquisition of a reasonably large vocabulary and the ability to use familiar words fluently. Handwriting practice, as one of the vital and most common ways to learn Chinese characters, would contribute to becoming familiar with new words for children. Once children have mastered the corresponding Chinese characters through handwriting practice, they should no longer need to rely on phonology, orthography, or morphology to construct information, and will be able to directly and accurately retrieve spelling information from long-term memory (Yan et al., 2012). Thus, early handwriting fluency does affect the development of later spelling accuracy.

Third, the findings of this study supported the hypothesis made regarding automatic information processing (LaBerge and Samuels, 1974), which posits that repeated practice will increase blocks of individual information processing, so as to improve accuracy. The current study extends this view to handwriting, indicating that handwriting practice is not simply a mechanical activity, but can promote the development of spelling accuracy and provide empirical evidence for practical writing teaching. Handwriting fluency could help children free up cognitive and attention resources for more effective information processing (Berninger, 1999). Thus, the meaning of words can be automatically retrieved through continuous repetition (LaBerge and Samuels, 1974). Based on the advantages provided by handwriting fluency, the orthographic structure of characters corresponding to meaning can be retrieved more quickly, and the correct character can be produced more precisely, which contributes to the improvement of spelling accuracy, to varying degrees (Limpo et al., 2018). Hence, handwriting fluency could help to increase children's spelling accuracy.

Effects of Spelling Accuracy on Handwriting Fluency

The current study suggested that previous spelling accuracy did predict the development of later handwriting fluency, which was consistent with previous research (Martlew, 1992; Sumner et al., 2014). These findings provide empirical support for the lexical quality hypothesis (Perfetti and Hart, 2002), which holds that high quality vocabulary representations can promote the rapid access of vocabulary. Better lexical representations are that individuals have a comprehensive grasp of vocabulary, in which the three dimensions (i.e., phonology, orthography, and semantics) of vocabulary are highly integrated in the mental lexicon. With an increasing frequency of the use of high-quality words, the automatic representation and access paths of these words have already been formed, which correspondingly accelerates the access speed of target words, and guides individuals to write quickly and effectively. Hence, spelling accuracy might support the development of subsequent handwriting fluency.

In contrast to previous English-language studies (Martlew, 1992; Sumner et al., 2014), in which the effect of spelling accuracy on handwriting fluency was mostly seen in children with dyslexia, the current study also found this effect in children without dyslexia. One possible reason is that Chinese is square script and morphosyllabic character, which has a writing system profoundly different from alphabetic language systems (Shu et al., 2003). With Chinese spelling, there are many radicals, and once children are aware of the purpose of morphemes and master these complex radicals precisely and skillfully, they can more accurately identify the orthography in their mental lexicons, therefore, more quickly selecting the correct words during dictation (Packard et al., 2006; Lam and McBride, 2018), even to the point of automatic processing, and their handwriting speed will increase correspondingly (Casalis et al., 2011). Children who develop sensitivity to radicals in the early stages may be more inclined to process radicals as a whole, which creates larger blocks with more information in their brains and reduces the cognitive load, even improves handwriting fluency later. However, if these characters are not learned accurately, it is very likely that confusion will occur in a child's memory, and the child will need more time to select character patterns when hearing the pronunciation during dictation. Stroke combination would then take up more cognitive resources, causing a distinct decrease in handwriting speed. For children who have not accumulated sensitivity to orthographic rules in the early stages, their processing efficiency of words is low. Due to the competition of cognitive resources such as attention and memory load, this fluent handwriting is difficult to maintain, so it will continue to affect their handwriting fluency in the later stage. This could also explain why a continued struggle with spelling accuracy in early childhood is more likely to lead to delayed handwriting output, which is detrimental to children's literacy development (Rønneberg and Torrance, 2017). Thus, early spelling accuracy predicts the development of subsequent handwriting fluency.

Psychoeducational Implications and Limitations

The findings of the current study are significant for correctly understanding children's handwriting and spelling skills. Previous studies have shown that consistent spelling practice is needed in the first 4 years of primary school (Medwell and Wray, 2010). Handwriting is the best practice for promoting the development of spelling skills (Graham, 2010) and the primary method for cultivating children's literacy (Wu et al., 1999). In terms of pedagogical practice, handwriting practice is necessary, in line with the development of writing, and this also supports the rationale of teachers' requirements for repeated handwriting practice when students are learning to write. When learning new words, it is necessary for children to become familiar with their structure through handwriting to improve the accurate retrieval of these words from memory. However, it is important to stress that these findings should not be misinterpreted as support for asking children to write words too mechanically, which can reduce children's interest in writing. Further, given that the present study has shown the importance of spelling accuracy in children's handwriting fluency, we suggest that during the teaching of spelling, teachers should explain the functions of strokes and radicals of words in detail, so as to help children learn meaningfully. On the basis of mastering the spelling skills of basic radicals and correct glyph structure, children can spell words correctly. Without struggle of how to spell, children can write more words fluently in limited time. On the one hand, it prevents the handwriting difficulties effectively, and on the other hand, it saves more cognitive resources to higher-order cognitive processing, such as logical organization and composition writing.

Despite these findings, some limitations of the current study should be discussed. First, the population was relatively small. In future studies, larger samples could be used to verify these findings. Second, only students in upper primary school grades were followed in the current study. Considering that early grade levels are the critical period for the development of children's literacy, it is necessary to conduct a comprehensive follow-up study to explore the developmental characteristics of handwriting and spelling throughout primary school.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Research Ethics Committee of Beijing Normal University. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

LL and XW: conception and design of the study. YD, LL, and XW: acquisition, analysis, and interpretation of data. YD and LL: drafting the work and revising it critically for important intellectual content.

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SUPPLEMENTARY MATERIAL

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The Impact of Different Writing Systems on Children's Spelling Error Profiles: Alphabetic, Akshara, and Hanzi Cases

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The importance of literacy in academics and the predominantly digital world cannot be understated. The literacy component of writing is less researched than that of reading, even though it holds equal significance for modern success. Spelling is an important aspect of the construct of literacy, and is more difficult to acquire than reading. Previous work on spelling error analysis for English provides insight into the sets of knowledge and cognitive processes required for children to perform the task, and their different strategies across development. However, different sets of skills and strategies may contribute to spelling across types of orthographies. In this study, we extend spelling error analysis to groups of biliterate children learning two scripts, which include English plus either: (a) another Latin-script alphabet with a shallow orthography (Malay); (b) a transparent alphasyllabary using akshara (Tamil); or (c) a non-alphabetic, morphosyllabic script using simplified hanzi characters (Mandarin Chinese). These sets of scripts vary in how speech is mapped to print. We utilized an error coding scheme based on triple-code theory to enumerate the occurrence of phonological, orthographic (graphemic), and morphological (semantic) types of spelling errors across the three language groups. Five hundred and sixty-eight Grade 1, 6-year-old children participated, with 128 English + Malay, 119 English + Tamil, and 321 English + Chinese children in each bilingual group. They completed a spelling to dictation task in their Asian language, with ten words taken from the grade level curriculum per language. Results indicate group differences in the proportions of error types, with more overall errors for Tamil, more phonological errors for Malay, and more irrelevant or non-sense words for Chinese. The implications are that different scripts present different challenges for young learners.

Keywords: spelling acquisition, triple-code theory, error analysis, bilingual children, Southeast Asian scripts

INTRODUCTION

Literacy skills are essential for academic and occupational success. Because of this, the development of literacy proficiency is a key concern for educators, and research into children's acquisition of said skills is extensive. Reading has received the lion's share of the research focus, with much less attention paid to spelling. Much of what is known about early spelling skills is based on

English and other alphabetic languages, and an extension to a greater variety of writing systems is yet to be established. The focus of this study is on spelling profiles of children learning Asian languages that vary in terms of their writing systems, representing three major types of systems. These include contrastive orthographies of: an alphabetic, Latin-scripted language (Malay); an alphasyllabary script with aksharas (Tamil); and a non-alphabetic, morphosyllabic script using hanzi characters (Chinese).

Following a framework of triple-word-form theory (Berninger et al., 2009; Bahr et al., 2015), we conducted a spelling error type analysis as a means to gain insight into underlying cognitive processes and learning mechanisms related to each of these written languages. A comparison across languages also allows for an accounting of the possible variations of these error types across the scripts. We view the results as an important initial step to developing a broader framework of spelling acquisition that may prove useful in both educational and research contexts, encompassing a wider range of languages.

In the following sections, we first review prominent models of spelling development, then studies of spelling for three different types of written languages: Malay, Tamil, and Chinese. These three languages, along with English, are official languages taught within the context of this study in Singapore. Following the education policy of Singapore, classes are taught in English, but children also learn one of the Asian languages at the same time, based on family ethnicity. Therefore, the current study allows us to examine spelling performance across these divergent language systems for children situated within the same national culture, educational system, and learning side-by-side in the same classrooms.

Models of Spelling Acquisition – The Case of English

Early studies of English spelling observed the types of spelling errors young learners make (Read, 1971; Gentry, 1982), and gleaned from these a developmental pattern of knowledge that children accumulate with experience. According to this view, children's knowledge about spelling patterns builds up from learning first an alphabetic principle (that letters represent certain speech sounds), then a pattern principle (that letters go together in certain ways), then a meaning principle (that letter patterns convey meaning in addition to sound) (Johnston et al., 2014). The developmental progression was postulated to follow the types of words encountered over the early grades: from simple syllable structured Anglo-Saxon words that require phonology-to-orthography mapping, to Norman-French words with multi-letter units requiring a consolidation of more complex graphemic units, to Greek and Latin words with stems and affixes to map to meanings (Invernizzi and Hayes, 2004). According to the work of Bear and colleagues, as children develop through spelling phases they may "use but confuse" principles not yet mastered, such as when they write a phonetically plausible but orthographically incorrect spelling, attempting to use letter-sound principles but confusing them (Bear et al., 2016).

Thus, children gradually accumulate different types of knowledge relevant to spelling the types of words they frequently encounter. Other models of spelling proposed that the accumulation of knowledge about spelling patterns does not follow developmental phases, but instead acquired strategies overlap and could be used flexibly at any time in development (Sharp et al., 2008). The emphasis was on the different types of linguistic knowledge required for accurate spelling. Coltheart et al. (2001) focused on lexical and sublexical knowledge in a dual-process model, with the former involving retrieval of whole word spellings from long-term memory, and the latter involving phonology-to-orthography conversion for writing sequences of letters corresponding to the sound sequences in the word. Lexical processing may be predominantly used with irregularly spelled words and sublexical processing for predictable words.

According to triple-word-form theory (Berninger et al., 2009; Garcia et al., 2010; Bahr et al., 2012, 2015) there are three types of linguistic knowledge children need to acquire to spell words correctly. First is phonological knowledge, to perceive, analyze, and identify the spoken word presented, for example, in a word dictation task (e.g., to perceive that the spoken word /sheep/ contains a long vowel and is different from /ship/). Second, there is orthographic knowledge, to produce written symbols (e.g., letters, graphemes, characters) to represent the perceived spoken word (e.g., to write the letter <—e> twice to represent the long vowel /i:/ in /shi:p/). And third is morphological knowledge, to recognize meaningful subunits within a spoken or written word (e.g., to identify that /treehouse/ is composed of the subunits /tree/ and /house/ or that the letter sequence <—ed> in the written word <jumped> represents the past tense inflection of the verb <to jump>). The triple-word-form theory suggests that although all three types of knowledge are necessary to become a proficient speller, children may need to rely to a greater extent on one type of knowledge depending on the word they are aiming to spell. For example, they may show greater reliance on orthographic knowledge to identify the "silent e" in /teibl/ and correctly write <table>, instead of <tabl> or <tabel>.

Bahr et al. (2012) developed a coding scheme for spelling error analysis based on the triple-word-form theory. The "Phonological, Orthographic, and Morphological Assessment System (POMAS)" was to categorize spelling errors of English-speaking Primary school students from grade 1 to 9 into phonological, orthographic, and morphological errors. Although initially introduced to explain spelling performance of monolingual English-speaking students, Bahr et al. (2015) adapted the POMAS coding scheme to Spanish to compare the spelling error profiles of Spanish-English bilingual adolescents. Their findings revealed both similarities and differences in the participant's English and Spanish spelling error profiles indicating a complex interaction of language-common and –specific factors involved in bilingual spelling development. While students committed a similar proportion of phonological errors in both languages, they showed a higher proportion of orthographic errors in Spanish, and the opposite pattern with respect to morphological errors. These results exemplify the potential of the triple-word-form theory as a theoretical framework and more specifically of the POMAS coding scheme as a practical tool to reach a better understanding of students' spelling performance across different languages. However, it remains unclear if the triple word form theory and the POMAS coding scheme can also be used to investigate spelling error profiles in a greater variety of writing systems, as for example present in many Asian languages.

Extending Models of Spelling Acquisition to Other Languages

Current research on spelling has extended beyond English, to include a range of more transparent alphabetic orthographies. In studies of Italian and German, early knowledge of word phonology and phonology to orthography correspondence predicted longer-term spelling outcomes years later (Landerl and Wimmer, 2008; Bigozzi et al., 2016). In a study of English, Spanish, Czechia, and Slovak speaking children, Caravolas et al. (2012) showed that spelling outcomes for all languages were similarly explained by letter knowledge, phoneme awareness, and rapid automatized naming. The authors suggested similar required skills for learning to spell across alphabetic languages. In an earlier study, Link and Caramazza (1994) applied the dual-route spelling model to two different writing systems: Arabic and Chinese. While generally compatible with Arabic, an alphabetic system, the model proved inadequate for Chinese, a non-alphabetic system. The model did not sufficiently capture the nature of orthographic representations for either script, though, because it was unclear whether knowledge about letters and diacritics are represented in similar ways within Arabic, while for Chinese the use of subcharacter (sublexical) knowledge for spelling did not appear to be readily distinguishable from character level knowledge (Link and Caramazza, 1994, pp. 283—289). In a more recent computational modeling study, Yang et al. (2013) demonstrated that a triangle model with orthographic, phonological, and semantic meaning-based representations could successfully simulate English and Chinese reading within the same model, suggesting that these three forms of representation underlie a broad range of written languages, at least for reading.

Studies focused more specifically on the diverse languages central to this study are summarized in the next sections. Where available, we review spelling error analysis for the transparent alphabetic system of Malay, alphasyllabaries like Tamil, and the morphosyllabary system of Chinese.

Malay Spelling

The Malay written language is a transparent Latin-script alphabet that has mostly 1:1 mappings between letters and their sounds (with only 1 vowel having 2 pronunciations – "e"). The language includes diphthongs and consonant clusters, and affixation is a common feature of words. Although it may be a common assumption that transparent alphabetic languages engender phonologically based strategies for spelling and reading, other forms of knowledge may contribute as well. For example, Rickard Liow and Lee (2004) study with 6—8 year-old Singaporean Malay-speaking children revealed that children with higher spelling ability demonstrated knowledge of suffix spelling even if they mispelled the word stems, whereas weaker spellers did not encode affixes accurately. The authors suggest that even at this young age good spellers may utilize morphological knowledge rather than relying on just single phoneme level correspondences to letters. This contrasts with a finding of young Malay-speakers in Indonesia, whose letter name knowledge was most predictive of spelling errors in word stems, as letter names and sounds are more consistent in Indonesian Malay (Winksel and Lee, 2014). In another study with Singaporean Malay-speaking 5—6 year olds, Jalil and Rickard Liow (2008) found that vowel substitution errors in word and pseudoword spellings were related to invented spellings based on knowledge of familiar words rather than letter-name substitutions or English phoneme-grapheme substitutions.

Tamil Spelling

The Tamil written language differs from simple alphabetic systems, because the script units (akshara) involve a spatial configuration that is not a simple linear representation of individual phonemes. Tamil akshara can represent consonants with inherent vowels, short vowels and dipthongs (e.g., the consonant ச/ca/ is formed with a muted stop consonant ச் /tʃ/ and a short vowel அ /ʌ/; Aaron and Joshi, 2005). Long vowels can be formed with the addition of diacritical marks where a small change in the writing of the symbol can denote a different sound (e.g., a small curved diacritic mark is included to the short vowel அ to form the long vowel ஆ; Aaron and Joshi, 2005). This all makes phoneme-to-grapheme conversion more complex than in alphabetic systems. The writing system also differs from strict syllabaries because the akshara can be broken down visually into the consonant and vowel components (Padakannaya and Mohanty, 2004). However, despite the complex orthographic structure, children appear to learn these patterns fairly readily, while still having difficulty representing phonological information even with a relatively transparent script.

Padakannaya and Mohanty (2004) proposed a psycholinguistic model of reading for Brahmi-derived Indian scripts, which involves a dual-route non-lexical and lexical account. Along this line, Nag et al. (2010) found mostly phonologically based, intra-akshara level spelling errors for grade 4—5 students of Kannada – an extensively studied akshara language. Similarly, for Tamil Nag and Narayanan (2019) reported that younger grade 1—3 children in India were able to preserve word length in their spellings, where substitution errors were much more common than the addition or omission of aksharas or intra-akshara phonemic markers. They found orthographic errors were rare, with most errors involving phonological or phonological-orthographic confusions. Older grade 6—12 students in Tamil-medium instruction were found by Aaron and Joshi (2005) to make primarily consonant (retroflex) spelling errors, rather than difficulty with vowels or diacritical marks.

Chinese Spelling

The Chinese written language is described as a morphosyllabary, and the script unit of characters (hanzi) are rectangular glyphs that may be a single unit or a complex unit with sub-character components (radicals) that correspond to phonetic or meaning-based representations. Each character (in simplified Chinese) is composed of 1 to 30 different strokes (Chen and Kao, 2002), and most characters in the Chinese orthography include radicals that carry meaning and pronunciation (Ho and Bryant, 1997). An understanding of character structure and radical meaning enhances children's spelling skill (Lam and McBride, 2018). Shen and Bear (2000) conducted the most extensive descriptive study of children's spelling errors in Chinese. From a wide sample of primary school students' Chinese writing samples, they analyzed 15 error types, which included patterns of misspellings (cuo4 zi4) and substitutions (bie2 zi4) at one of the three layers of characters: strokes, radicals, and configurations. They then summarized these as categories of phonological, graphemic, and semantic errors. Phonological error types were initially most prevalent, but with age, graphemic and semantic error types increased in frequency while phonological errors decreased. The authors compared this developmental trend to English spelling development (noted above), from a sound emphasis (alphabetic principle) to shape (pattern principle) to meaning emphasis (meaning principle) across the primary school years.

Tong et al. (2009) utilized a similar coding scheme as Shen and Bear (2000) to examine spelling errors by kindergarteners (6-year-olds) in Hong Kong (though their analysis was at the level of words having two or more characters). In contrast to Shen and Bear (2000), they found the preponderance of errors were meaning-based, morphological types of errors ("lexical, sublexical, single omission"). Orthographic types of errors ("reconfiguration, similar configuration, stroke change") were the second most frequent, and phonological errors ("homophone and semi-homophone") were least frequent.

Although an error analysis approach has been usefully applied across the writing systems described above, there has not been a systematic examination across these types of writing systems. As the children in the current study are young bilinguals, we do note that there is evidence of cross-language influence for speaking, listening, reading, and writing as well (Figueredo, 2006). Thus, the findings may be affected by such cross-linguistic influence. An investigation of bilingual spelling patterns is beyond the scope of the current study, but we consider this possible influence in the hypotheses and results. The only bilingual model of spelling of which we are aware, by Tainturier (2019) (BAST), is meant for skilled adult spellers of alphabetic languages and is not a learning model.

Current Study

We examine the types of spelling errors for primary grade 1 children learning different scripts according to the triple-word-form model, using 3 error types (phonological, orthographic-graphemic, and morphological) as defined below. We note that these definitions may differ from the manner with which errors have been considered in some previous work (e.g., Shen and Bear, 2000), that followed the "use but confuse" model. In that tradition, errors are defined according to the knowledge children are expected to be using but perhaps not precisely (Bear et al., 2016). We further distinguish the error types here from metalinguistic awareness, which reflects one's conscious understanding of and ability to analyze and manipulate the sound (phonological) or meaning (morphological) structure of spoken words.

Phonological errors are defined by an incorrect representation of the sounds. This type of error includes the use of an allophone, an omission or addition of phonological elements, which can also include tone, stress, and retroflex (supra segmental). Bahr et al. (2015) refer to these as phonological skeleton elements.

Graphemic-orthographic errors are defined as spelling conveying the same phonology but with incorrect, ambiguous letters. Examples include vowel diagraphs (silent e), consonant diagraphs, letter doubling, flaps, and diacritic marks. Graphemic errors are defined as letter or character reversals, incorrect orientation or misspelling a character with a similar form or omission or addition of strokes.

Morphological-semantic errors are defined as misspelling the target character or word with one that preserves the correct representation of sound but that has a different semantic meaning (e.g., a homophone), or a substitution with a semantically related word. This includes words, or parts of the word, that sound alike but have different meanings. Examples include omission or substitutions of inflections, derivations, and homophones.

Given the variations across scripts, we examined the nature of children's spelling errors in Malay, Tamil, and Chinese, by addressing the following research questions:

(1) Does the frequency of overall spelling errors differ across the Asian language groups?
We expect that the orthographic breadth of the scripts will result in more difficulty for the languages with a larger graphemic inventory (Nag, 2017) and more complex units (i.e., Tamil and Chinese).

(2) Is there a difference in the proportion of specific triple-word-form spelling error types across and within the Asian language groups?
Based on the previous studies reviewed above, we expect that the different scripts will entail different types of spelling errors, with more phonological errors in Tamil, more morphological errors in Chinese, and more phonological and morphological errors in Malay. Alternatively, given the children's biliterate experience, where they all learn to spell in English at an early age, this may yield a common influence on the prevalence of error types, if spelling strategies transfer between their known languages.

(3) What are the most frequently occurring subtypes of spelling errors for each Asian language group?
We predict that our findings will follow patterns found for the monolingual and individual language research reported previously, with most frequently phonological error types in Tamil, morphological and orthographic errors in Chinese, and phonological and morphological types in Malay. Alternatively, following linguistic models such as the script dependence hypothesis (Geva and Siegel, 2000) and the transfer facilitation model (Koda, 2007), shared strategies across English and each language may be determined by their typological distance. In this case, Malay would most closely reflect English

error types (phonological), while Chinese would deviate with more morphological errors, and Tamil with more orthographic errors.

By understanding the phonological, graphemic-orthographic, and morphological-semantic influences of spelling errors, we may attain a deeper understanding of the basis and source of spelling errors in different languages. This not only provides insight to the rules and strategies that children utilize when spelling words with different scripts, it can also inform instructional activities or inspire pedagogical approaches to facilitate children's spelling skills acquisition. By determining the domain in which common spelling errors are committed in a certain language, we gain understanding of the unique features each language brings into the language mix.

MATERIALS AND METHODS

Participants

In this study we examined Asian language spelling error profiles of 568 children attending grade 1 of Primary school in Singapore. These children represented a subsample of a larger longitudinal project entitled Singapore Kindergarten Impact Project that aimed to investigate cognitive development from pre- to early primary school (Ng et al., 2014). Findings from overlapping samples in this project are reported in several other publications, such as Yao et al. (2017), Sun et al. (2018), O'Brien et al. (2019), However, this is the first analysis of children's Asian language spelling errors within this project.

The three different Asian writing systems were chosen due to the typological differences that exist in the multicultural and multiracial environment of Singapore. The demographics of Singapore (Singapore Department of Statistics, 2019, Resident population in Singapore as of June 2018, by ethnic group) are split into 4 main ethnic categorizations of Chinese (74.30%), Malay (13.40%), Indian (9.02%) and Other (3.28%) with official languages – Mandarin, Malay, Tamil and English – corresponding to their ethnic categorisation. The education system in Singapore is bilingual where the main medium of instruction is English and students are taught a second language (Malay, Mandarin, or Tamil), typically based on their ethnic category. Children are exposed to these languages from an early age. The age of onset, quantity, and quality of input received in their home environment in English and one of the above-mentioned Asian languages contributes to their development as simultaneous bilinguals even before entering formal education. Once preschool education commences, their bilingual proficiency is strengthened through daily lessons in English and one of the Asian languages mentioned before. This also includes formal instruction in learning to read and write in both languages. Thus, the sample size and writing systems chosen in this study are considered to reflect the proportion and demographic of the resident population.

The children in this study were native-speakers of English and Chinese (n = 321), Malay (n = 128), and Tamil (n = 119) attending grade 1 of Primary school in Singapore. There were no gender differences in the total number of spelling errors, nor any interaction with the language groups by gender for total errors committed, $F(2, 561) = 0.33$, p = n.s. **Table 1** presents information on each Asian language group's background information, including their age, maternal education, and non-verbal reasoning skills, along with home language and literacy environment and bilingual receptive vocabulary skills (see Section "Measures" for details on the sources of this information).

While analyses of variance (ANOVAs) revealed that children in all three Asian language groups were of the same age on average, there were significant differences in maternal education, non-verbal reasoning skills, home language and literacy environment, and bilingual receptive vocabulary skills across participant groups. To control for these differences, mothers' education was used as a matching variable to select a subsample of 120 of these children from the full sample. The same background information on this subsample is described in **Table 2**.

Results from ANOVAs indicated that after controlling for mother's education, there were no longer differences across Asian language groups in non-verbal reasoning skills, home language and literacy environment nor bilingual receptive vocabulary skills. As explained in the results sections, all analyses were first computed on the full sample of participants that completed the Asian language spelling task (N = 568, as in **Table 1**) and then the same analyses were repeated with the subsample of participants (N = 120, as in **Table 2**) controlling for the impact of the above-mentioned background variables on the results.

TABLE 1 | Children's background information across the three Asian language groups (N = 568).

	Chinese (n = 321)	Malay (n = 128)	Tamil (n = 119)	F-value	p-Value
Age (in months)	80.40(3.76)	81.27(3.70)	81.00(3.92)	2.66	0.071
Maternal education[a]	7.98(2.13)	5.53(2.23)	8.60(1.76)	75.38	<0.001
Non-verbal reasoning skills[b]	16.94(5.02)	14.50(5.19)	13.63(4.87)	22.43	<0.001
Home language environment[c]	0.37(0.44)	0.07(0.47)	0.09(0.55)	27.15	<0.001
Bilingual receptive vocabulary skills[d]	0.15(0.16)	0.09(0.13)	0.17(0.17)	8.20	<0.001
English spelling scores[e]	21.12(4.14)	18.13(4.90)	22.08(4.40)	26.08	<0.001

[a]*Measured on a scale from 1 to 11 based on the different educational levels that an adult can achieve in Singapore (for more details see parent questionnaire description).* [b]*Measured in raw scores.* [c]*Expressed as an index based on the information reported by parents for English and Chinese or Malay or Tamil home input (see parent questionnaire description).* [d]*Expressed as the difference between the English and Chinese or Malay or Tamil receptive vocabulary scores obtained by children.* [e]*Total raw scores Wilkinson and Robertson, 2006. F- and p-Values are reported from between group ANOVAs.*

TABLE 2 | Subsample's background information across three Asian language groups (N = 120).

	Chinese (n = 40)	Malay (n = 40)	Tamil (n = 40)	F-value	p-Value
p Age (in months)	81.44(3.63)	81.10(4.11)	82.35(3.97)	1.09	0.339
Maternal education	7.03(1.89)	7.03(1.89)	7.03(1.89)	0.00	1.000
Non-verbal reasoning skills	15.33(4.47)	14.74(5.80)	14.33(5.71)	0.342	0.711
Home language environment	0.31(0.50)	0.14(0.49)	0.22(0.54)	0.986	0.376
Bilingual receptive vocabulary skills	0.17(0.18)	0.14(0.24)	0.19(0.12)	0.806	0.449
English spelling scores[a]	19.77(3.23)	19.34(4.77)	20.00(4.52)	0.24	0.79

[a]*Total raw scores. Reported measures are the same as in* ***Table 1****. F- and p-values are reported from between group ANOVAs.*

Measures

Parent Questionnaire

Parents completed a questionnaire on basic demographics (e.g., age, gender, and ethnicity), and children's home environment (e.g., parents' educational qualifications, housing type, household income, amount of time spent with various members of the household on a typical weekday/weekend). Specifically for mother's education parents were asked to select a number between one and 11 corresponding to one of the following levels of the Singaporean educational level, ranging from completion of: primary school (1), O-level or grade 10 (4), A-level or grade 12 (6), a technical certificate or polytechnic diploma (7, 8), to a bachelor, master, or doctoral degree (9, 10, 11). This information was used as a proxy for children's socio-economic status (SES). Furthermore, parents were asked to provide information on the quantity of input received by children in each language (i.e., the proportion of exposure to English and to Chinese/Malay/Tamil) per family member, and how much time the child spent with each family member. Based on their responses, we calculated a weighted family wide proportion of language exposure (weighted by the amount of time spent with each family member) for English and for the Asian language (Chinese/Malay/Tamil). Then a relative home language environment index was calculated by subtracting a composite score of language for the Asian language input from that for English. Index scores range from −1 to +1, and positive index scores reflect a stronger home language environment in English than in the Asian language, while a negative index scores indicates the opposite pattern (see **Tables 1**, **2**).

Non-verbal Reasoning Skills

The Raven's Coloured Progressive Matrices (CPM) was used to measure children's non-verbal reasoning skills (Raven et al., 2004). This task consists of three sets of 12 items of increasing difficulty within each set. Children were asked to select the missing piece between a set of alternatives to complete a matrix. Administration was terminated after four consecutive incorrect responses for each of the three stimuli sets of the task and the total number of correct responses across all three sets was used as the total score of children's non-verbal responding skills.

Bilingual Receptive Vocabulary Skills

For this purpose, the Bilingual Language Assessment Battery (BLAB – Rickard-Liow et al., 2013) was administered. It is a locally developed measure widely used in Singapore (e.g., Yeong and Rickard Liow, 2012), and consists of a spoken word-picture matching with a total of 80 items and three practice trials. The task was rendered on iPads. For each trial, the child listened to an audio-recorded word and selected one of four pictures on the screen that matched the word. Children completed the English version, as well as the Chinese or Malay or Tamil version of the task. Based on children's scores on the English and Asian language task, an index was computed of the relative bilingual receptive vocabulary skills by subtracting the Chinese/Malay/Tamil score from the English score and dividing this number by the sum of the Asian and English language scores. In this way, positive indices reflected stronger receptive vocabulary skills in English, as compared to Chinese/Malay/Tamil, while negative indices represented the opposite pattern (see **Tables 1**, **2**).

Asian Language Spelling

Children in each Asian language group were asked to spell ten words presented through a word dictation task. The examiner first read the item out loud in isolation, then presented it in the context of a sentence, and again dictated the word in isolation. **Supplementary Appendix A** shows the spelling, IPA transcription, and English translation of the ten words used in each version of the task (Chinese, Malay, and Tamil).

The items were selected from the Singaporean language instruction curricula for Primary school 1 (Ministry of Education [MOE], 2017a,b,c), to obtain an ecologically valid measure of the spelling activities children are exposed to in regular classroom instruction. However, this meant that the items differed naturally in psycholinguistic complexity (e.g., no. of phonemes, no. of graphemes/characters, visual complexity, etc.) across the three Asian language versions, following the characteristic features of each language. **Table 3** presents an overview of the psycholinguistic characteristics of the spelling task for each Asian language version and **Supplementary Appendix B** provides further details for each individual item. The differences in psycholinguistic complexity are inherent to the language-specific characteristics of each of the writing systems, as discussed in the introduction of this report.

Procedure

This study derived from the overall longitudinal project (Ng et al., 2014) which received ethical approval from the Nanyang Technological University Institutional Review Board were invited to participate in the overall project when their children were

TABLE 3 | Psycholinguistic characteristics of the three Asian language versions of the spelling task.

Psycholinguistic characteristics	Chinese	Malay	Tamil
Phonological characteristics			
No. of phonemes	1 – 3	3 – 9	4 – 11
Phonologically complex items[a]	70%	10%	60%
Graphemic-orthographic characteristics			
No. of graphemes/characters	1	3 – 10	2 – 7
Graphemic complex items[b]	60%	10%	100%
Visual complexity[c]	19–41	10–14	13–26
Morphological-semantic characteristics			
Items with homophones	90%	NA	NA
Morphologically complex items[d]	0%	20%	10%

[a]*An item was judged as complex if it contained a dipthong, long vowel, retroflex consonant or consonant cluster and as simple if none of these phonemic units were present.* [b]*An item was judged as complex if it contained at least one composed grapheme (digraph, composed character, built up akshara) and was otherwise considered simple.* [c]*Based on multidimensional measure using GraphCom (Chang et al., 2018).* [d]*An item was judged as complex if it contained at least one pre- or suffix or represented a compound word formed of at least two root words and was otherwise considered simple. NA, Not applicable to this writing system.*

attending Kindergarten 1 (approximately 4 – 5 years of age). Once they signed written consent forms, they were asked to complete the above-mentioned parent questionnaires. Children then participated in a larger battery of tasks in individual testing sessions of approximately 30 to 60 min conducted in a quiet room assigned by the school they were attending. Amongst the overall battery of tasks, we collected information on children's non-verbal reasoning and bilingual receptive vocabulary skills at Kindergarten 1. In a final wave of data collection at the beginning of Primary school 1 (approximately 6 – 7 years), we administered the Asian language spelling measure that is the focus in this study.

Data Analysis

As a first step, transcriptions of all children's responses on the Asian language spelling task were entered into an excel file and the total number of spelling errors committed by each child was tallied. From this, only those children that showed at least one spelling error were included in the analyses. Based on a spelling error coding scheme specifically designed for this study the errors per item per child were classified and summarized. In **Table 4** we present an overview of the error categories included in each Asian language coding scheme, and **Supplementary Appendix C** provides details of the complete coding scheme per language.

Each spelling error was first characterized as a phonological, graphemic-orthographic, semantic-morphological or other spelling error. Then we further categorized these errors into language-specific error types (e.g., vowel addition, etc.). While some of these error subcategories could occur for more than one Asian language (e.g., consonant deletion present in Tamil and Malay coding scheme), others were specific to one of the writing systems (e.g., short versus long vowel substitution is only present in Tamil coding scheme).

Three native-speaking research assistants assigned each spelling error to one of the above-mentioned categories for each Asian language group, respectively. They were previously trained by one of the three authors of this report. In addition, at least 20% of the overall spelling errors were double-scored by the authors of this report and revealed an inter-rater reliability of K = 0.79 – 1.00, indicating good agreement between the raters (Feuerman and Miller, 2008) (Chinese: K = 0.79, CI 95% [0.72 – 0.86], $p < 0.001$, Malay: K = 0.96, CI 95% [0.94 – 0.98], $p < 0.001$, Tamil: K = 0.80, 95% CI [0.72 – 0.87], $p < 0.001$). For the Chinese language, consensus was first established between two raters. Subsequently, a third rater completed 20% of the overall scoring and inter-rater reliability was calculated based on this sample. For the Tamil and Malay languages, two raters scored the spelling errors individually and when there was a discrepancy, consensus was reached either through discussion or by consulting with linguistic experts.

RESULTS

As a first step, in **Table 5** we present the descriptive statistics on the total number of spelling errors committed by each Asian language group, as well as on the proportion of different spelling error types (phonological, graphemic-orthographic, morphological-semantic, and others) for the full sample (N = 568) that completed the word dictation task. As previously noted in the methods section, there were significant differences between participants' SES across the three Asian language groups. To avoid the impact of this potentially confounding variable on the analyses, we therefore selected a subsample from each Asian language group using information on mothers' education as a proxy for SES as a matching variable. Descriptive statistics on the spelling performance of the resulting matched subsample (N = 120) are presented in **Table 2**.

Descriptive statistics for the full and subsample revealed that the assumptions for parametric statistical analyses were not met for several outcome measures. Therefore, non-parametric analyses were conducted to address each research question.

Each of the research questions mentioned in the introduction section was first addressed by conducting analyses on the full sample dataset (N = 568). To compensate for unequal numbers of participants across the three language groups in the full sample (Chinese, n = 321; Malay n = 128; Tamil n = 119), weighted means were used in the analyses. To control for the impact of SES, in a second step the same analyses were repeated on

TABLE 4 | Overview of Asian language spelling error coding scheme.

Error category	Chinese	Type	Malay	Type	Tamil	Type
Phonological errors						
Phonetic radical addition, substitution or omission	✓	PC1	NA		NA	
Single vowel substitution	NA		✓	PM1	✓	PT1
Single vowel addition	NA		✓	PM2	✓	PT2
Single vowel omission	NA		✓	PM3	✓	PT3
Dipthong substitution, addition or omission	NA		✓	PM4	✓[NA]	
Short vowel vs. long vowel substitution	NA		NA		✓	PT4
Long vowel vs. short vowel substitution	NA		NA		✓	PT5
Consonant substitution	NA		✓	PM5	✓	PT6
Retroflex consonant substitution	NA		NA		✓	PT7
Consonant addition	NA		✓	PM6	✓	PT8
Consonant omission	NA		✓	PM7	✓	PT9
Similar sounding character/word substitution	✓	PC2	✓	PM8	✓	PT10
Partial reversal of phoneme sequence	NA		✓	PM9	✓	PT11
Graphemic-orthographic errors						
Reconfiguration of characters or components of characters	✓	GC1	NA		NA	
Similar formed or structured character/grapheme substitution	✓	GC2	✓	GM1	✓	GT1
Addition, omission, or protrusion of strokes	✓	GC3	NA	GM2	✓	GT2
Addition, omission or substitution of diacritics	NA		NA		✓	GT3
Morphological-semantic errors						
Substitution of semantically related character/word	✓	MC1	✓	MM1	✓	MT1
Substitution of homophone character/word	✓	MC2	NA		NA	
Morpheme omission (character, pre-/suffix or root)	✓	MC3	✓	MM2	✓	MT2
Other errors						
Substitution by irrelevant word/non-word	✓	OC1	✓	OM1	✓	OT1
No response	✓	OC2	✓	OM2	✓	OT2

NA, Not applicable to this writing system; ✓, Applicable; NA, Applicable in general to this writing system, but not a possible error with the item set used in this study; PC, PM, and PT, Phonological error for Chinese, Malay, Tamil, respectively; GC, GM, and GT, Graphemic-orthographic error for Chinese, Malay, Tamil, respectively; MC, MM, and MT, Morphological-semantic error for Chinese, Malay, Tamil, respectively; OC, OM, and OT, Other errors for Chinese, Malay, Tamil, respectively.

the subsample dataset that included participants matched on mothers' education (N = 120). When comparing the results between the full sample and subsample analyses, there were no overall differences, although effect sizes tended to be larger in the subsample analyses than in the full sample analyses. In the following sections, the set of analyses is presented addressing the research questions.

Research Question 1

To address the first research question, a Kruskal—Wallis test was computed to identify significant differences in the number of total spelling errors committed by children across the three Asian language groups. The full sample analysis revealed a statistically significant difference across groups, $H(2, 934) = 45.90$, $p < 0.001$, $\eta^2 = 0.05$. *Post hoc* analyses showed that the Tamil language group (M = 8.62, SD = 2.23, Mdn = 9.00) on average committed significantly more spelling errors than the Chinese group (M = 7.50, SD = 1.85, Mdn = 8.00), $H(1, 678) = 55.00$, $p < 0.001$, $\eta^2 = 0.08$, and the Malay group (M = 7.31, SD = 4.38, Mdn = 8.00), $H(1, 612) = 13.46$, $p < 0.001$, $\eta^2 = 0.02$. There was no significant difference between the average number of total spelling errors committed between the Chinese and the Malay language groups, $H(1, 577) < 0.01$, $p = 0.942$, $\eta^2 < 0.001$.

Equivalent analysis of the subsample dataset controlling for children's SES showed the same overall effect as obtained by the full sample analyses. More specifically, there was a significant difference in the average number of total spelling errors committed across the three Asian language groups, $H(2, 119) = 12.60$, $p = 0.002$, $\eta^2 = 0.11$. Again, *post hoc* analyses indicated that Tamil language group (M = 9.10, SD = 1.98, Mdn = 9.00) on average committed significantly more spelling errors than the Chinese group (M = 7.78, SD = 2.36, Mdn = 8.00), $H(1, 79) = 5.79$, $p < 0.001$, $\eta^2 = 0.07$, and the Malay group (M = 6.05, SD = 4.43, Mdn = 4.00), $H(1, 79) = 10.05$, $p < 0.001$, $\eta^2 = 0.12$. There was no significant difference between the average number of total spelling errors committed between the Chinese and the Malay language groups, $H(1, 79) = 3.43$, $p = 0.060$, $\eta^2 = 0.04$. **Figure 1** summarizes these results.

Research Question 2

To address the second research question, the first focus was on investigating potential differences in the proportion of the triple-code types of spelling errors (phonological, graphemic-orthographic, morphological-semantic, and others) committed across Asian language groups. Following Bahr et al. (2015), we assumed potential interrelatedness (ipsitivity) of the four dependent variables measuring

TABLE 5a | Average overall errors and proportions of error types for Asian language groups in the full sample (*N* = 568).

Asian language group	Spelling error measure	*M* (*SD*)	*Mdn*	Range	Skewness (*SE*)	Kurtosis (*SE*)
Chinese (*n* = 321)						
	Total errors	7.50 (1.85)	8.00	0.00 – 13.00	−1.02(0.14)	4.30(0.27)
	Proportion of P	0.03 (0.12)	0.00	0.00 – 1.00	6.43(0.14)	45.46(0.27)
	Proportion of G	0.09 (0.13)	0.00	0.00 – 1.00	2.14(0.14)	8.73(0.27)
	Proportion of M	0.09 (0.10)	0.10	0.00 – 0.43	0.90(0.14)	0.09(0.27)
	Proportion of O	0.79 (0.21)	0.83	0.00 – 1.00	−1.42(0.14)	2.84(0.27)
Malay (*n* = 128)						
	Total errors	7.31 (4.38)	8.00	0.00 – 18.00	0.16(0.21)	−0.98(0.43)
	Proportion of P	0.68 (0.24)	0.73	0.00 – 1.00	−1.11(0.21)	1.30(0.43)
	Proportion of G	0.15 (0.18)	0.11	0.00 – 1.00	2.17(0.21)	6.23(0.43)
	Proportion of M	0.06 (0.09)	0.00	0.00 – 0.38	1.23(0.21)	0.60(0.43)
	Proportion of O	0.11 (0.24)	0.00	0.00 – 1.00	2.68(0.37)	7.39(0.73)
Tamil (*n* = 119)						
	Total errors	8.62 (2.23)	9.00	3.00 – 15.00	−0.00(0.22)	0.73(0.44)
	Proportion of P	0.44 (0.31)	0.43	0.00 – 1.00	0.12(0.22)	−1.17(0.44)
	Proportion of G	0.07 (0.78)	0.00	0.00 – 0.30	0.85(0.22)	−0.13(0.44)
	Proportion of M	0.00 (0.03)	0.00	0.00 – 0.25	7.45(0.22)	59.44(0.44)
	Proportion of O	0.49 (0.33)	0.50	0.00 – 1.00	0.02(0.22)	−1.24(0.44)

P, Phonological errors; G, Graphemic-orthographic errors; M, Morphological-semantic errors; O, Other errors.

TABLE 5b | Average overall errors and proportions of error types for Asian language groups across the subsample (*N* = 120).

Asian language group	Spelling error measure	*M* (*SD*)	*Mdn*	Range	Skewness (*SE*)	Kurtosis (*SE*)
Chinese (*n* = 40)						
	Total errors	7.78 (2.36)	8.00	0.00 – 12.00	−1.65(0.37)	4.40(0.73)
	Proportion of P	0.04 (0.16)	0.00	0.00 – 1.00	5.71(0.37)	34.19(0.73)
	Proportion of G	0.08 (0.11)	0.00	0.00 – 0.33	1.28(0.37)	0.26(0.73)
	Proportion of M	0.08 (0.23)	0.00	0.00 – 0.43	1.49(0.37)	1.54(0.73)
	Proportion of O	0.81 (2.36)	0.89	0.00 – 1.00	−1.50(0.37)	2.65(0.73)
Malay (*n* = 40)						
	Total errors	6.05 (4.43)	4.00	0.00 – 14.00	0.43(0.37)	−1.24(0.73)
	Proportion of P	0.70 (0.24)	0.75	0.00 – 1.00	−1.38(0.37)	1.95(0.73)
	Proportion of G	0.12 (0.12)	0.11	0.00 – 0.38	1.06(0.37)	1.24(0.73)
	Proportion of M	0.07 (0.09)	0.00	0.00 – 0.50	1.38(0.37)	2.05(0.73)
	Proportion of O	0.11 (0.24)	0.00	0.00 – 1.00	2.68(0.37)	7.39(0.73)
Tamil (*n* = 40)						
	Total errors	9.10 (1.98)	9.00	5.00 – 15.00	0.68(0.37)	1.65(0.73)
	Proportion of P	0.40 (0.33)	0.33	0.00 – 1.00	0.44(0.37)	−1.20(0.73)
	Proportion of G	0.07 (0.7)	0.08	0.00 – 0.29	0.82(0.37)	0.31(0.73)
	Proportion of	0.00 (0.02)	0.00	0.00 – 0.13	6.33(0.37)	40.00(0.73)
	Proportion of O	0.53 (0.36)	0.58	0.00 – 1.00	−0.28(0.37)	−1.33(0.73)

P, Phonological errors; G, Graphemic-orthographic errors; M, Morphological-semantic errors; O, Other errors. Subsample is matched across language groups for SES (mother's education).

different spelling error types expressed in proportions based on the total number of spelling errors committed by each child. Therefore, Kruskal—Wallis tests were computed separately for each spelling error type and a Bonferroni correction was implemented for multiple comparisons to interpret results (adjusted $p < 0.013$ for four comparisons).

Results for the full sample analysis revealed a statistically significant difference in the proportion of phonological errors committed across groups, $H(2, 934) = 535.85$, $p < 0.001$, $\eta^2 = 0.57$. *Post hoc* analyses showed that the Malay language group ($M = 0.68$, $SD = 0.24$, $Mdn = 0.73$) on average evidenced a significantly higher proportion of phonological spelling errors than the Tamil language group ($M = 0.44$, $SD = 0.31$, $Mdn = 0.43$), $H(1, 612) = 13.46$, $p < 0.001$, $\eta^2 = 0.02$ and the Chinese language group ($M = 0.03$, $SD = 0.12$, $Mdn = 0.00$), $H(1, 577) = 409.96$, $p < 0.001$, $\eta^2 = 0.71$. Furthermore, the Tamil language group on average showed a significantly higher proportion of phonological errors than the Chinese language group, $H(1, 678) = 378.07$, $p < 0.001$,

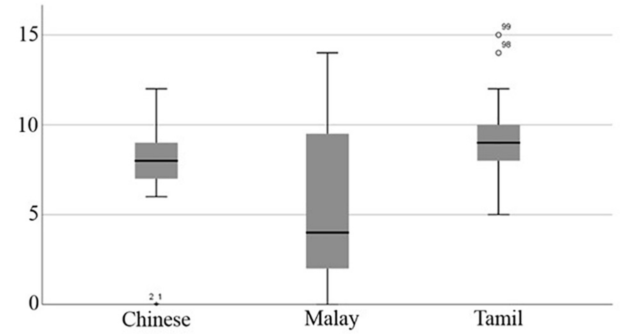

FIGURE 1 | Total number of errors committed by Chinese, Malay, and Tamil Asian language groups in subsample matched for SES (N = 120).

η^2 = 0.56. Analysis on the subsample dataset revealed equivalent results and are detailed in **Table 6** and summarized in **Figure 2A**.

In relation to the proportion of graphemic-orthographic errors, there were no statistically significant differences across Asian language groups in either the full sample analysis, $H(2, 678) = 3.91$, $p = 0.048$, $\eta^2 < 0.01$, or in the subsample analysis (see **Table 6**). This means that all three Asian language groups showed similar proportions of graphemic-orthographic errors (see **Figure 2B**).

For morphological-semantic errors, once again results evidenced significant differences in the proportion of errors of this type committed across the Asian language groups based on the full sample analysis, $H(2, 678) = 214.46$, $p < 0.001$, $\eta^2 = 0.32$. More specifically, the Tamil language group ($M = 0.00$, $SD = 0.03$, $Mdn = 0.0$) showed a significantly lower proportion of morphological-semantic errors than the Chinese language group ($M = 0.09$, $SD = 0.10$, $Mdn = 0.10$), $H(2, 678) = 214.46$, $p < 0.001$, $\eta^2 = 0.32$ and the Malay language group ($M = 0.06$, $SD = 0.09$, $Mdn = 0.00$), $H(2, 612) = 144.60$, $p < 0.001$, $\eta^2 = 0.24$. Furthermore, the Chinese language group showed a significantly higher proportion of morphological-semantic errors than the Malay language group, $H(2, 577) = 10.23$, $p = 0.001$, $\eta^2 = 0.02$. These findings are summarized in **Figure 2C** and are consistent with the results found in equivalent analysis based on the subsample dataset (see **Table 6**).

With respect to the proportion of "other" errors, there was also a significant difference across Asian language groups, $H(2, 934) = 448.02$, $p < 0.001$, $\eta^2 = 0.48$. The Chinese language group ($M = 0.79$, $SD = 0.21$, $Mdn = 0.83$) showed a significantly higher proportion of other errors than the Tamil group ($M = 0.49$, $SD = 0.33$, $Mdn = 0.50$), $H(2, 678) = 144.51$, $p < 0.001$, $\eta^2 = 0.21$, and the Malay language group ($M = 0.11$, $SD = 0.23$, $Mdn = 0.00$), $H(2, 577) = 358.17$, $p < 0.001$, $\eta^2 = 0.62$. In addition, results indicated a higher proportion of other errors for the Tamil as compared to the Malay language group, $H(2, 612) = 213.17$, $p < 0.001$, $\eta^2 = 0.35$. Once again, consistent results were found when computing equivalent analyses on the subsample dataset (see **Table 6**). In **Figure 2D** the above-mentioned findings are presented.

To address the second part of the second research question, regarding within-group differences, three independent Friedman's ANOVAs were conducted. These were each done to investigate potential significant differences between the proportion of different spelling error types (phonological, graphemic-orthographic, morphological-semantic, and others) for each group: that is, which of the triple-code error types predominated within each language group?

First, for the Chinese language group there was an overall significant difference between the proportion of spelling error types in the full sample analysis, $F(3, 321) = 699.20$, $p < 0.001$. The highest proportion of errors was found for the "other" category of errors ($M = 0.79$, $SD = 0.21$, $Mdn = 0.83$), followed by morphological-semantic errors ($M = 0.09$, $SD = 0.10$, $Mdn = 0.10$) and graphemic-orthographic errors ($M = 0.09$, $SD = 0.13$, $Mdn = 0.00$), and finally phonological errors last ($M = 0.03$, $SD = 0.12$, $Mdn = 0.00$). Analysis of the subsample for the Chinese language group replicated these results, $F(3, 39) = 89.59$, $p < 0.001$ and indicated a significantly higher proportion of "other" errors as compared to phonological, graphemic-orthographic, and morphological-semantic errors, as revealed by *post hoc* analyses, $p < 0.001$. **Figure 3A** illustrates these results.

Second, for the Malay language group there was also an overall significant difference between the proportion of error types children committed, $F(3, 127) = 204.88$, $p < 0.001$. Phonological errors showed the highest proportion ($M = 0.68$, $SD = 0.24$, $Mdn = 0.73$), followed by graphemic-orthographic errors ($M = 0.15$, $SD = 0.18$, $Mdn = 0.11$), other errors ($M = 0.11$, $SD = 0.23$, $Mdn = 0.00$), and morphological errors ($M = 0.06$, $SD = 0.09$, $Mdn = 0.00$). Equivalent subsample analysis also showed a significant effect of error type, $F(3, 39) = 66.94$, $p < 0.001$. *Post hoc* analyses revealed significant differences between the proportion of phonological and morphological-semantic and other errors on one hand, and between other and morphological-semantic errors and graphemic-orthographic errors on the other hand, $p < 0.001$. These results are summarized in **Figure 3B**.

Finally, for the Tamil group results once again showed a significant overall difference between the proportion of different error types committed by children, $F(2, 119) = 216.42$, $p < 0.001$. "Other" errors occurred in the highest proportion ($M = 0.49$, $SD = 0.33$, $Mdn = 0.50$), followed by phonological ($M = 0.44$, $SD = 0.31$, $Mdn = 0.43$), graphemic-orthographic ($M = 0.07$, $SD = 0.78$, $Mdn = 0.00$) and finally, morphological-semantic ($M = 0.00$, $SD = 0.03$, $Mdn = 0.00$). Parallel subsample analysis confirmed the overall difference between error types, $F(3, 39) = 66.94$, $p < 0.001$. In addition, *post hoc* analyses indicated a significantly higher proportion of phonological errors and other errors as compared to graphemic-orthographic and morphological-semantic errors, respectively, $p < 0.001$. **Figure 3C** reflects these results.

Research Question 3

In relation to the third research question, we aimed to further characterize the specific subtypes of spelling errors

TABLE 6 | Kruskal Wallis analysis of triple-code errors by language groups in the subsample.

Spelling error measure	Overall results (2, 119)			*Post hoc* analyses								
				Chinese vs. Tamil (1, 79)			Chinese vs. Malay (1, 79)			Malay vs. Tamil (1, 79)		
	H	*p*	η^2	*H*	*p*	η^2	*H*	*p*	η^2	*H*	*p*	η^2
P	66.54	< 0.001	0.56	41.02	< 0.001	0.52	53.83	< 0.001	0.68	13.84	< 0.001	0.18
G	5.77	0.056	0.05	0.37	0.541	< 0.01	4.45	0.035	0.05	3.71	0.05	0.05
M	20.92	< 0.001	0.18	16.57	< 0.001	0.21	0.04	0.844	< 0.01	20.88	< 0.001	0.26
O	12.60	< 0.001	0.11	14.07	< 0.001	0.18	50.24	< 0.001	0.64	27.82	< 0.001	0.35

P, Phonological errors; G, Graphemic-orthographic errors; M, Morphological-semantic errors; O, Other errors.

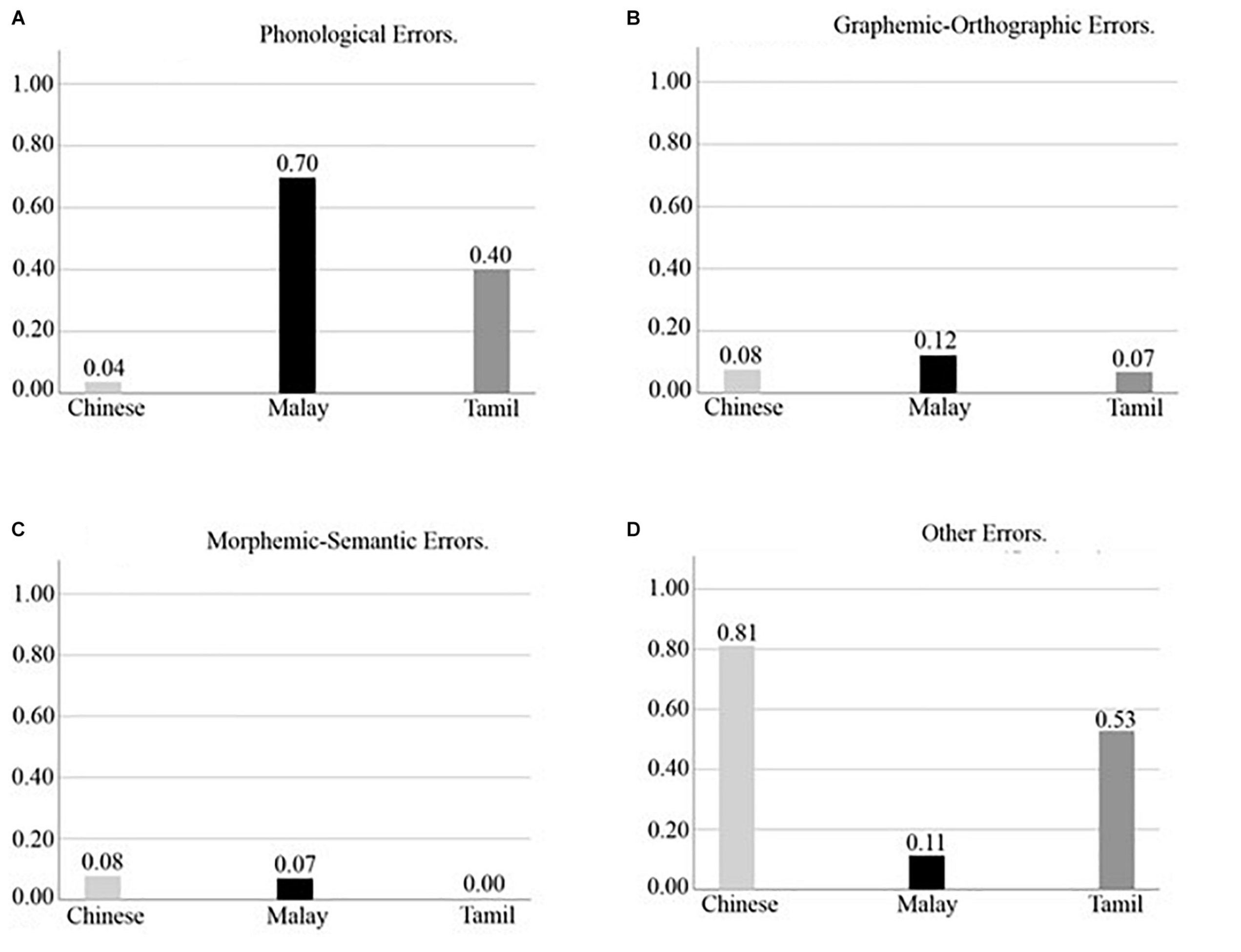

FIGURE 2 | Proportion of Phonological Errors **(A)**, Graphemic-Orthographic Errors **(B)**, Morphemic-Semantic Errors **(C)**, and Other Errors **(D)** in Chinese, Malay, and Tamil Asian language groups in subsample matched for SES (*N* = 120).

committed within each broader error category (phonological, graphemic-orthographic, morphological-semantic, and others) that emerged from the coding scheme used in this study (see Section "Methods" and **Supplementary Appendix C**). To this end, we calculated the frequencies of each subtype of spelling error committed by children in each Asian language group. In **Tables 7a–c** information is presented on the three most frequently occurring subtypes of errors for each broader error category. These data were computed across the full sample.

DISCUSSION

With the aim of broadening frameworks of spelling acquisition, we examined children's performance in diverse types of scripts

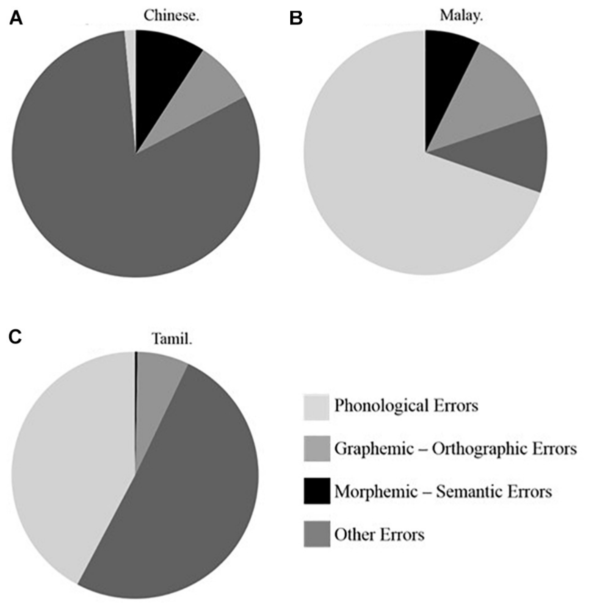

FIGURE 3 | Proportion of Phonological Errors, Graphemic-Orthographic Errors, Morphemic-Semantic Errors, and Other Errors in Chinese **(A)**, Malay **(B)**, and Tamil **(C)** Asian language groups in subsample matched for SES (N = 120).

using a traditional approach of error type analysis. From a large group of children in primary grade 1 learning an Asian alphabetic script, akshara script or hanzi script, we asked whether the nature of spelling errors differed across scripts, and whether there are commonalities. By identifying script-general and script-specific features of spelling skills in this systematic investigation across the writing systems, this study contributes to a broader framework of spelling acquisition which should prove useful in a range of educational and research contexts.

Overall Errors Across Language Groups

The first finding indicated that of the three groups we examined, those spelling Tamil words made more errors overall than the other groups. This was true within the whole sample, and the effect was even larger when SES was controlled within the matched subsample. Several reasons could explain this result, including the large orthographic inventory for Tamil, where children must learn the 247 graphemic representations or aksharas. This was in line with our expectation that orthographic breadth would yield more difficulties with spelling. While this challenging inventory size would apply even moreso to children learning Chinese characters, for Tamil there are both visually confusable and phonetically confusable aksharas which require attention to fine details of the complex symbols. That is, while the Chinese characters had a higher range of visual complexity compared with the Tamil aksharas (based on Chang et al., 2018), all items in the Tamil list were considered graphemically complex compared with 60% of the Chinese items being graphemically complex (refer to **Table 3**). Also, the mapping system from speech to print is more arbitrary for Chinese, whereas there is a systematic relationship for aksharas. As such, children first learning Tamil may begin to understand this mapping system and therefore may be more able to attempt to spell words which they are unsure of. With Chinese, young learners may not have a systematic knowledge to draw upon when attempting to write unknown characters, which may explain a large proportion of blank responses or random guesses when they are unsure of how to spell the Chinese characters. Further, even though the relation of spelling to sound may be very systematic for Tamil, the relation is also complex, as noted by Nag and Narayanan (2019), where both syllable and phoneme levels are represented within words. Making sense of this dual-level representation of phonology in writing may take time for children to acquire.

Specific Types of Errors Across Language Groups

Inspection of the broad types of errors that contributed to children's performance revealed differences across the scripts when a triple-code framework was considered. Examining phonological, morphological, and orthographic-graphemic errors separately, the language groups were only similar in the proportion of the latter type. All three groups differed in the amount of phonological types of errors, where these were most prevalent in Malay spelling and least prevalent in Chinese spelling, with Tamil spelling coming in between the two. Given the alphabetic structure of Malay, as well as Tamil to some degree, these errors may not be surprising. The Tamil and Chinese findings fit with previous spelling studies. Nag et al. (2010), Nag and Narayanan (2019) found most akshara-based spelling errors to be of a phonological nature. Further, Tong et al. (2009) found in their Hong Kong sample of kindergarteners that phonological errors were the most rare type in children's character writing. These errors were also very rare for the current sample of Chinese speakers.

Considering morphological types of errors, these were very rare in Tamil spellings. Both the Chinese and Malay language groups made more of these types of errors than did the Tamil group. Even though these types of errors were not that frequent in Chinese and Malay, the occurrence rates were similar across these two groups. It was suggested in earlier studies by Rickard Liow and Lee (2004) that Singaporean children learning to spell in Malay tended to use morphological knowledge. As well, Tong et al. (2009) found that morphologically based errors predominated in Chinese writing by young children. The set of results followed previous monolingual findings for each of the three languages, according to phonological, orthographic and morphological error types, and did not support the alternative hypothesis that cross-linguistic influence from learning English would result in similar types of errors across the Asian languages.

Finally, the "other" category of errors, which included blank responses or substitutions of unrelated words (otherwise considered random guesses), also differed in occurrence rates between all the language groups. These were by far most common for Chinese writing, with Tamil writing coming in second highest for this category, and were more rare for Malay writing. The ability to sound out words and the use of a very familiar,

TABLE 7a | Most frequently occurring subtypes of spelling errors within triple-code categories for Chinese.

Spelling error measure	Total *n*	Rank 1	Rank 2	Rank 3
Other errors	1908	Substitution by irrelevant word/non-word (OC1 – *n* = 1304)	No response (OC2 – *n* = 604)	
Morphological-semantic	243	Substitution of homophone (MC2 – *n* = 108)	Morpheme omission (MC3 – *n* = 79)	Substitution of semantically related character (MC1 – *n* = 56)
Graphemic-orthographic	219	Addition, omission or protrusion of strokes (GC3 – *n* = 171)	Similar formed or structured character substitution (GC2 – *n* = 39)	Reconfiguration of characters or components of characters (GC1 – *n* = 9)
Phonological errors	39	Phonetic radical addition, substitution or omission (PC1 – *n* = 39)	Similar sounding character/word substitution (PC2 – *n* = 0)	

n, number of errors across the full sample of Chinese-speaking participants.

TABLE 7b | Most frequently occurring subtypes of spelling errors within triple-code categories for Malay.

Spelling error measure	Total *n*	Rank 1	Rank 2	Rank 3
Other errors	234	Substitution by irrelevant word/non-word (OM1 – *n* = 185)	Non-response (OM2 – *n* = 49)	
Morphological-semantic	85	Morpheme Omission (MM2 – *n* = 55)	Substitution of semantically related character/word (MM1 – *n* = 30)	
Graphemic-orthographic	102	Similar formed or structured grapheme substitution (GM1 – *n* = 102)		
Phonological errors	375	Single vowel substitution (PM1 – *n* = 186)	Single vowel omission (PM3 – *n* = 119)	Consonant omission (PM7 – *n* = 70)

n, number of errors across the full sample of Malay-speaking participants.

TABLE 7c | Most frequently occurring subtypes of spelling errors within triple-code categories for Tamil.

Spelling error measure	Total *n*	Rank 1	Rank 2	Rank 3
Other errors	474	Substitution by irrelevant word/non-word (OT1 – *n* = 250)	No response (OT2 – *n* = 224)	
Phonological errors	471	Consonant substitution (PT6 – *n* = 118)	Retroflex consonant substitution (PT7 – *n* = 109)	Similar sounding word substitution (PT10 – *n* = 50)
Graphemic-orthographic	75	Similar formed or structured grapheme substitution (GT1 – *n* = 71)	Addition, omission or substitution of diacritics (GT3 – *n* = 2)	Addition, omission or protrusion of strokes (GT2 – *n* = 2)
Morphological-semantic	4	Morpheme omission (MT2 – *n* = 4)	Substitution of semantically related word (MT1 – *n* = 0)	

n, number of errors across the full sample of Tamil-speaking participants.

constrained alphabet may have meant that Malay spellers are better positioned to make more accurate or plausible attempts at unknown spellings with either phonologically or morphologically close approximations.

Prevalent Error Types per Language

Zooming in within each language group, there were some expectations in terms of the types of errors that children may be most susceptible to given the nature of the various scripts. For Chinese, it was expected that morphologically based errors would be most frequent, as in Tong et al. (2009), and graphemic-orthographic errors would be second highest in proportion. These two error types were statistically equivalent in their rates in the current study, but they were much less common than the top "other" error type. As noted above, some of these "other" errors included blank, null responses, but most "other" errors (68% of them) involved writing an unrelated word or a made-up, illegal character (**Table 7a**). Thus, children often attempted to write something even when they did not know how to represent the dictated word. Across all errors, morphological-semantically based homophone substitutions accounted for only 4.5% of all errors committed, while sub-character omissions or substitutions related to morphemes accounted for about 5.6% of overall errors. This indicates that neither whole character nor sub-character knowledge related to meaning played a major role in children's spelling at this stage in the current sample. More frequent in terms of overall errors were stroke mistakes (about 7%) where strokes were either omitted, added or inaccurate, while at the same time configuration errors were almost non-existent. This suggests children had general orthographic knowledge with regard to the overall orientation and how components are represented in characters, but character-specific knowledge about stroke components is still developing. Likewise, phonological information did not play a role in children's spelling attempts, with just over 1% of overall errors involving phonetic radical additions, omissions or substitutions (**Table 7a**).

For Malay spelling, although similar transparent alphabetic languages using the Latin script suggest a strong reliance on phonological knowledge for decoding and encoding, previous research in Singapore indicated the importance of morphological knowledge. Jalil and Rickard Liow (2008) found that children's vowel substitutions came more from familiar words that were similar to the target word, rather than phonemic substitutions. Rickard Liow and Lee (2004) also suggested a stronger reliance on morphological knowledge by young Malay spellers. According to the present sample, phonologically based errors were predominant, with graphemic-orthographic errors second most common. Both of these were greater than the morphological and other error types. Phonological errors involved mostly vowel substitutions or omissions (23% and 15% of overall errors, respectively). The other types of errors, where irrelevant or non-words were written, accounted for 23% of overall errors. And graphemic-orthographic errors involving letter reversals accounted for 12% of overall errors. Thus, when attempting to spell unfamiliar words in Malay, children tend to write something, and they tend to approximate the actual word rather than writing non-sense words (only 6% of errors were non-response, blanks). Their approximations involve confusions mainly about how vowel sounds are represented, with some still confusing letters with reversed forms (e.g., "b" for "d").

As for Tamil, we expected that vowels and their diacritical representations would prove most difficult, following findings by Nag and Narayanan (2019), and that these would therefore include phonologically based errors. We found that most children's spelling errors involved either other types (49%) or phonological types (44%) with almost no morphological errors. Out of all the errors, 24% included wrong words or non-word attempts, while 22% were left blank. Another 22% of all errors were due to substitutions of consonants. Thus, the present findings followed from Nag and Narayanan (2019) in that many errors were phonologically based, but in this sample they were more similar to the older learners in Aaron and Joshi (2005), who also found more consonant than vowel spelling errors. On the other hand, there were only few graphemic-orthographic errors overall (7% of all errors), suggesting children quickly develop an understanding of how the akshara are formed, similar to Nag and Narayanan (2019), but they require a longer period of time to distinguish between representation of consonants within akshara.

Overall, the present findings suggest major differences in how children who are in the beginning stages of literacy acquisition encode words, in this case in their other language (besides English). Of the triple-code representations for words – i.e., sound, shape and meaning-based codes (phonological, orthographic, and morphological-semantic) – these do not appear to follow a universal developmental trend, as suggested by Shen and Bear (2000). Rather, the multiple knowledge sources from the triple codes may developmentally overlap, as suggested by Bahr et al. (2009). Thus, the use of different representational codes can be dynamically applied to the situation or specific item to be encoded. This means children may need to rely on different types of knowledge depending on the word they are trying to spell – they could adjust to relying to a greater extent on their phonological, orthographic or morphological knowledge. Furthermore, the specifics of the script in use and the constraints of that script may require use of a specific representational code to a greater or lesser extent.

Thus, rather than a universal set of stages that children progress through on their way to becoming proficient spellers, children more likely accumulate knowledge of the orthographic patterns of their script as well as the phonological and morphological information these encrypt (e.g., Sharp et al., 2008). Treiman and Kessler (2014) theory of Integration of Multiple Patterns (IMP) accounts for how children apply multiple patterns for spelling even within the same word. They contend that what is learned includes both general patterns and word specific patterns of spelling, and that these are accumulated with experience that may involve both implicit learning (statistical learning) of properties of the language, as well as explicit instruction in terms of general rules. Learned patterns also include how they relate to linguistic features of the spoken language. Similar to this, Nag and Narayanan (2019) find overlap in children's mastering of multiple orthographic features of Tamil, where some features take a longer span of time to master especially vowel markers like diacritics.

Regarding universal aspects of spelling, Verhoeven and Perfetti (2017) specify that all writing systems utilize a graphical script with orthographic principles for how it maps to different linguistic units: phonemes, morphemes, syllables. As learners gain experience with specific words, they may become able to retrieve whole words (lexical access) without fully computing the mapping principle. But initially, decoding or encoding words is computationally driven, such as through morphological deconstruction or phonological recoding of sub-character/sub-word units. Where languages differ is how these computations are carried out – either via activation of only phonology, or some combination of phonology and other codes like morphology. In the present study, we tried to gain a glimpse through children's spelling patterns (and error types) into the types of representations that they activate to spell words in their various scripts.

Limitations

The approach we took to studying early spelling acquisition across different writing systems has some limitations and may require further study in order to generalize the results. First, for the spelling error analysis, we used an approach whereby children were asked to spell lists of words derived from their class curricula. While this provided ecological validity and yielded sets of items that typify the types of linguistic material they experience in a learning environment, it did not allow us to compare performance across a more uniform set of items. Experimentally controlled lists of words that are equalized across the scripts in terms of psycholinguistic properties would allow a more balanced assessment of the extent to which the triple codes are applied to the task of spelling. For example, there were few instances of complex words in the Malay list, meaning morphological complexity was limited. Also, there were only two types of phonologically based errors for Chinese character writing. Future studies could attempt to equate the numbers of these items even if they are less frequent in some languages.

Another drawback is that we only examined children's performance cross-sectionally at one point in time, so it is difficult to make judgements about the direction of learning the underlying principles for spelling. For example, phonological errors may mean they are attempting to represent the sounds correctly, but fall short of accurately doing so. We considered that if children are making errors in some realm, e.g., phonology, then they have not yet mastered the principles of their script based on that code. In other words, children may make many phonological errors and few orthographic errors, because, we would assume, they have mastered orthographic principles but not yet phonology-orthography principles. To disentangle these assumptions, a longitudinal examination of the growth or stability of accurate features would need to be conducted.

Finally, the current sample includes a set of children in a specific multilingual context, with all experiencing English as the school medium of instruction, and many learning an Asian language as a second or heritage language. Therefore, cross-language influence could come into play and there may be differences in how children process the Asian language scripts compared to those living abroad.

CONCLUSION

Despite the shortcomings, this study may contribute some theoretical and practical implications. That is, comparison of children within the same classrooms learning different Asian scripts allows us to consider what strategies and challenges are present for all scripts, and which may be script-specific. What do children "pick-up" on early in their literacy learning of each script? Following from Treiman and Kessler (2014) IMP model, this provides information about the types of features children implicitly learn from their experience with their language, and the features that prove problematic (e.g., phonological for Malay and Tamil). Across all the groups, graphemic-orthographic errors were similarly rare, indicating that the visual-orthographic code may be picked up early on. The number of "other" errors for Chinese and Tamil suggests that explicit teaching of general patterns regarding how the orthographic patterns relate to spoken language may be in order. As Treiman and Kessler (2014) explain, the patterns in writing systems allow children to make generalizations across words, and instructional supports may aid in such generalizations. They consider that children can benefit from feedback not only about how their misspellings are wrong, but why they may be wrong. By highlighting triple-code theory, we can consider how to focus such feedback on the relevant types of errors children tend to make when learning different types of scripts.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by NTU Institutional Review Board. Written informed consent to participate in this study was provided by the participants' legal guardian.

AUTHOR CONTRIBUTIONS

BO'B contributed to conception of the work, interpretation of data, and drafting the work for intellectual content. MH contributed to design of the work, data acquisition, interpretation, and revising work. NA contributed to data acquisition, interpretation, and revising work. NL contributed to data analysis, interpretation, and revising work.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2020.00870/full#supplementary-material

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Morpho-Orthographic Complexity in Affix Spelling in Hebrew: A Novel Psycholinguistic Outlook Across the School Years

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The current study examined the factors underlying native Hebrew speakers' ability to learn homophonous affix spelling. It takes a novel view in investigating the effect of morpho-orthographic complexity of affix representation on the development of affix spelling across the school years. The role of five morpho-orthographic principles in homophonous affix letter spelling was studied: (i) morpho-orthographic transparency; (ii) affix letter prevalence; (iii) morpho-phonological competition; (iv) overtness of the phonological-orthographic link; and (v) phono-morpho-orthographic consistency. Taken together, these five principles of affix spelling constitute complexity metrics that pinpoint the loci of spelling challenge in homophonous Hebrew affixes. Study participants were 83 monolingual Hebrew-speaking students in four grade levels – 2nd, 4th, 7th, and 10th grades. The research instrument was a spelling task of 244 words containing affix letters in 57 morphological categories. The affixes appearing in the target words represented 56 different affix categories, covering all non-root morphological roles, both inflectional and derivational. While correct spelling increased across grade levels, a hierarchy emerged in interaction with grade level regarding these criteria: Younger spellers were mostly assisted by morpho-orthographic sites, morphological category frequency, and phonological transparency – while spelling in higher grade levels was more affected by morpho-orthographic prevalence. Thus, knowledge of how morphological roles are deployed in the orthography emerges as the most significant factor that affects learning to spell affix letters in Hebrew.

Keywords: affix, spelling, development, morphology, word frequency

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INTRODUCTION

The development of spelling skills is essential for children's literacy acquisition, as it increasingly promotes higher-order writing processes (Stage and Wagner, 1992; Graham and Santangelo, 2014). Much of the spelling literature primarily focused on how spellings are constructed from phonological forms (e.g., Barry and Seymour, 1988; Treiman et al., 2002; Treiman et al., 2015). This framework has been expanded in the last decades to a multi-faceted view of the combined roles of phonology and grammar in learning to spell. According to this view, several knowledge bases, including the phonological, orthographic, and morphological patterns inherent to words are involved in spelling acquisition from early childhood (Angelelli et al., 2014;

Treiman and Kessler, 2014). The current investigation is at the interface of Hebrew phonology, morphology and orthography with cognitive factors of pattern detection and generalization, on the one hand, and psycholinguistic factors of transparency, frequency, and prevalence, on the other, across the school years. Specifically, we examine the effect of morpho-orthographic complexity on the path of acquisition of homophonous affix spelling in Hebrew-speaking spellers from 2nd to 10th grade. Complexity is expressed by five novel metrics: (i) morpho-orthographic transparency; (ii) affix letter prevalence; (iii) morpho-phonological competition; (iv) overtness of the phonological-orthographic link; and (v) phono-morpho-orthographic consistency.

Theoretical Framework

This study arises from several theoretical assumptions, which provide the framework for the study and its hypotheses.

Usage-Based Learning

The psycholinguistic learning theory adopted in the current context is the Usage-Based approach, where learning is regarded as the result of discerning repeating patterns in the input, leading to the emergence of categories as the result of changes in the system (Diessel, 2019). Linguistic systematicity emerges from experience with individual usage events during exposure to spoken and written language, in a process that is graded, probabilistic, interactive, and context-sensitive, under constant pressure from changing linguistic input (Tomasello, 2003; Abbot-Smith and Tomasello, 2006; McCauley and Christiansen, 2019). Importantly, usage-based approaches emphasize the critical role of low-level (i.e., relatively specific) generalizations in learning, taking into account frequency factors and the similarity of the exemplar being learned to others already stored. Thus, spelling performance improves over many learning trials as morpho-lexical patterns are learned as generalizations over memories of words (Aguado-Orea and Pine, 2015; Rácz et al., 2015). The diachronic process whereby the consistent morphological spelling of English derivational suffixes arose from homophonous variants supports this view of usage-based development (Berg and Aronoff, 2017).

As the source of generalizations is the ambient (spoken and written) language, native language learners need to pay attention to the special typological features of the language being learned (Cysouw, 2005), such as a rich morphology (Ravid, 2012, 2019b), and the properties of the notational system being learned (Ravid and Tolchinsky, 2002; Sampson, 2016; Martinez-Adrian and Gallardo-Del-Puerto, 2017).

Spelling as a Source of Lexical Quality

A second theoretical assumption guiding the current study is that spelling knowledge is lexical in nature, that is, it is part of language users' knowledge about words and patterns of similarities that link words together. Recent models of the mental lexicon regard it as a dynamic structure in which words constitute the prime lexical representations (Blevins, 2016). Words may be similar in sound (*doctor, document*), in meaning (*tall, high*), or in meaning-bearing structure (*high/height, document/documentary*). With time and frequent use, these links come to organize the mental lexicon by abstract representations of phonological, semantic or morphological similarity patterns (Clark, 2017), yielding a system of constructions that is capable of expressing meaning matched to form (Goldberg, 2006). Studies of spoken language acquisition underscore the role of statistical properties of the ambient language (such as type and token frequency, transparency, regularity, consistency, salience, and neighborhood density) in the process of language acquisition and development (MacRoy-Higgins et al., 2013; Nation, 2013; Ambridge et al., 2015). In learning to spell, learners would be looking for similar consistent and meaningful statistical patterns in the visual representation of word-internal units that they have mapped out for spoken language (Levin et al., 2001; Ravid, 2012; McCutchen and Stull, 2015; Northey et al., 2016; Treiman, 2018a; Treiman et al., 2019). Therefore, current thought in the developmental psycholinguistics of spelling is that its acquisition and consolidation constitute part of the lexical and grammatical knowledge that children accumulate across the school years (Treiman, 2017). Learning to spell is regarded as part of the acquisition of "lexical quality" in a particular language, and good spellers have qualitative lexical representations (Perfetti, 2007): The more a person knows about a word in terms of its lexical semantics, phonology, morphology, and syntax, the more "qualitative" its representation and retrieval. A stable orthographic representation (= correct spelling) is an important signal of a word's lexical quality.

Language Typology, Orthographic Typology and Morphological Cues

A third theoretical assumption relates to the language type, the type of the orthography, and their relation to spelling acquisition. From the point of view of the language type, the organization of the lexicon in a given language has developmental implications. Children growing up in morphology-rich languages figure out early on that this is "where the action is" – where meanings and forms densely coalesce in language-specific ways (Berman, 1985). In learning to spell, these children would be looking for the very same categories and relationships in written language that they have mapped out for spoken language.

From the point of view of the orthographic type, we should note the relationship between orthography, phonology and morphology. In languages with alphabetical orthographies, the grapho-phonemic code expresses the crucial relationship between orthography and phonology, and learning to spell begins with cracking this code, creating pathways that delineate coarse-grained networks between phonological segments and graphemes that are adequate for reading (Goswami, 2002; Treiman, 2018b). However, in very few, if any, orthographies, is this initial knowledge adequate for the level of spelling, which requires finer-grained mappings and hence precision in selecting one grapheme over another (Holmes and Babauta, 2005). In fact, alphabetical orthographies often systematically express meanings or affix functions via written morphological units, and they may ignore finer morpho-phonological distinctions to express the meaningful generalizations of the morphological system (see a current summary in Sandra, 2018).

In many languages with alphabetical orthographies, morphology – the structural organization of meaning within the word – constitutes the architecture of hidden units mediating the complex and often opaque relationships between phonology and orthography. This is certainly true for Hebrew, where many semantic notions are expressed within the word, with major morphological systems organizing the lexicon and morpho-phonological alternations prevalent in it (Ravid, 2012, 2019a; Schwarzwald, 2002). But it is also true of languages with less dense morphological systematicity: A recent corpus study of written English across a millennium (750–1700 AD) traces the emergence of affix spelling from variegated beginnings to clear morphological marking of nouns, adjectives, and verbs – e.g., the –OUS adjectival suffix (Berg and Aronoff, 2017). The authors remark that "Crucially, this is information that the phonological system does not provide – it is a distinct feature of the writing system" (p. 45), in which the spelling distinguishes homophonous suffixes or word endings and allows readers to access lexical and syntactic information directly from the orthographic representations.

As written language represents morphological constructs distinctly from spoken language, often overriding or ignoring phonological constructs, the task of the learning speller would then be to discover and identify morphological categories in the orthography and link them up to spoken categories. In learning to spell morphological categories, the strength of a morphological pattern depends on the number of words that exhibit it, and on the degree to which it is evident in these words.

Affix spelling (e.g., past-tense *–ed*) has been the subject of a series of acquisitional studies on grade school children, showing how morphology increasingly participated in children's spelling choices. Nunes et al. (1997) found that English-speaking first grade children learned the bi-morphemic nature of KISSED (first spelled KIST), and then overgeneralized this spelling (e.g., SOFED for SOFT), before reaching correct usage (Walker and Hauerwas, 2006). The effect of morphological learning was also apparent in the tendency to simplify consonant clusters more in mono-morphemic words (e.g., BRAND) than in bi-morphemic words (e.g., RAINED) (Treiman and Cassar, 1996). In the same way, Kandel et al. (2012) found that French-speaking children took longer to write at the morpheme boundaries of derived words. A similar route was found in a longitudinal study of Greek first graders (Chliounaki and Bryant, 2002) who were learning to spell the alternative orthographic forms of the vowels *o* and *e*: As children began to use the new spellings, they overgeneralized them to inappropriate environments, first in inflections and then in stems. Finally, correct spellings were restricted to appropriate contexts. Moreover, Nunes et al. (2006) report that correct spelling of -ED predicted performance on different tasks of morphological awareness even when controlling for age and IQ, showing that children's morphological representations were enhanced as a result of learning to spell those morphemes. These studies testify to children's emerging construal of morphemes in writing and the gradual establishment of morpho-graphic patterns. Importantly, it seems that children's ability to process the word's morphological structure assists them as they start to spell, interfacing with phonology, semantics and orthography (Breadmore and Deacon, 2019).

Against this background, the approach in the current study pinpoints three knowledge domains as necessary to spelling acquisition: (i) how phonological segments map onto graphemes; (ii) the specific properties of the orthographic system; and (iii) the nature of the morphological segments represented by the orthography. In order to acquire mature knowledge of an orthography, a learner has to be proficient in each of these different domains, to construct their cognitive representations so as be able to retrieve them at will, and to map this knowledge onto the specific orthography being learned (Kargl and Landerl, 2018). The goal of spelling is thus achieving a high-quality lexical fit with correct orthographic representation, which expresses morphological information (Desrochers et al., 2018). To this end, young spellers need to keep track of multiple co-occurrences of different units, monitoring the frequencies, regularities and consistent behavior of phonemes and morphemes in words, on the one hand, and how they are expressed in the specific orthographic patterns of their language, on the other.

Hebrew Spelling: Orthography, Phonology, Morphology

The current study is a developmental investigation of how children learn to spell affix letters in Hebrew, a language with non-linear morphology, where discontinuous roots and prosodic patterns combine to form words. As an initial example, take ***l**i**m**e**d**/**m**e**l**u**m**a**d**/**t**a**l**m**i**d** "taught/scholar/pupil," three words that share the same root *l-m-d* meaning "learn" (in bold). The same root is inserted into three different pattern templates that provide vowels interspersed between root radicals and consonantal prefixes or suffixes. Relevantly, recent models of spelling representation (Dehaene et al., 2006) suggest that our brain is sensitive not only to adjacent but also to discontinuous letter combinations that need to be tracked, as in the case of Hebrew.

A major challenge in spelling Hebrew involves the non-transparent mapping of phonology to the orthography, that is, homophony. Extensive neutralizations (or mergers) of previously distinct phonemes have rendered Modern Hebrew phonology very different from its Classical counterparts (Bolozky, 1997; Ravid, 2005). Several sets of Classical consonants merged, resulting in the loss of historical phonological distinctions (Weinberg, 1966; Laufer and Condax, 1981; Schwarzwald, 2001). When phonological distinctions are no longer directly encoded in the orthography, homophony is entailed: a single phoneme can be spelled by more than one grapheme. In order to correctly spell a homophone (e.g., *t* by either ט or ת), knowing the morphological role it serves in the word is critical. As root letters, homophones are extremely challenging, with high type frequency and low token frequency: All 22 letters participate in about 1,500 different roots (Ravid et al., 2016), with the Zipfian frequency typical of lexical elements, so that many repeated occurrences of the same root are necessary for its spelling. However, natural language texts are not "saturated" by lexical units (words and roots), that is, words and roots do not occur repeatedly in the same corpus (Ackerman and Malouf, 2013). In addition, the choice of correct root spelling is conditioned by a complex set of characteristics including root radical position, letter frequency, and morpho-phonological considerations. Therefore, the acquisition of root spelling is a long and arduous process (Ravid, 2001, 2005, 2012).

Affix Spelling in Hebrew

In contrast, affix spelling, which is the focus of the current study, is generally less challenging than root spelling, as most affixes have lower type and higher token frequencies, coupled with higher morpho-orthographic transparency, than roots (Ravid, 2001). Only 11 of the 22 alphabet letters serve in affix letters, and they stand for about 20 morphological roles, both derivational and inflectional. Texts are much more saturated by affix than by root morphemes. Thus, learning to spell affix letters is aided by the low type frequency of affix letters, on the one hand, and their very high token frequency as grammatical morphemes with various affixes, on the other. Most importantly, the phonological-orthographic complexity of homophones is reduced in affix spelling, as in most cases, only one of the two possible graphemes serves as an affix letter. For example, of the two letters ת, ט representing *t*, only ת represents an affix. The same is true of the two letters כ, ק representing *k,* and the two letters כ, ח representing *x,* respectively: ק and ח do not have affix roles. Therefore, a large part of the homophonous challenge to spelling affix letters disappears (Gillis and Ravid, 2006).

A major challenge for affix spelling in Hebrew is identifying affixes as such: spellers need to know whether the homophone has a root or affix role, as this will determine the path in spelling. As a root segment, both spelling options are viable, and thus challenging as homophones; but as an affix letter, homophony is in most cases no longer a problem. The orthographic structure of the Hebrew word is helpful in the identification of letters as roots or affixes: root letters typically congregate in the center of the written Hebrew word, whereas affix letters take peripheral positions in the outer envelope of the word. For example, the written string ובמכתבים "and-in-the-letter-s," the bolded letters at both sides of the root כתב "write" respectively, from right to left, represent affixal roles of conjunction, preposition, pattern prefix and plural suffix. And in the string לכשתבואנה "by the time-they (feminine)-will-arrive," the bolded affix letters, respectively, represent the roles of time, future tense, third person, feminine, and plural. The small number of affixes (low type frequency), their ubiquity in the language (high token frequency), and their distinct peripheral positions all serve as reliable morphological pointers to affix morphology. Therefore, identifying the morphological role of the homophonous letter as an affix versus root letter is critical in achieving correct spelling (Ravid, 2012).

However, not all affixes are easy to identify in their non-root roles, as the boundaries between root and affix sites might be blurred. This can happen, for example, in words with irregular roots such as *to'élet* תועלת "benefit," where the root (bolded in transcription and in Hebrew script) is not entirely consonantal, so that the first ת might be interpreted as a root letter. There are other factors that might stand in the way of a successful mapping of the morphology-phonology-orthography link, which promotes correct spelling. Frequency and coherence (= consistency) of letter, word and category can hinder or facilitate affix identification and spelling, especially in specific sites. Thus, for example, consonantal *v* is more likely to be linked to ו as an affix at the beginning of the word (the conjunction *ve*-), and less to ו at the end of a word, where it has few roles, e.g., representing an allomorph of the 3rd person possessive in *–iv.*

Previous studies have suggested that children learning to spell consider the morphological regularities of their orthography, and that they might also use large-sized processing units in spelling (Angelelli et al., 2014; Treiman, 2017). However, to the best of our knowledge, no study has produced a metric to classify and quantify the complexity of affix spellings. Previous studies have established that frequency seems to play a major role in the development of affix spelling because children's spelling accuracy increases as they progress in age (e.g., Treiman et al., 1993). For example, English-speaking and French-speaking children demonstrated implicit learning of the morphological patterns in their orthography (Cassar and Treiman, 1997; Pacton et al., 2001, 2002), leading them to prefer the more frequent orthographic spelling patterns.

Moreover, recent studies have pointed to the characteristics of the alphabetic writing system as a major factor that influences spellers' sensitivity to morphology and not just phonology when determining which spelling alternative is correct (Angelelli et al., 2014; Treiman, 2017). A study including French-speaking first, second, and third graders that examined the acquisition of silent-letter endings (Sénéchal et al., 2016) demonstrated that the absence of phonological cues resulted in children making more errors in pseudoword spelling with silent-letter endings. Another study with Arabic-speaking high school students revealed that 10th graders were still making mistakes when affix letters were interdigitated within root letters, indicating that when affixation modifies the morphological structure of the word, choosing the familiar letter string is still a dominant strategy (Oren, 2001). Taken together, it appears that using a familiar orthographic form is a common strategy of spelling production, even in skilled spellers (Treiman et al., 2015).

Current Study

This current Hebrew study differs from previous studies on the same topic in several respects (Treiman et al., 1993; Treiman and Cassar, 1997; Pacton et al., 2001, 2002; Angelelli et al., 2014; Sénéchal et al., 2016; Treiman, 2017). First, from a typological perspective, the current study examines spelling acquisition as a specific morphological knowledge domain constrained by the morpho-orthographic behavior of affix letters. Second, from a developmental perspective, spelling achievement is examined across the school years as increasingly complex spelling patterns are overcome in learning. A final perspective is gained through the classification and mapping of affix spelling complexity according to five morpho-orthographic principles, as elaborated below in the "Materials and Methods" section.

The current study takes a novel view in investigating the effect of morpho-orthographic complexity of affix representation on the development of Hebrew spelling across the school years. We specifically examined the role of five morpho-orthographic principles in homophonous affix letter spelling: (i) morpho-orthographic transparency; (ii) affix letter prevalence; (iii) morpho-phonological competition; (iv) overtness of the phonological-orthographic link; and (v) phono-morpho-orthographic consistency (see a detailed presentation in the "Materials and Methods" section). Taken together, these five principles of affix spelling constitute complexity metrics that pinpoint the loci of spelling challenges in homophonous Hebrew affixes. Their examination in the current study provides a fine-grained depiction of the development of affix spelling and the factors that determine the sequence and pace of its acquisition. We hypothesized that word frequency and the morpho-orthographic metrics of affix spelling constitute two separate factors that independently predict different spelling skills across development. To investigate this hypothesis, the Affix Letter Spelling Task, representing all affixes and all of their morphological roles in Hebrew, was administered to the study participants, as delineated below. Given the literature review, we predicted higher scores on high-frequency words, words with transparent demarcation of root from affix envelope, prevalent affixes, affixes without morphological competition, affixes expressing overt phonological-orthographic links, and affixes with phono-morpho-orthographic consistency.

MATERIALS AND METHODS

Participants

Study participants were 83 monolingual Hebrew-speaking students in four grade levels – 2nd, 4th, 7th, and 10th grades (39 boys and 44 girls). No significant difference was found in the gender distribution between the four grade levels $\chi^2(3) = 1.49$, $p = 0.684$. Participants were typically developing readers selected according to the following criteria: (i) normal performance on a non-verbal general intelligence test (Wechsler, 1991); (ii) performance on a standard vocabulary test (Wechsler, 1999); and (iii) normal reading speed and accuracy on a standard reading test (Schiff et al., 2008). **Table 1** shows the background characteristics of the participants (gender and age) and their performances on the background tests. Results showed that participants' non-verbal intelligence, vocabulary, and reading accuracy and fluency scores were within the normal range. Furthermore, none of the participants had any hearing impairment, attention deficit disorder nor a history of neurological or emotional disorder, as reported by clinicians, educational professionals and the adult participants themselves.

Participants were selected from public primary schools and high school in the greater Tel Aviv area in Israel. The Tel Aviv schools chosen for the study are located in the center as well as the northern part of the city. The study was conducted according to the principles of the Helsinki Declaration and was approved by the Ministry of Education and the Institutional Review Board at Bar Ilan University. Parents were informed of the screening activities and had to approve their child's participation. All data concerning individual performances were analyzed strictly for research purposes.

Materials

The Screening Tests

Non-verbal intelligence was assessed by the WASI Matrix Reasoning subtest (Wechsler, 1999). This task requires participants to choose an item from the bottom of the figure that would complete the pattern at the top. The maximum raw score is 60. Test reliability coefficient is 0.96.

Vocabulary was also assessed by the WASI Matrix Reasoning subtest (Wechsler, 1999). The vocabulary subset consists of four picture items and 38 word items.

The word reading accuracy test required participants to read aloud a list containing 112 non-vowelized words. Scores ranged from 0 to 112, reflecting the number of correct answers given, with higher scores indicating higher reading accuracy. In the word reading fluency test, participants read aloud as many words as possible in 45 s from a list containing 104 words (Schiff et al., 2008). The wordlist used in the fluency test differed from the words used in the accuracy test. Scores ranged from 0 to 104, reflecting the number of accurate words the participant read in 45 s, with higher scores indicating higher reading fluency. Words in both tests increased in difficulty.

The Affix Letter Spelling Task

The research instrument was a spelling-to-dictation task, which consisted of 224 words, each containing one homophonous affix letter (Schiff and Levie, 2017). The affixes appearing in the target words represented 56 different affix categories (four words per affix category), covering all of the function (non-root) morphological roles of Hebrew affix letters, both inflectional and derivational (Ravid, 2012). For example, the prefixal conjunction *ve* "and" spelled ו constituted one category, the tense/person prefix *t-* spelled ת constituted another, the nominal pattern suffix *t-* spelled ת constituted yet another category, and the suffixal *-xa* indicating second person masculine was a fourth affix category.

Half of the words (112) were of high frequency and half (112) were of low frequency. In order to validate the classification of the division of the words in the spelling task according to their level of frequency in the language (low frequency, high frequency), an initial list of 228 words was given to ten judges, experts in the field of language and Hebrew linguistics. Each judge was requested to rank the level of frequency of the word on a scale of 1 (the word is not frequently used in the language) to 5 (the word is frequently used in the language). Words that were ranked by all ten judges as having frequency levels of 1 or 2 in the language were defined as non-frequent words, while words that were ranked by all ten judges as having frequency levels of 4 or 5 were defined as frequent words. Four words were removed from the final test administered to the participants of the study, due to lack of consent among the judges with regards to their frequent use in the language.

Procedure

Words in the spelling test were randomized and administered in a spelling-to-dictation task. The dictation task was administered orally and individually, preceded by three examples. Each target word was presented in the context of a short sentence to

TABLE 1 | The background characteristics of the participants (gender and age) and their performances on the vocabulary and reading tests.

	Second	Fourth	Seventh	Tenth	Statistical differences
	(1)	(2)	(3)	(4)	
Gender (Boys/Girls)	12/11	8/14	10/11	9/8	$\chi^2(3) = 1.49$, $p = 0.684$
Age	7.48 (0.49)	9.55 (0.41)	12.64 (0.45)	15.62 (0.49)	$F(3,79) = 1196.36$, $p = 0.000$, $\eta_p^2 = 0.98$ *Scheffe:* $1 < 2 < 3 < 4$
Vocabulary[1]	10.26 (1.42)	10.14 (1.88)	10.29 (1.35)	10.35 (1.87)	$F(3,79) = 0.06$, $p = 0.980$, $\eta_p^2 = 0.00$
Matrix[1]	10.57 (1.38)	10.50 (1.54)	11.24 (1.30)	11.00 (1.97)	$F(3,79) = 1.12$, $p = 0.346$, $\eta_p^2 = 0.04$
Reading speed[2]	43.17 (10.73)	52.86 (7.51)	74.52 (9.95)	76.59 (8.69)	$F(3,79) = 63.77$, $p = 0.000$, $\eta_p^2 = 0.71$ *Scheffe:* $1 < 2 < 3 = 4$
Reading accuracy[2]	77.91 (9.40)	87.18 (7.08)	96.19 (4.62)	102.06 (4.92)	$F(3,79) = 47.06$, $p = 0.000$, $\eta_p^2 = 0.64$ *Scheffe:* $1 < 2 < 3 = 4$

[1]Normal performance – all the performance ranged between 7 and 13 (M = 10.00, SD = 1.50); [2]The reading speed and accuracy are in an appropriate level regarding the participants age.

assure clarity of meaning and eliminate possible ambiguity. The examiner read aloud each target word in its sentential context in a neutral tone without emphasizing the presence of possible orthographic difficulties. Participants were instructed to write only the target word, which was repeated at the beginning and end of each sentence (Gillis and Ravid, 2006). For example: *mishkéfet, yesh la-yéled mishkéfet*; *tixtevu mishkéfet* "goggles, the boy has goggles; please write: goggles." To ensure that the children had correctly perceived the target words, the examiner asked them to repeat each one before they wrote it down. No feedback was provided on the correctness of the written response. Pauses were allowed if requested. Spontaneous corrections were accepted.

Coding

Two variables were taken into consideration in coding the task affixes – the frequency of the word in which the target affix appeared and the five morpho-orthographic principles of homophonous affix spelling, serving as criteria for evaluating affix complexity. Thus, each affix on the test was assigned binary values regarding each of the five criteria, as explained, illustrated and motivated below.

(1) The first criterion was *the transparency of the affix envelope*, i.e., the degree to which it is possible to demarcate the central root morpheme from the affixal periphery. For example, in transparently structured words such as תרדמה *ta**rdem**a* "slumber," it is easy to perceive the affix letters ה, ת (signifying pattern prefix and suffix) in the margins of the word, clearly demarcated from the regular, consonantal root morpheme in the center of the word. However, the root in *t**o**'**é**l**et* תועלת "benefit" (in bold in the transcription and in the Hebrew script) is irregular, partially non-consonantal, so that the ו at its beginning can be confused with marking a pattern vowel. This obscures the construal of the word's prefixal ת and suffixal ת as affixes: the first ת can be easily interpreted as a root letter, as in the superficially similar word *toféret* תופרת "seamstress." The binary value for this criterion was either clearly demarcated or opaque. When the affix envelope is clearly demarcated, it is easier to identify homophonous letters as belonging to it and thus to reduce homophony complexity. We expected homophonous letters in clearly demarcated envelopes to be spelled more correctly.

(2) *Affix letter prevalence*, that is, the frequency of the letter in its morphological and orthographic roles, represents its category size. This notion reflects to what extent the number of morphological affix roles the letter represents as well as their variety and prevalence (Ravid, 2012). Thus, a letter with many affix roles is likely to have many occurrences in written Hebrew, which would strengthen not only the role of the letter as affix but also the environments where it is likely to appear (Ambridge et al., 2015). For example, ת (consistently pronounced *t*), which appears in both prefix and suffix positions, has 11 morphological roles, not only signifying feminine gender and second person in various contexts, but also participating in many derivational roles (Ravid, 2019a). In contrast, כ has only two affix roles, both inflectional, which are obscured by the fact that כ represents both the stop *k* and the spirant *x*, i.e., is not phonologically stable; with further constraints on its occurrence in these phonological roles as prefix or suffix. The morpho-orthographic prevalence of letters in the current study was based on the analyses in Ravid (2012, 2019a). It was further assessed by four language and spelling experts, who assessed the category size for each affix letter in each of the task words on a scale from 1 to 5, with a high value of Cronbach's alpha (0.90). The binary value for this criterion was either prevalent or non-prevalent. We thus expected homophonous letters with high prevalence to be spelled more correctly.

(3) A third criterion took into account the existence of morphological "enemies," i.e., *internal morpho-phonological competitors*. This criterion resonates the main pathway to correct spelling in the identification of homophonous letters in their affix roles, i.e., lack of graphemic competitors for the same phonological segment. However, the identification of an affix letter as such (that is, not a root letter) is a necessary, but not a sufficient condition for correct affix spelling even in clearly demarcated environments. The sufficient condition is the absence of competitors in the *same* affix role. This condition becomes necessary in the spelling of ה *h*, and י *y*, which both serve as tense (past and future tense,

tense, respectively) prefixes in specific verb morphology environments. For example, 3rd person singular ***h**itkadem* "advanced" התקדם and ***y**itkadem* "will advance" יתקדם differ only in the first letter of the prefix, which is extremely similar phonologically and also shares the same inflectional role (tense-person). Such competition *within the affix category* reduces spellers' ability to differentiate between the two homophones. The binary value for this criterion was either the presence or absence of internal competitors. We expected homophonous segments with internal morpho-phonological competitors to increase the complexity of the spelling task and thus to reduce success scores, especially in younger spellers.

(4) A fourth criterion concerned *the overtness of the phonological-orthographic* link. In most cases of Hebrew spelling, phonological information is directly linked to the orthography (even though they may not be consistently linked in the case of homophony). Thus, in most cases a letter represents a phonological segment. However, there are cases of *covert* phonology, where the orthographic segment does not represent a phonological unit, but rather, and only, a morphological unit. For example, the possessive suffix *-av* "his" יו - is spelled with י *y* which is not directly linked to any phonological segment normally related to י . The binary value for this criterion was either overt or covert phonology. We expected covert phonology to increase the complexity of the spelling task and thus reduce success scores, especially in younger spellers.

(5) A fifth and last criterion was *phono-morpho-orthographic consistency*, relating to the degree of consistency in spelling patterns that spellers can adhere to as a generalization. One such spelling pattern is the prevalent link between a final feminine *-a* being universally spelled by ה, as in the feminine noun, adjective and verb *malk**a*** מלכה "queen," *sgur**a*** סגורה "closed," and *hisbir**a*** הסבירה "explained," respectively. This link and similar spelling patterns generally point to the representation of final vowels by one of the אהוי vowel-marking letters (Ravid, 2012). The generalization that is elicited from these highly frequent spelling patterns is that open syllables at the end of a word should be "closed" in writing by one of the אהוי letters, especially ה. When this generalization is violated, as in *katávta* כתבת "you, masculine wrote," it is very difficult to overcome the tendency to add a final closing letter. The binary value for this criterion was either conforming or violating phono-morpho-orthographic consistency. We expected the violation of consistent spelling patterns to increase spelling complexity, and to be acquired later on.

RESULTS

Homophonous affix letters in the study were each assigned five binary values corresponding to the five morphological criteria as described above under Coding. Before examining the study questions and hypotheses, we conducted Shapiro–Wilk tests in order to examine whether the spelling scores were normally distributed for each of the frequency values of each word (non-frequent words, frequent words), grades, and for each of the five criteria. Some of the success scores were not normally distributed. Therefore, we examined the study questions and hypotheses by conducting both parametric and non-parametric tests. The non-parametric analyses findings matched the findings of the parametric analyses. Therefore, we present the findings of the ANOVA's analyses, instead of using non-parametric analyses – Wilcoxon tests. In the current study multiple hypotheses were tested among a small sample size. In these cases, the chance of observing a rare event increases, and the risk of making type I errors increases. In order to decrease this risk in cases where the two or three-way interactions were significant, Bonferroni correction was used.

In order to examine the success scores of homophonous affix spelling by word frequency, grade and each of the five study criteria, five $4 \times 2 \times 2$ repeated measures analyses of variance (ANOVA) were conducted, with grade (second, fourth, seventh, tenth) as the between-subject variable, and word frequency (non-frequent words, frequent words) and the binary attribute of each criterion (no, yes) as the within-subject variables. It should be noted that prior to the examining the research questions, we looked at potential gender differences in the spelling scores on the frequency values of each word, grade and for each of the five criteria. No significant differences between males and females were found in the spelling scores (t-values ranged between 0.02 and 1.93 and p-values ranged between 0.077 and 0.986). Therefore, the gender of the participants was not used as another between subject-variable in the repeated measures analyses.

Transparency of the Affix Envelope

The main effects of word frequency and transparency of affix envelope were significant [$F(1,79) = 32.82$, $p = 0.000$, $\eta_p^2 = 0.29$ and $F(1,79) = 367.05$, $p = 0.000$, $\eta_p^2 = 0.82$, respectively], indicating higher spelling scores of frequent words and of affix letters in demarcated envelopes. Furthermore, the main effect of grade was also significant, $F(3,79) = 46.26$, $p = 0.000$, $\eta_p^2 = 0.64$. Scheffe *post hoc* analysis indicated that spelling scores increased with age and schooling. No significant differences were found in the spelling scores between seventh and tenth grade students ($p = 0.299$).

The two-way interaction of grade and transparency of affix envelope was significant, $F(3,79) = 25.94$, $p = 0.000$, $\eta_p^2 = 0.50$. Bonferroni analyses indicated that the spelling scores of affix letters in demarcated envelopes were significantly greater than in the non-demarcated envelopes in all grades ($ps = 0.000$). The effect size decreased as the age of the student increased ($\eta_p^2 = 0.93$, $\eta_p^2 = 0.82$, $\eta_p^2 = 0.69$, and $\eta_p^2 = 0.70$ for the second, fourth, seventh, and tenth grades).

The two way interaction of word frequency and transparency of affix envelope was also significant, $F(1,79) = 4.94$, $p = 0.029$, $\eta_p^2 = 0.06$. Bonferroni analyses indicated that the spelling scores of affix letters in demarcated envelopes were significantly greater than in non-demarcated envelopes in both frequent and non-frequent words ($ps = 0.000$). The effect size was greater in non-frequent words compared to frequent words ($\eta_p^2 = 0.75$ and $\eta_p^2 = 0.60$, respectively).

Finally, the two way interaction of grade and word frequency and the three way interaction were not significant [$F(3,79) = 1.74$, $p = 0.166$, $\eta_p{}^2 = 0.06$ and $F(3,79) = 0.99$, $p = 0.403$, $\eta_p{}^2 = 0.04$, respectively] (see **Table 2**).

Affix Letter Prevalence

The main effects of word frequency and affix letter prevalence were significant [$F(1,79) = 47.98$, $p = 0.000$, $\eta_p{}^2 = 0.38$ and $F(1,79) = 332.68$, $p = 0.000$, $\eta_p{}^2 = 0.81$, respectively], indicating higher spelling scores of frequent words as well as when the letter is prevalent in its morphological roles. Furthermore, the main effect of grade was also significant, $F(3,79) = 45.10$, $p = 0.000$, $\eta_p{}^2 = 0.63$. Scheffe *post hoc* analysis indicated that spelling scores increased with age and schooling. No significant differences were found in the spelling scores between the seventh and the tenth grade students ($p = 0.49$).

All the two-way interactions were significant [grade and word frequency: $F(3,79) = 6.53$, $p = 0.001$, $\eta_p{}^2 = 0.20$, grade and affix letter prevalence; $F(3,79) = 55.94$, $p = 0.000$, $\eta_p{}^2 = 0.68$, word frequency and affix letter prevalence: $F(1,79) = 30.27$, $p = 0.000$, $\eta_p{}^2 = 0.28$]. Finally, the three-way interaction was significant $F(3,79) = 6.87$, $p = 0.000$, $\eta_p{}^2 = 0.21$. Bonferroni analyses indicated that the spelling scores of affix letters when the letter is prevalent in its morphological roles were significantly greater than when the letter is not, in the second, fourth, and seventh grades ($ps = 0.000$) but not in the tenth grade ($ps > 0.05$). These results were found in both frequent and non-frequent words. The effect sizes were greater in non-frequent words compared to frequent words (Non-frequent words: $\eta_p{}^2 = 0.96$, $\eta_p{}^2 = 0.80$, $\eta_p{}^2 = 0.70$ for the second, fourth, and seventh grades and $\eta_p{}^2 = 0.84$, $\eta_p{}^2 = 0.75$, $\eta_p{}^2 = 0.63$ for the frequent words) (see **Figure 1**).

Morpho-Phonological Competition

The main effects of word frequency and morpho-phonological competition were significant [$F(1,79) = 46.64$, $p = 0.000$, $\eta_p{}^2 = 0.37$ and $F(1,79) = 116.14$, $p = 0.000$, $\eta_p{}^2 = 0.59$, respectively], indicating higher spelling scores of frequent words and in cases of no competitors. Furthermore, the main effect of grade was also significant, $F(3,79) = 37.58$, $p = 0.000$, $\eta_p{}^2 = 0.59$. Scheffe *post hoc* analysis indicated that the spelling scores increased with age and schooling. No significant differences were found in the spelling scores between the seventh and the tenth grade students ($p = 0.713$).

The two-way interaction of grade and word frequency was significant, $F(3,79) = 4.55$, $p = 0.005$, $\eta_p{}^2 = 0.15$. Bonferroni analyses indicated that spelling scores of frequent words were significantly higher than non-frequent words among the second, fourth and seventh grades ($ps = 0.000$), but not in the tenth grade ($p = 0.756$).

The two-way interaction of grade and morpho-phonological competition was significant, $F(3,79) = 28.41$, $p = 0.000$, $\eta_p{}^2 = 0.52$. Bonferroni analyses indicated that the spelling scores of affix letters in cases of no competitors were significantly greater than in cases with competitors, in the second, fourth, and seventh grades, but not in the tenth grade ($p = 0.505$).

The two way interaction of word frequency and morpho-phonological competition was also significant, $F(1,79) = 7.69$, $p = 0.007$, $\eta_p{}^2 = 0.09$. Bonferroni analyses indicated that the spelling scores of affix letters in cases of no competitors were significantly greater than in cases of no competitors in both frequent and non-frequent words ($ps = 0.000$). The effect size was greater in non-frequent words compared to frequent words ($\eta_p{}^2 = 0.46$ and $\eta_p{}^2 = 0.43$, respectively).

Finally, the three way interaction was not significant, $F(3,79) = 1.26$, $p = 0.295$, $\eta_p{}^2 = 0.05$ (see **Table 3**).

Overtness of the Phonological-Orthographic Link

The main effects of word frequency and phonological overtness were significant [$F(1,79) = 29.60$, $p = 0.000$, $\eta_p{}^2 = 0.27$ and $F(1,79) = 307.79$, $p = 0.000$, $\eta_p{}^2 = 0.80$, respectively], indicating higher spelling scores of frequent words and with overt phonology. Furthermore, the main effect of grade was also significant, $F(3,79) = 52.81$, $p = 0.000$, $\eta_p{}^2 = 0.67$. Scheffe *post hoc* analysis indicated that the spelling scores increased with age and schooling. No significant differences were found

TABLE 2 | Means (and SD) of the success scores (%) of spelling function by word frequency, grade and demarcated function envelope.

		Non-demarcated envelope		Demarcated envelope	
Word frequency	**Grade**	**Mean**	**SD**	**Mean**	**SD**
Non-frequent words	Second	42.75%	13.13	81.80%	8.13
	Fourth	59.85%	14.00	88.13%	7.75
	Seventh	75.79%	15.57	95.14%	2.89
	Tenth	85.78%	7.07	98.73%	0.79
Frequent words	Second	46.38%	19.43	86.02%	8.12
	Fourth	70.45%	21.32	92.35%	6.31
	Seventh	83.33%	11.79	97.60%	1.99
	Tenth	89.71%	10.00	99.28%	0.36

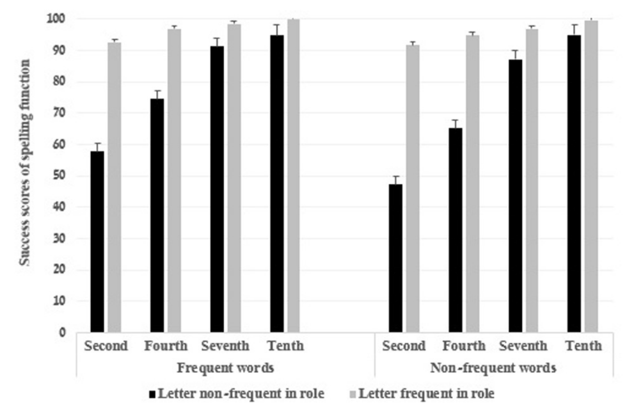

FIGURE 1 | The success scores (%) of spelling function by word frequency, grade, and letter frequency in its morphological role.

in the spelling scores between the seventh and the tenth grade students ($p = 0.616$).

The two-way interaction of grade and word frequency was significant, $F(3,79) = 4.11$, $p = 0.009$, $\eta_p^2 = 0.14$. Bonferroni analyses indicated that spelling scores of frequent words significantly higher than non-frequent words among the second and the fourth grades ($ps = 0.000$), but not in the seventh and tenth grade ($p = 0.075$ and $p = 0.773$, respectively).

The two-way interaction of grade and phonological overtness was significant, $F(3,79) = 39.80$, $p = 0.000$, $\eta_p^2 = 0.60$. Bonferroni analyses indicated that the spelling scores of affix letters with overt phonology were significantly greater than with covert phonology in all grades ($ps = 0.000$). The effect size decreased as the age of the students increased ($\eta_p^2 = 0.94$, $\eta_p^2 = 0.71$, $\eta_p^2 = 0.64$, and $\eta_p^2 = 0.59$ for the second, fourth, seventh, and tenth grades).

The two way interaction of word frequency and phonological overtness was also significant, $F(1,79) = 12.71$, $p = 0.001$, $\eta_p^2 = 0.14$. Bonferroni analyses indicated that the spelling scores of affix letters with overt phonology were significantly greater than with covert phonology in both frequent and non-frequent words ($ps = 0.000$). The effect size was greater in non-frequent words compared to frequent words ($\eta_p^2 = 0.64$ and $\eta_p^2 = 0.51$, respectively). Finally, the three way interaction was not significant, $F(3,79) = 2.34$, $p = 0.079$, $\eta_p^2 = 0.08$ (see **Table 4**).

Phono-Morpho-Orthographic Consistency

The main effects of word frequency and phono-morpho-orthographic consistency were significant [$F(1,79) = 37.57$, $p = 0.000$, $\eta_p^2 = 0.32$ and $F(1,79) = 43.15$, $p = 0.000$, $\eta_p^2 = 0.35$, respectively], indicating higher spelling scores of frequent words and letters consistently following a generalization. Furthermore, the main effect of grade was also significant, $F(3,79) = 33.79$, $p = 0.000$, $\eta_p^2 = 0.56$. Scheffe *post hoc* analysis indicated that the spelling scores increased with age and schooling. No significant differences were found in the spelling scores between the seventh and the tenth grade students ($p = 0.867$).

The two-way interactions of grade and word frequency, $F(3,79) = 4.03$, $p = 0.010$, $\eta_p^2 = 0.13$ and grade and phono-morpho-orthographic consistency, $F(3,79) = 2.96$, $p = 0.000$, $\eta_p^2 = 0.10$ were significant. The interaction of word frequency and phono-morpho-orthographic consistency was not significant, $F(1,79) = 0.82$, $p = 0.367$, $\eta_p^2 = 0.01$. Finally, the three-way interaction was significant $F(3,79) = 2.96$, $p = 0.037$, $\eta_p^2 = 0.10$. Bonferroni analyses indicated that the spelling scores of consistent affix letters were significantly greater than when the letter violated a generalization, in the second and fourth grades ($ps = 0.000$) but not in the seventh and tenth grade ($ps > 0.05$) (**Figure 2**). These results were found in both frequent and non-frequent words. The effect sizes were greater in non-frequent words compared to frequent words (Non-frequent words: $\eta_p^2 = 0.64$, $\eta_p^2 = 0.29$ for the second and fourth grades and $\eta_p^2 = 0.57$, $\eta_p^2 = 0.41$ for the frequent words) (see **Figures 3, 4**).

TABLE 3 | Means (and SD) of the success scores (%) of spelling function by word frequency, grade and phonological and morphological competition.

		No-competitors		Competitors	
Word frequency	**Grade**	**Mean**	**SD**	**Mean**	**SD**
Non-frequent words	Second	90.15%	2.64	62.71%	15.48
	Fourth	93.54%	4.39	78.94%	14.87
	Seventh	96.73%	2.59	91.56%	4.86
	Tenth	98.30%	1.21	96.84%	2.62
Frequent words	Second	92.58%	3.60	66.69%	16.28
	Fourth	95.68%	4.05	83.32%	13.91
	Seventh	98.08%	1.47	94.30%	3.21
	Tenth	98.64%	1.36	96.94%	2.01

TABLE 4 | Means (and SD) of the success scores (%) of spelling function by word frequency, grade and covert phonology.

		Covert		Overt	
Word frequency	**Grade**	**Mean**	**SD**	**Mean**	**SD**
Non-frequent words	Second	23.67%	16.85	82.76%	8.06
	Fourth	57.07%	20.66	88.33%	7.68
	Seventh	79.37%	11.80	95.17%	3.20
	Tenth	86.93%	10.57	99.08%	1.09
Frequent words	Second	42.51%	27.56	85.43%	7.83
	Fourth	70.71%	24.62	91.87%	6.45
	Seventh	85.19%	12.34	97.18%	2.12
	Tenth	88.24%	12.71	99.17%	0.45

Spelling Performance Across Morpho-Orthographic Criteria, Age and Frequency

The discrepancy between the binary values of each measure represents to what extent it results in higher success scores on spelling homophonous affix letters. In order to examine the differences in the discrepancy between the binary values of each morpho-orthographic principle of homophonous affix spelling

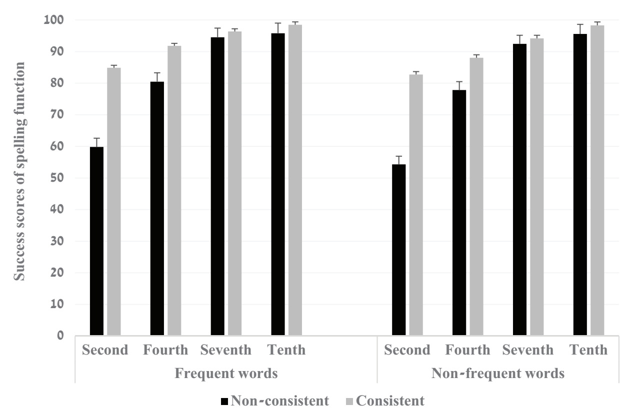

FIGURE 2 | The success scores (%) of spelling function by word frequency, grade and orthographic consistency.

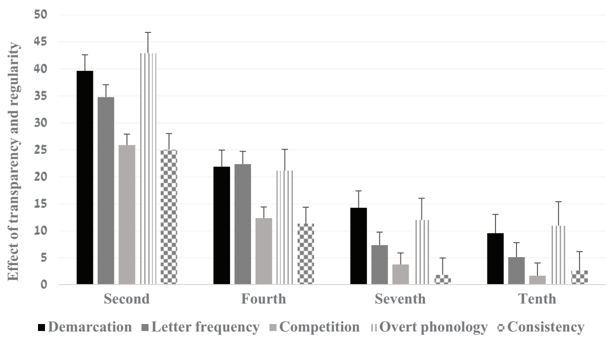

FIGURE 3 | The effect of transparency and regularity by word frequency, grade and morphological categories in frequent words.

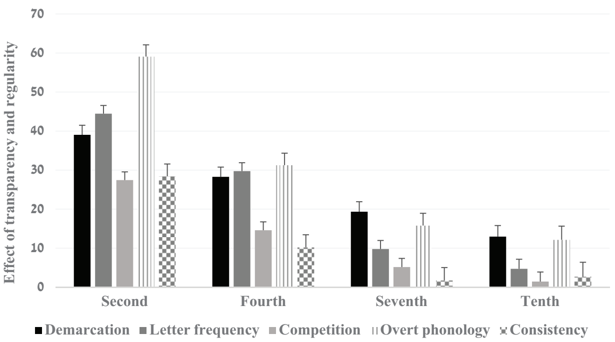

FIGURE 4 | The effect of transparency and regularity by word frequency, grade and morphological categories in non-frequent words.

by word frequency, grade and the five morphological categories, three-way (4 × 2 × 5) repeated measures analyses of variance (ANOVA) were conducted. The between-subject variable was grade; word frequency and affix regularity, transparency and consistency (RTC), as expressed by the five criteria, were the within-subject variables. The dependent variable was the level of discrepancy between the binary values that indicated the effects of affix RTC as expressed by the five criteria.

The main effect of word frequency was significant, $F(1,79) = 20.99$, $p = 0.000$, $\eta_p^2 = 0.21$, indicating a stronger effect of affix RTC in non-frequent words. The main effects of affix RTC was significant, $F(4,76) = 23.47$, $p = 0.000$, $\eta_p^2 = 0.55$. Bonferroni analysis indicated that transparent affix envelope, affix letter prevalence and overt phonology were more diagnostic than morpho-phonological competition and phono-morpho-orthographic consistency ($ps = 0.000$). Furthermore, the main effect of grade was also significant, $F(3,79) = 55.09$, $p = 0.000$, $\eta_p^2 = 0.68$. Scheffe *post hoc* analysis indicated that the spelling scores increased with age and schooling. No significant differences were found in the spelling scores between the seventh and the tenth grade students ($p = 0.867$).

The two-way interactions of grade and affix RTC $F(12,201) = 4.10$, $p = 0.000$, $\eta_p^2 = 0.17$ and word frequency and affix RTC, $F(4,76) = 6.09$, $p = 0.000$, $\eta_p^2 = 0.24$ were significant. The interaction of grade and word frequency was not significant, $F(3,79) = 2.23$, $p = 0.092$, $\eta_p^2 = 0.08$. Finally, the three-way interaction was significant $F(12,201) = 3.97$, $p = 0.000$, $\eta_p^2 = 0.17$. Bonferroni analyses indicated that transparent affix envelope, affix letter prevalence and overt phonology were more diagnostic than morpho-phonological competition and phono-morpho-orthographic consistency among the second and the fourth grades students ($ps < 0.05$). No significant differences were found between the morpho-phonological competition and phono-morpho-orthographic consistency criteria ($ps = 0.99$). In the seventh and in the tenth grades, affix envelope transparency was more diagnostic than competition. No significant differences were found between affix letter prevalence, phonological overtness and phono-morpho-orthographic consistency ($ps > 0.05$).

DISCUSSION

Selecting among the alternative spellings of a phoneme can be a challenge for spellers. Learning to spell in any alphabetical writing system requires understanding how the written language represents the spoken language. In alphabetical systems, spellers rely heavily on the phonological rules that designate letter-sound correspondences (Sprenger-Charolles et al., 1998). However, when spelling irregular words, using phoneme-grapheme correspondences does not necessarily yield proper spellings, thus the alphabetic strategy is eventually supplemented by knowledge of the morphological regularities of the orthography. The current study joins recent research in languages from different typologies, suggesting that in learning to spell, children come to exploit grammatical regularities in their language, matching them with large-sized processing units in spelling (Taha and Saiegh-Haddad, 2017; Bar-On and Kuperman, 2019; Breadmore and Deacon, 2019). Taken together, these studies show that both phonological and morphological skills have a reciprocal relationship with spelling development, indicating the need to set aside the classical dual-route approach in favor of an integration of several linguistic dimensions with sensitivity to distributional morpho-orthographic patterns (Casalis, 2018).

Hebrew, like other languages with alphabetic writing systems, does not have a perfect one-to-one phoneme-to-letter relation, nor is it the only language to represent morphology in its orthographic patterns. In fact, orthographies most often ignore phonological differences to express the coarser-grained, semantically grounded generalizations of the morphological system (Berg and Aronoff, 2017). For example, the English adjective suffix *-ic* has three different pronunciations in *electric, electricity*, and *electrician* – *k* in the adjective, *s* in the nominal derived from the adjective preceding the abstract suffix *–ity*, and *š* in the agent noun derived from the adjective preceding the agent suffix *–ian*. All three phonological variations are spelled uniformly by the letter sequence -IC, signifying the adjective suffix. This is not an isolated occurrence: *-ic* adjectives such as *pacific, tactic, basic;* derived- *icity* nominals such as *complicity, felicity, authenticity,* and derived- *ician* agent nouns such as *phonetician, politician, technician* – all reinforcing the consistent relationship between the spelling and pronunciation of the –*ic* suffix in these three morphological classes (Ravid, 2012). Learning the spelling of such morphological families will benefit from the interaction of grammatical meaning, phonological allomorphy, and orthographic consistency (Sandra, 2018). In fact, morphological knowledge has been shown to play a key role in adults' spelling abilities. Perry et al. (2002) showed that English-speaking adults take into account morphological chunks in assessing "wordlikeness" in spelling judgments: they pointed at morphologically complex non-words as being most wordlike, and did not merely adhere to smaller units guided by phonological considerations. Thus, morphologically motivated orthographic representations can be assumed to exist in the linguistic cognition of mature spellers, and they can serve to facilitate spelling in cases of disrupted phoneme-to-grapheme mapping (Gillis and Ravid, 2006).

The current study traced the developmental route of homophonous affix letter spelling in Hebrew, as reflecting the changing roles of five morpho-orthographic principles – morpho-orthographic transparency, affix letter prevalence, morpho-phonological competition, overtness of the phonological-orthographic link, and phono-morpho-orthographic consistency. Specifically, the present study aimed to investigate whether and when Hebrew-speaking school-going children and adolescents apply these morpho-orthsographic principles in learning to spell, suggesting that they are sensitive to morphology and not just phonology.

Within the affix spelling system, there can be a wide range of structural complexity, from the use of fixed affix sequences or chains to more complex and variable probabilistic patterns that are less predictable. In the current paper we examined children's grasp of the difference between high and low "morpho-orthographic complexity" of affix letter spelling, as presented in Schiff and Levie (2017). To this end, this study developed a metric to quantify the complexity of different categories of affix spellings, assessing this complexity along two dimensions: (i) word frequency and (ii) affix regularity, transparency and consistency (RTC), as expressed by the five criteria.

The overall picture that emerged from the results is as predicted, indicating a long and protracted learning trajectory of affix letter spelling in Hebrew. Two findings in this study indicate that spelling of affix letters in Hebrew evolves with age: first, the increased accuracy across all affix letters in the spelling task; and second, the changing roles of the five criteria making up the RTC metric. All affixes showed a learning curve that was not over in 7th grade, and in some cases, showed that spelling acquisition of homophonous affix letters was still under way even in high school. These results do not present the same picture as in Ravid (2001); Ravid and Bar-On (2005), and Gillis and Ravid (2006), where homophonous affix letters appeared to be learned in the early years of elementary school. This discrepancy is explained by the two innovations of this study. First, unlike all previous studies on the morphology of Hebrew spelling, this study did not compare root with affix letters, where affix homophones are in general easier to acquire than root homophones; rather, the current study focused on the acquisition of affix letters alone, which allowed us to probe deeper into all factors underlying their learning. And second, the previous studies on homophonous affix letters mainly sampled those with typical behavior – consonantal letters with high morphological prevalence and consistent behavior, in words with demarcated envelopes. These indeed demonstrated very early acquisition in the current study as well. In contrast, the present study examined the full array of Hebrew affix letters, both consonantal and with vowel values, with all of their functions, revealing the differing roles of the five spelling principles in overcoming RTC challenges across the school years.

An important finding in this study is that the higher the complexity and irregularity in spelling, the higher the differences between the lower and higher grade participants. The differentiated reliance on spelling principles across the grade levels in this study demonstrates this effect. We found that 2nd and 4th graders heavily relied on the principle of phono-morpho-orthographic consistency, that is, adhered to the strong generalization of ה marking the end of words with final *a*. This knowledge, already present in kindergarteners (Levin et al., 2001), reflects the high frequency of feminine *a* represented by ה in Hebrew (Ravid and Haimowitz, 2006). However, to achieve correct spelling of all final open syllables, spellers need to note that words of masculine gender ending with *a* violate this generalization, as they are not spelled with a final ה. For example, *katávta* "you, masculine, wrote" is correctly spelled as כתבת, while many 4th graders still spell it erroneously with a final ה as כתבתה. Thus, in 4th grade, young spellers are still challenged by the specific environments where the final ה generalization does not apply. Acquiring this knowledge, at the interface of grammatical gender marking, guttural/pharyngeal phonological segments, and specific orthographic, requires further morphological learning and more experience with written Hebrew.

While already able to overcome the tendency to adhere to morpho-orthographic consistency, 7th graders were still challenged in the current study by two factors – morpho-phonological competition and letter prevalence, as indicated by their spelling patterns. These results reflect ongoing learning of increasingly specific grammatical environments requiring increasingly honed phonological discernment and the ability to relate the autonomous domains of speech and writing (Karmiloff-Smith, 1994; Ravid, 2019b). In the case of morpho-phonological competition, 7th graders need, for example, to spell out the subtle phonological difference between past and future verb prefixes (*h* vs. *y*), which translates to different spellings (ה vs. י), both competing in the same morpho-phonological arena. In the case of letter prevalence, 7th graders need to recruit information about rare spelling/affix matchings, for example final *v* marking plural possessives by ו (*ban-av* "his sons"). While Hebrew-speaking 7th graders have already gained command of a great deal of Hebrew morphology and its written correlates, this study shows that learning of lexically specific, literate, rarer affixes is still under way.

The most challenging affixes in the current study, which did not gain complete mastery even in 10th graders (2 years away from high school graduation) are those in violation of the principles of transparent envelope and overt phonology.

These are two extreme cases which fundamentally undermine the phonology-morphology-orthography link that enables the correct spelling of affixes. In the case of non-transparent affix envelopes, the demarcation of the root core from the affix margins is opaque, so that all homophones are treated as having two spelling options. For example, in cases of morphological metathesis such as *histader* "get arranged," the root *s* exchanges place with the affixal *t,* so that it is not clear whether the *t* is affixal (and thus has only one possible spelling as ת), or a root letter (and thus has two possible spellings as ת or ט). In the case of covert phonology, letters are not linked up with phonological segments, e.g., *-av* spelled with י (normally reflecting the vowel *i*). These extreme violations of affix spelling patterns, which require specialized knowledge of rare morpho-phonological constructions, still challenge 10th graders. This is in line with evidence from non-Semitic studies. For instance, a study conducted among French-speaking first, second and third graders on the acquisition of silent-letter endings (Sénéchal et al., 2016) confirmed that children have difficulty using silent-letter endings when spelling pseudowords, as the absence of phonological cues makes it harder to retrieve the silent forms from memory. The present results suggest that the tendency to use a familiar orthographic form often wins out in spelling production, even in skilled spellers (Treiman et al., 2015).

The results of this study are also in line with previous studies that suggested that frequency is a major factor influencing any inquiry into linguistic skills (Ambridge et al., 2015), including both reading (Weekes et al., 2006) and spelling (Alegria and Mousty, 1996; Lété et al., 2008) development. The study described here indicates that frequency plays a major role in the development of affix spelling as children's spelling accuracy becomes gradually higher as they progress in age. Our results indicate that in lower grades, frequency is essential to spelling accuracy, but with increased age and spelling experience, performance on non-frequent words improves compared to that of frequent words. Moreover, the difference between the spelling accuracy of words with differing RTC affixation decreased as age and frequency increased. Our interpretation is that older participants have acquired the lexical representations of words with less regular, transparent and consistent affix patterns, and thus were not disadvantaged in spelling these words compared to words with regular affix letters.

The results of this study thus suggest that the typological characteristics of the language and its alphabetic writing system contribute to spellers' sensitivity to morphology when determining which spelling alternative is correct (Gillis and Ravid, 2006). Similar to our Hebrew-speaking participants, English-speaking and French-speaking children also demonstrated implicit learning of the morphological patterns in their orthography (Treiman et al., 1993; Treiman and Cassar, 1997; Pacton et al., 2001, 2002).

Theoretical and Applied Implications

One contribution of this study is toward the resolution of the debate regarding the dual/singular model in explaining the results of this spelling study (Holmes and Babauta, 2005). According to our interpretation of the data, the dual-route model may not explain the acquisition of Hebrew affix spelling. While it has been useful in explaining the differences in performance between dichotomous regular and irregular cases in the acquisition of a given linguistic structure, spelling of affix letters in Hebrew goes beyond the regular-irregular dichotomy to include complex features of grammar, phonology, and orthography. The evidence from the present study suggests that children may share a common learning mechanism for spelling complex words. Our analysis demonstrated the impact on spelling performance of all factors - the demarcation of the affix envelope, the prevalence of affix letters in various morphological roles, morpho-phonological competition among morphologically similar affixes, the overtness of the phonological-orthographic link, and the consistency of the phono-morpho-orthographic link. Examining their differential contributions helped us provide a more nuanced account of the development of affix spelling, one that determines to a large extent the sequence and pace at which affix spelling categories are acquired.

The items in our spelling test were all real words, and thus additional work is needed to determine whether morpho-orthographic principles of affix spelling also influence the spelling of non-words. For example, is it more difficult to spell a non-word with a phonologically covert or non-demarcated affix envelope? Another issue for future research concerns the examination of affix spelling acquisition in reading impaired populations, with the ultimate goal of using specific morpho-orthographic principles of affix spelling in diagnosis and remedial instruction.

Although questions remain, our results shed light on the specific characteristics of affix spelling that influence spellers' choices when more than one option is available. First, Hebrew-speaking children do not acquire accurate spelling of all Hebrew words and structures at the same rate. This goes beyond previous studies, which focused on the difference between homophonous root and affix spelling (Ravid, 2001, 2005): now we know that affixes differ among themselves in the challenges they pose to spellers, and we have been able to capture these differences both theoretically and empirically. Secondly, we have shown that spellers in this study became less sensitive to frequency distributions as they become older. This indicates that Hebrew affix spelling is indeed morpho-lexical in nature: with age and schooling, older children and adolescents expand their mental lexicons to include less frequent items, more abstract and lexically specific words, and more morphologically complex words with more and different affixes. Thirdly, we have seen that our participants relied on different phonological, morphological and orthographic knowledge at different stages of their affix spelling development. This means that the consolidation of a qualitative knowledge base of affix spelling is part of the period of Later Language Development (the school years), and is tightly linked to the development of mature and coherent links between phonology, lexicon, and grammar. Finally, acquisition of correct affix spelling of a word clearly depended on the complexity of the spelling pattern being acquired in terms of the metrics that we first introduced in this novel study.

Taken together, the accumulated evidence suggests that even though phonology is a major factor in spelling acquisition

(Bosman and Van Orden, 1997), and sound-to-symbol mapping represents a vital self-instruction process for processing new words (Ehri, 1992; Share, 1999), young children also have to rely on morphological knowledge, if they are to select between different spellings (Angelelli et al., 2014; Treiman, 2017) of a word. These characteristics of affix spelling may not necessarily be exclusive to Hebrew and could be relevant to a wide array of languages and their orthographies.

Moreover, applied implications can be gained from this study for our understanding of how Hebrew morphology is learned and in particular, how the developmental path of learning to spell involves complex morphological structures. As the Hebrew lexicon and grammar are strongly organized by morphological principles (Schiff and Raveh, 2007; Ravid, 2012; Schiff et al., 2016; Ashkenazi et al., 2019), these findings have clear clinical and educational ramifications. First and foremost, these results strongly suggest that rigorous morphological instruction is necessary in teaching children and adolescents to identify and use morphological cues in spoken and written Hebrew. Even more importantly, we now have a solid knowledge base regarding the acquisition route of all classes of affixes classified in phonological, morphological and lexical categories. This body of knowledge can be used to inform teachers of emphases in their spelling instruction and to enable clinicians to focus on specific categories in response to children's persistent error patterns. In sum, the well-motivated, detailed, empirically endorsed information this study provides can thus be of immense value to educators, remedial teachers, educational psychologists, and speech-language pathologists.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ministry of Education (Israel) and the Bar Ilan Ethics Committee. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

SR is an MA student whose Master's thesis was jointly directed by RS and DR. Data was collected by SR. RS and DR wrote the manuscript together.

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The Impact of Orthography on Text Production in Three Languages: Catalan, English, and Spanish

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Learning to write effectively is key for learning and participation in social communities. In English, transcription skills (handwriting and spelling) constrain written production at the early stages of learning to write. The effect of transcription diminishes with age, when reading skills enhance text production. Less is known about how transcription and reading interact with writing in other languages. In this study, we explore the relationships between spelling, reading and the length and quality of written text produced by primary school children speaking three different languages: Catalan, English, and Spanish. These languages are good test cases for models of writing development as they contrast orthographically and morphologically. Participants produced a written narrative text and completed standardized assessments of handwriting, spelling, reading decoding, and reading comprehension. Language had a significant effect on text production measures: young Spanish children produced longer texts which were of higher quality than the other two cohorts. They also produced the lowest number of spelling errors both at the root and for affixed morphemes. By contrast, the English children produced the highest number of both types of errors. The Catalan children did not differ significantly from their English peers for root level spelling but produced significantly fewer spelling errors at the affixed morpheme level. To test how transcription and reading skills impact on text production skills, we conducted regression analysis for each language. Different patterns of relationships between transcription, reading and text production emerged. In Catalan only handwriting fluency accounted for significant variance in text productivity and quality. By contrast, for the English children significant variance in productivity was accounted for by reading and handwriting fluency and for text quality by handwriting fluency and spelling. For the Spanish children reading skills were the significant factor for text quality. No other models were significant. Implications for developmental models of writing development are discussed.

Keywords: spelling, reading, writing system, text production, cross linguistic comparison

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INTRODUCTION

Learning to write effectively and efficiently is a foundational skill for both learning at school and gaining employment in the workplace. To date models of writing development have been primarily developed from studies of children learning to write in English (Juel, 1988; Berninger et al., 2002; Berninger and Winn, 2006). In this study, we explore the relationships between spelling, reading, and written text production in children in primary schools speaking three different languages: Catalan, English, and Spanish. Our focus is on the differential performance in spelling between orthographies and, how these skills underpin written text productivity and quality across the elementary school years.

Orthographies place different demands on children's language and literacy skills. Significant advances have been made in our understanding of the processes that underpin reading decoding and single word spelling by comparing performance across orthographies (see for example, Moll et al., 2014; Landerl et al., 2019), but much less is known about the ways in which the interplay between orthographic differences and language typologies influence writing performance and writing development. To capture differences comparisons of children writing in different orthographies using similar measures with comparable analytic approaches are needed. We address this gap in the current literature by examining pupil performance with the same measures within the same study design across three languages, which vary in orthographic consistency and morphological complexity. To our knowledge this is the first study to compare spelling and written products across three languages.

Producing Written Text

Producing a piece of written text requires the writer to generate ideas and represent these in a symbolic form. The "simple view of writing" (Berninger et al., 1992; Berninger and Amtmann, 2003) and, later, the "not-so-simple view of writing" (Berninger and Winn, 2006) have conceptualized the multiple components of the writing system. The model synthesizes diverse trends in compositional research whereby transcription skills (handwriting or typing and spelling) and executive functions enable text generation at word sentence and text level. More recently the role of more distal factors such as oral language and reading have been incorporated into these models (see for example, Kim and Park, 2019). There is increasing evidence that two key dimensions of the writing product capture writing development in elementary school children: productivity and text quality (see for example, Berninger and Swanson, 1994; Graham et al., 1997; Olinghouse and Graham, 2009).

For novice writers, especially in English, spelling skills are thought to limit the efficiency of translation (see Kent and Wanzek, 2016, for a recent meta analysis). In English spelling requires a substantial allocation of memory resources and executive control for young writers and a lack of fluency in spelling directly constrains productivity and the quality of written texts (Graham et al., 1997; Moll et al., 2014). The demands of single word spelling, effectively, limit the cognitive resources available for the linguistic generation of the text, and thereby reduce the potential impact of other skills on the quality of early written compositions. However, children who learn to write in languages other than English may encounter different difficulties in producing written texts. For example, languages such as Italian, Turkish, and Greek have more shallow orthographies than English, but a more complex inflectional morphology (Nikolopoulos et al., 2006; Babayigit and Stainthorp, 2011; Arfe et al., 2016). For transparent orthographies the regularity of the orthography reduces the demands in generating written texts at the single word level, that is spelling, however, the complexity of the morphology of the language increases the demand on text generation (Berman, 2014; Reilly et al., 2014; Arfe et al., 2016).

While beginning writing is underpinned by spelling skills, in English reading also influences written text production. Word reading skills are associated with spelling skills (Abbott and Berninger, 1993) and word recognition skills consistently predict spelling skills at all elementary year grades (Abbott et al., 2010). Improvement in word reading leads to an improvement in spelling (Ahmed et al., 2014). Additionally, reading decoding is a good predictor of orthography consistent rule learning as reading decoding supports orthographic knowledge in spelling development (Caravolas et al., 2012). There is thus consistent evidence that single word decoding supports single word spelling. By corollary, poor reading comprehension impacts on text level writing, where pupils with lower reading comprehension, but age appropriate spelling ability, produce texts which are less sophisticated and more limited in comparison to their age matched peers (Cragg and Nation, 2006). Recent findings suggests that reading-to-writing models, that is reading supports writing, are superior, especially for the word and text levels of writing in elementary school (Ahmed et al., 2014). Yet only moderate associations between writing and measures of reading are reported for writers in English (Kent and Wanzek, 2016), perhaps reflecting the nature of the orthography. Reading skills are likely to become more important once basic spelling skills are mastered and in languages where spelling causes fewer challenges for children.

The Impact of Orthography on Learning to Write

While there are a few exceptions, studies typically focus on spelling and written text production in English, a deep orthography where learning to spell can be challenging (but see Caravolas, 2004; Caravolas et al., 2012). Indeed, English has been described as an "outlier orthography" in terms of the inconsistency of its phoneme to grapheme correspondences and regarded as the least consistent of any alphabetic orthography (Ziegler et al., 1997). By contrast single word reading and single word spelling skills are learned more quickly in more consistent orthographies (Landerl et al., 1997). Studies of reading acquisition commonly demonstrate that rates differ between children learning opaque and transparent orthographies. In English, the rate of development is twice as slow for reading as in more shallow orthographies (Seymour et al., 2003). Similarly, Wimmer and Landerl (1997) observed faster single word spelling development rates in German, considered a more transparent orthography than English. In a recent comparison of the spelling accuracy of English and Italian speaking pupils in grades 2–5, Marinelli et al. (2015) demonstrated both faster rates of spelling development in Italian and more persistent cross-linguistic gaps in spelling than in reading accuracy, suggesting that spelling accuracy, but not reading accuracy, is moderated by orthographic consistency. Furthermore, the inconsistency of orthographies is usually stronger from phoneme to grapheme than from grapheme to phoneme; making spelling a particularly challenging skill to master in inconsistent orthographies (see Ziegler et al., 1996, 1997). However, these studies have not considered the relationships between orthography and written text production. In this study, we examine the extent to which the orthographies of three languages (Catalan, English, and Spanish) that contrast in their orthographic consistency underpin spelling development and written text production.

LANGUAGE TYPOLOGIES

Spanish, Catalan, and English reflect the continuum of orthographies where Spanish, a highly transparent orthography has consistent relationships from phoneme to grapheme and grapheme to phoneme (nearly 100% of the letters have one phoneme only and nearly 90% of phonemes are represented by only one grapheme). By contrast, English is characterized by a high level of inconsistency in both reading and spelling (only 72% of the letters have a single phoneme and 62% of the phonemes can be represented by only one grapheme). Catalan contrasts with both Spanish and English. It is neither as transparent as the Spanish orthography nor as opaque as the English orthography [where 76% of the letters represent only one phoneme 70% of the phonemes can be represented by only one grapheme (ERN-LWE) COST-Action IS0703 Spelling Report; Caravolas et al., 2012]. The Catalan and Spanish orthographic systems also differ from English in their use of a graphic accent to mark the stressed syllable in a number of words. In Catalan the phonological content of the vowel requires different graphic marks, in cases where one vowel represents more than one phoneme. In addition to drawing on phoneme grapheme conversion processes spelling in Catalan and Spanish requires knowledge and use of the prosody of the word. The conventional use of the accent system is usually acquired after children have mastered the phoneme to letter correspondences (Defior et al., 2009).

The three languages examined in this study also contrast in their morphological systems. English, a Germanic language, has a sparse morphology, particularly at the inflectional level whereas Catalan and Spanish, both Romance languages, have rich morphologies. English typically uses three to four morphemes to encode person, tense and aspect. For instance, the s morpheme of the present tense suffices to differentiate the third singular person. In Spanish and Catalan up to 47 different morphemes are used to inflect determinants, nouns and adjectives for number and gender, and verbs for aspect, mode, tense, person, and number, in contrast with the previous example for English, both Spanish and Catalan use 18 different suffixes to mark each person of the present tense paradigm (Alarcos, 2007). The accurate use of these morphological markers underpins text quality.

Morphological information is particularly important in the spelling of low frequency words (Defior et al., 2008), a potential indicator of higher quality texts (Olinghouse and Graham, 2009). At least with alphabetic orthographies, the use of morphological cues in children's spelling would appear to differ depending on the interplay between the characteristics of the orthographic system and the morphological structure of the language. Ravid and Gillis (2006) showed that young children speaking Hebrew, a language with a highly synthetic morphology, used morphological cues to a greater extent than children of the same age who speak Dutch, a language with a much sparser morphology. A similar effect of a salient morphology was shown for children learning to spell in Spanish (Defior et al., 2009) and Catalan (Llaurado and Tolchinsky, 2016). These studies used a single word spelling task, so whether children use morphological cues to support their text based spelling and improve text quality needs elucidation.

These differences between the three languages studied are predicted to affect both the children's spelling and also their written texts. As has been demonstrated previously we predicted that the Spanish transparent orthography will lead to few (if any spelling errors) whereas for Catalan and English spelling will be compromised in the early stages of learning to write. However, we anticipated that the more prominent morphology of Catalan would reduce the presence of affixed morpheme based errors in this language relative to English. The previously under researched role of accents is predicted to affect the children's spelling and writing in different ways. In both Catalan and Spanish we expected missing accents to be an important cause source of spelling error. Moreover we anticipated that this will have a greater influence on the spelling of children in Catalan because spelling words conventionally is more challenging in Catalan than in Spanish and in Catalan children must learn where to use an accent and which kind of accent they must use.

ASSESSING WRITTEN TEXT

The assessment of children's writing raises challenges both conceptually and methodologically (see Dockrell et al., 2019). Both holistic scoring and analytic scoring of writing products have been used to capture writing development (Abbott and Berninger, 1993; Scott and Windsor, 2000; Mackie and Dockrell, 2004; McMaster and Espin, 2007; Lee et al., 2010; Wagner et al., 2011; Puranik and AlOtaiba, 2012). Analytic scoring provides a more detailed and comprehensive scoring system. One approach distinguishes the macrostructure and the microstructure of the texts produced, capturing the two key dimensions identified of productivity and text quality (Berninger and Swanson, 1994; Graham et al., 1997; Olinghouse and Graham, 2009).

Analyses of texts at the macrostructure level typically focuses on the use of a bespoke holistic scoring scale (see for example, Koutsoftas and Gray, 2012) which captures quality. Productivity by contrast is typically a text level microstructure measure of length in either total number of words or sentences produced. Research has also considered microstructure in more detail including, for example, both the nature of students' spelling errors, lexical diversity or grammatical accuracy.

How differences in the writing systems influence the ways in which language and literacy underpin the development of the written product has begun to be explored within cohorts speaking different languages. In English, it is well established that spelling skills underpin both text productivity and text quality (Graham et al., 1997; Berninger et al., 2006; Kim et al., 2015). Different patterns have been observed in other languages. Babayigit and Stainthorp (2011) studying children writing in Turkish, a relatively transparent orthography, found that transcription skills and reading comprehension were related to text quality rather than productivity rates. Similarly, in Italian, another transparent orthography, the spelling skills of the Italian children explained text quality but not text productivity (Arfe et al., 2016). These differences between English and more transparent orthographies may reflect differences in developmental processes but may equally be explained by the use of different measures or different analytic techniques. To further our understanding of how the relationship between spelling skills and written text production relate, studies mapping equivalent processes, using comparable measures at similar developmental phases are needed.

There is clear evidence to suggest that there will be differences across the orthographies in children's spelling competence. However, the impact of these spelling differences on the written products and the nature of the errors produced is less clear. Spelling errors reflect particular aspects of the language that challenge children. Catalan, English, and Spanish are likely to pose different spelling challenges due to their orthographic differences. These differences can be captured by analyzing the types of written errors that are produced. A number of systems exist to capture the nature of children's spelling errors and these microstructure analyses should reflect the languages studied. Error analysis of children's spelling at phonological, orthographic, and morphological levels can highlight the differential impact of these processes on text production (Share, 2008; Critten et al., 2014). Moreover, morphological analysis of both base words and bound morphemes (see Nagy et al., 2006) provides detailed information about the developing writer's skills (Nunes et al., 1997). In sum, bound morphemes such as inflectional and derivational morphemes play an important role when constructing meaningful text and may represent and increased source of difficulty for text generation in languages with complex morphological systems.

THE CURRENT STUDY

To examine these questions, and as part of a larger study, three different age groups of Catalan, English, and Spanish children produced a narrative writing task and completed standardized assessments of handwriting, spelling, reading decoding, and reading comprehension. We predicted that the transparency of Spanish would result in few spelling errors, increased productivity and as a result higher quality texts. Given the children's spelling performance we anticipated a reduced impact of spelling on text productivity and text quality. However, given the role of reading on the written text of good spellers in transparent orthographies we anticipated that text quality would be predicted by the children's reading levels. For English children we anticipated that they would be least productive and produce the lowest quality texts, especially at the younger ages, given the challenges they face with spelling. As has been found in previous studies in English, we predicted that both spelling and handwriting would underpin written productivity and text quality. There have been few studies exploring Catalan but we anticipated that the children would produce more spelling errors that the Spanish children but significantly fewer than the English children, particularly with affixes given the more prominent morphology in the language. For children writing in Catalan we predicted writing productivity to be underpinned by spelling and handwriting skills but given the morphological complexity of the language that writing quality would be underpinned by transcription and reading.

METHODS

Participants

Two hundred and eighty-four elementary school pupils from England (n = 86), Catalonia (n = 113), and Spain (n = 85) participated in this study. Pupils attended year 2, 4, and 6 in three schools, one in each region, which were purposely selected to reflect the mainstream population. The English cohort attended a school in South East London. As Catalonia is a region with two official languages, Catalan and Spanish, the Catalan cohort was bilingual. Catalan is the only language of instruction in schools and it was the dominant language (spoken at home too) for a vast majority of the participants. The Spanish cohort attended a school in Ciudad Real, a Spanish monolingual region in Spain. All children in each year group participated in the study. No child was reported to have a hearing or visual impairment. For the English cohort, mean age in months was M = 87, SD = 3.96 (range 81–92) for the 31 children (15 boys) in Year 2, M = 111, SD = 5.63 (range 105–117) for the 27 children (11 boys) in Year 4, and M = 135, SD = 3.48 (range 129–140) for the 28 children (18 boys) in Year 6. For the Catalan cohort, mean age in months was M = 94, SD = 3.19 (range 88–99) for the 38 children (22 boys) in Year 2, M = 117, SD = 4.65 (range 113–123) for the 35 children (16 boys) in Year 4, and M = 140, SD = 3.88 (range 135–146) for the 40 children (22 boys) in Year 6. For the Spanish cohort, mean age in months was M = 92, SD = 3.34 (75–86) for the 26 children (13 boys) in Year 2, M = 116, SD = 2.97 (range 113–124) for the 29 children (16 boys) in Year 4, and M = 140, SD = 3.51 (range 135–146) for the 30 children (22 boys) in Year 6. The difference between the mean age of the Catalan and Spanish, and the English participants is explained by different school entry dates (England September to August, in Catalonia and Spain January to December) and age in months is controlled for in relevant analysis.

Measures

Children were assessed on a range of measures to examine their transcription and literacy skills. All children were assessed in their first language using measures appropriate for the population.

Measures of Transcription

Handwriting fluency

Children are asked to write as many alphabet letters as possible in 1 min (Wagner et al., 2011). Children are asked to write all the alphabet letters in order, using lower case letters. If children finish writing all letters before a minute, they are asked to continue to write starting with "a" again. This task assesses how well children access, retrieve, and write alphabet letter forms automatically. All teachers confirmed that the children in their classes knew how to write the alphabet.

Dictated spelling

English: British Abilities Scales II (BAS II); Spelling Scale: This scale provides a number of phonetically regular and irregular words to assess the child's ability to produce correct spellings. Each item is first presented in isolation, then within the context of a sentence, and finally in isolation. The child has to respond by writing the word and for this study 40 words were dictated to children in each year: reliability 0.91; validity with Wechsler Objective Reading Dimension (WORD) spelling 0.63.

Catalan: We used a bespoke task created by Tolchinsky (in press). Participants had to write down the words dictated by the experimenter. Each word was repeated twice before proceeding to the next one. Due to the lack of an updated Catalan word frequency dictionary the target words were selected from the Corpus Cesca; a corpus of written Catalan produced by school children (Llaurado et al., 2012) demonstrating the validity of the task. The selected words were from the same semantic field – food and the same grammatical category – nouns, and they were controlled for frequency and orthographic difficulty. Each participant had to spell a total of 40 words; four sets of words divided for frequency (high and low) and orthographic difficulty (high and low).

Spanish: The same task that was used in Catalan but adapted for Spanish (Llaurado and Tolchinsky, 2016).

Reading

Word level reading

English: Test of Word Reading Efficiency (TOWRE; Torgesen et al., 1999): This contains two subtests. The Sight Word Efficiency (SWE) subtest assesses the number of real printed words that can be accurately identified within 45 s, and the Phonetic Decoding Efficiency (PDE) subtest measures the number of pronounceable printed non-words that can be accurately decoded within 45 s.

Catalan: We adapted the PROLEC-R Lexical Processes, word and pseudoword reading for Spanish: reliability 0.79. This contains two subtests. The word reading subtest assesses the time that takes a child to accurately read a set of 40 real printed words, and the non-word reading subtest that measures the time it takes a child to accurately decode a list of 40 pronounceable printed non-words.

Spanish: We used the PROLEC-R Lexical Processes, word and pseudoword reading for Spanish: reliability 0.79. This contains two subtests. The word reading subtest assesses the time that takes a child to accurately read a set of 40 real printed words, and the nonword reading subtest that measures the time it takes a child to accurately decode a list of 40 pronounceable printed non-words.

Reading comprehension

English: The New Group Reading Test. This is a standardized assessment using a multiple-choice format to assess children's ability to complete sentences and comprehend written passages. It can be administered to groups. Reliability (Cronbach's alpha: 0.90) is high.

Catalan: ACL (Avaluació de la Comprensió Lectora). This test comprises a set of seven texts for each school year. For each text, children are requested to read it individually and then answer a set of multiple choice questions. Avaluació de la Comprensió Lectora has been extendedly used in studies on Catalan reading. It has a reliability of KR-20: 0.080–0.083. Its validity, assessed as the correlation between the results obtained by a child on ACL and the child's teacher assessment of his/her reading comprehension skills, is of 0.99.

Spanish: ACL (Evaluación de la comprensión lectora). This test comprises a set of seven texts for each school year. For each text, children are requested to read it individually and then answer a set of multiple choice questions. Avaluació de la Comprensió Lectora has been extendedly used in studies on Spanish reading. It has a reliability of KR-20: 0.078 to 0.083. Its validity, assessed as the correlation between the results obtained by a child on ACL and the child's teacher assessment of his/her reading comprehension skills, is of 0.97.

Writing Measures

All children were asked to produce a written response to the prompt "What is your ideal place for a holiday like and why." This task is based on the standardized assessment of writing in the Weschler Objective Language Dimensions test (WOLD; Weschler, 2005) and has been used in a number of studies.

Procedure

Pupils were assessed twice, as a class group for the writing measure and individually in schools for the transcription and literacy measures. The individual assessment lasted over 50 min. The writing prompt used in the analyses was presented to the class on the second session.

To ensure all pupils were familiar with the writing activity, they were provided with an opportunity to practice the writing task with a different narrative prompt a few days before the writing assessment. These data were not included in the analyses. On the writing assessment day, pupils were asked to produce a written response to the prompt "What is your ideal holiday place like and why." The task was not time limited, the researcher had a 50 min long class period to explain to the pupils the purpose of the task, hand out the necessary materials and deliver the task prompts. On average, pupils wrote for 20 min and no child requested extra time to finish his or her text once the time the session was over. For the three cohorts, language teachers were present in the classroom during the task. Ethical approval was secured from the authors institution (UCL-IOE for review). Informed consent from schools and parents was provided prior to any testing.

Transcription and Coding of Texts

Transcription of texts

A literal copy of all written outlines and texts was transcribed and entered in a standard format using the Systematic Analysis of Language Transcript conventions (SALT; Miller and Chapman, 2000). Systematic Analysis of Language Transcript conventions allows for the automatic coding of certain text features and for the creation of codes specifically created for the purpose of the study.

CODING OF WRITTEN TEXTS

All coding was done by the first author. Written texts were coded for productivity and their overall quality. Productivity was computed as the total number of words in each text, a measure that has been widely used as an indicator of compositional length (Deacon and Kirby, 2004; Kim et al., 2011). Words used in the title, when there was one were included in the total. When a child made a word segmentation mistake, we counted the number of intended words. Any deleted or crossed over words were not included in the final total. Quality was scored using a holistically scale derived from the WOLD. We present this scale in **Box 1**.

CODING OF THE SPELLING ERRORS

Word Level Spelling Errors

We calculated the number of words that were misspelt, for instance, “amagin” [amazing] was coded as one misspelt word, and divided it by the total number of words written. If the text contained words written in a language other than English, Catalan, or Spanish, respectively, we did not include these words in the final count of either the total number of misspelled words or total number of written words. This provided a score reflecting the proportion of words spelled incorrectly.

Number of Spelling Errors

It was possible for words to contain several spelling errors. Thus the total number of spelling errors were computed, for instance “amagin” [amazing] was coded for two misspellings: A wrong letter “ama**g**in” and a missing letter “amagin[**g**],” and divided it by the total number of words (excluding those not written in the target language). This resulted in a measure of spelling errors that could be classified by type into three different error types:

Spelling Errors at the Root Level

We calculated the number of spelling errors in each word at the root level and divided the total number of these spelling errors by the total number of words in the text (excluding the words written in a language that was not the target language).

Spelling Errors at the Affix Level

We calculated the number of spelling errors in each morphologically complex word at the affixed morphemes and divided the total number of these by the total number of affixed words in the text (excluding the words written in a language that was not the target language).

Misspellings Due to Absence of an Accent Mark

We calculated the number of misspelling due to a missing accent mark and divided it by the total number of words that require and accent according to the orthographic norm.

BOX 1 | Rubric used for coding the quality of the written texts.

0: Unintelligible text or too few words to judge the content of the text or text which was irrelevant to the target prompt.
1: Response which included a list of elements or characteristics but did not indicate why this reflected “why or how this should make an ideal place for a holiday”.
2: Included information and indicated why or how this relates to an ideal holiday place. Could either be an extensive list with no elaboration or single element or characteristic with some descriptive details about that element or characteristic.
3: Ideas (elements or characteristics) are related to each other or to the main idea provides additional descriptive information or detail.
4: Generally well written engaging the reader with ideas clearly related to each other with the addition of clarifying descriptive detail.
5: Presents a substantial amount of description and varied detail of the topic. The ideas and details are clarified with several descriptions or thorough elaboration.
6: Well written and presents clear, organized and developed descriptions of the topic. The ideas and details are clarified and related through the use of effective transitions, resulting in an overall sense of the subject. Effectiveness is enhanced through the use of vivid imagery.

RESULTS

A series of factorial ANOVAs were used to compare the main effects of language and year group and any interaction effect between the two on the writing measures. When interaction effects were significant subsequent ANOVAs were computed. Age was included as a covariate given the differences between countries in the start date of the school year. Zero order correlations explored the relationships between spelling, handwriting, reading, text productivity, and text quality. For each language we examined whether age, transcription skills (handwriting or spelling), or reading predicted productivity, accuracy, and quality of writing using linear regression.

Text Productivity

Figure 1 presents mean (SDs) of text productivity by year group and language cohort. The number of words in the written text varied significantly by language [$F(2,284) = 12.036$, $p < 0.001$, $p\eta^2 = 0.080$] but not with school year [$F(2,284) = 1.456$, $p = 0.235$, $p\eta^2 = 0.011$]. The interaction between school year and language was significant [$F(4,284) = 5.676$, $p < 0.001$, $p\eta^2 = 0.077$]. Comparisons by language in separate analyses revealed that, in Year 2, the Spanish cohort was significantly more productive [$F(2,94) = 6.468$, $p = 0.002$, $p\eta^2 = 0.12$] than their English peers ($p = 0.001$), but not more than the Catalan children ($p = 0.158$). The Catalan and English cohorts did not differ at this point ($p = 0.178$). No differences by language cohort were evident in Year 4 [$F(2,89) = 2.484$, $p = 0.089$, $p\eta^2 = 0.05$]. In Year 6, language had a significant effect [$F(2,98) = 14.323$, $p < 0.001$, $p\eta^2 = 0.23$] and the Catalan pupils were significantly more productive than both English ($p = 0.001$) and Spanish ($p = 0.003$) pupils, but these two did not differ significantly ($p = 0.244$). For each language, performance across year groups was examined. In English

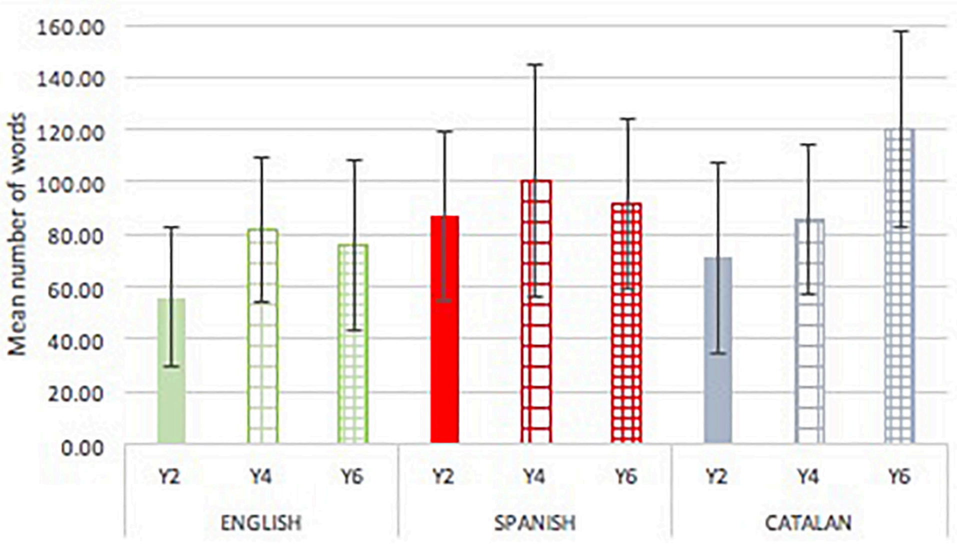

FIGURE 1 | Mean (SD) text productivity (number of words) by language and school grade.

[$F(2,86) = 6.449$, $p = 0.002$, $p\eta^2 = 0.134$], students in Year 2 produced significantly fewer words than students in Year 4 in English ($p = 0.003$), and in Catalan [$F(2,113) = 20.381$, $p < 0.001$, $p\eta^2 = 0.27$] students in Year 4 produced significantly fewer words than in Year 6 ($p < 0.001$). In Spanish [$F(2,85) = 0.928$, $p = 0.400$, $p\eta^2 = 0.022$], there were no significant changes by year group.

Text Quality

Figure 2 presents mean (SDs) of text quality by year group and language cohort. The quality of texts varied by language [$F(2,284) = 38.828$, $p < 0.001$, $p\eta^2 = 0.188$] with a much larger language effect for text quality than for productivity, and increased with school year [$F(2,284) = 100.449$, $p < 0.001$, $p\eta^2 = 0.044$]. The school year by language interaction was also significant [$F(4,284) = 4.557$, $p = 0.001$, $p\eta^2 = 0.062$]. Comparisons between languages in separate analysis showed that children writing in Spanish produced significantly better quality texts that both their English and Catalan peers in Year 2 [$F(2,94) = 32.357$, $p < 0.001$, $p\eta^2 = 0.42$], and Year 4 [$F(2,92) = 14.274$, $p < 0.001$, $p\eta^2 = 0.24$] ($p < 0.001$ for all post-hoc contrast) but not in Year 6 [$F(2,95) = 1.526$, $p = 0.223$, $p\eta^2 = 0.03$]. The differences between the English and Catalan children were not significant at any point. Children obtained higher scores for quality by year group in all the languages. For each language, performance across year groups was examined. Results revealed that, in Catalan [$F(2,113) = 67.565$, $p < 0.001$, $p\eta^2 = 0.551$], English [$F(2,86) = 30.410$, $p < 0.001$, $p\eta^2 = 0.423$] and Spanish [$F(2,85) = 19.000$, $p < 0.001$, $p\eta^2 = 0.317$], children in Year 4 produced significantly better texts than children in Year 2 ($p < 0.001$, for all post-hoc contrasts). The contrast between Years 4 and 6 was significant in English ($p = 0.034$) and Catalan ($p < 0.001$) but not for Spanish ($p = 1.000$).

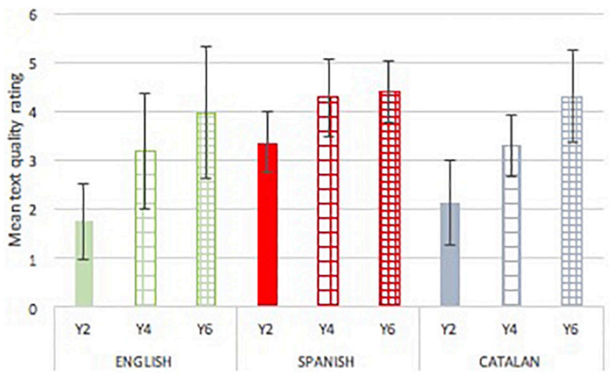

FIGURE 2 | Mean (SD) text quality by language and school grade.

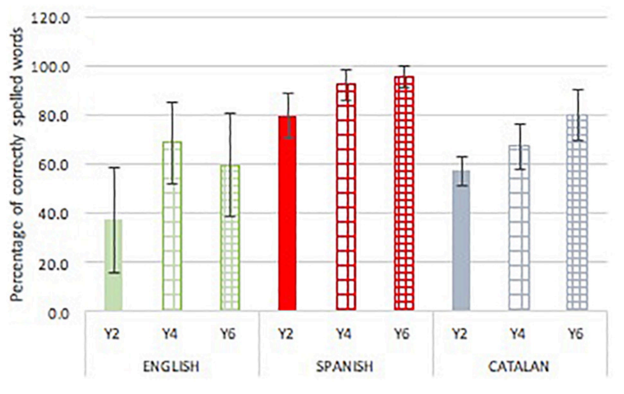

FIGURE 3 | Mean (SD) percentage of correctly spelled words by language and school grade.

Spelling Performance in Dictation

Both language [$F(2,284) = 153.249$, $p < 0.001$, $p\eta^2 = 0.54$] and school year [$F(2,284) = 69.409$, $p < 0.001$, $p\eta^2 = 0.34$] had a significant effect on performance on the single word dictation task (see **Figure 3**). The school year by language interaction was also significant [$F(4,284) = 8.252$, $p = 0.001$, $p\eta^2 = 0.11$]. Contrasts by language in separate analysis showed significant differences between all languages in Year 2 [$F(2,94) = 66.549$, $p < 0.001$, $p\eta^2 = 0.59$] and Year 6 [$F(2,98) = 54.533$, $p < 0.001$, $p\eta^2 = 0.53$) ($p < 0.001$ for all post-hoc contrasts]. In Year 4 [$F(2,92) = 46.723$, $p < 0.001$, $p\eta^2 = 0.51$] the difference was significant only between Spanish on the one hand, and English and Catalan on the other hand ($p < 0.001$ for both post-hoc contrasts). For each language, performance across year groups was examined. This showed that performance increased in English [$F(2,86) = 19.129$, $p < 0.001$, $p\eta^2 = 0.32$], Catalan [$F(2,113) = 67.698$, $p < 0.001$, $p\eta^2 = 0.55$], and Spanish [$F(2,85) = 39.904$, $p < 0.001$, $p\eta^2 = 0.49$], between Years 2 and 4 ($p < 0.001$ for all post-hoc contrasts), with the Year 4 pupils spelling more words correctly. The Year 4 and Year 6 contrast, however, was only significant for the Catalan children ($p < 0.001$).

Spelling Performance in Narrative Writing

The numbers of words with spelling errors were examined. The main effect of language [$F(2,283) = 35.256$, $p < 0.001$, $p\eta^2 = 0.20$] and school year [$F(2,283) = 60.912$, $p < 0.001$, $p\eta^2 = 0.31$] were significant for the proportion of spelling errors students produced in their written texts. The school year by language interaction was also significant [$F(2,283) = 5.911$, $p < 0.001$, $p\eta^2 = 0.08$]. **Figure 4** shows that the Catalan cohort produced the highest proportion of words with spelling errors at all school years and Spanish cohort the lowest. Comparisons by language in separate analysis revealed that, in Year 2 [$F(2,93) = 22.726$, $p < 0.001$, $p\eta^2 = 0.34$], the Catalan cohort produced a significantly higher proportion of misspelled words compared to English and Spanish ($p < 0.001$ for both post-hoc contrasts), and this repeated in Year 4 [$F(2,92) = 7.948$, $p = 0.001$, $p\eta^2 = 0.15$] ($p = 006$, $p = 002$ for the two post-hoc contrasts, respectively). In Year 6 [$F(2,98) = 5.675$, $p = 0.005$, $p\eta^2 = 0.11$], Catalan children still misspelled a higher proportion of words than any of the two other cohorts but only the differences between Catalan and Spanish remained significant ($p = 006$). Comparisons by school year in separate analysis showed that the English children [$F(2,86) = 15.692$, $p < 0.001$, $p\eta^2 = 0.27$] misspelled a significantly lower number of words in Year 4 than in Year 2 ($p < 0.001$), but the contrast between Years 6 and 4 was not significant. The Spanish cohort [$F(2,84) = 5.816$, $p = 0.004$, $p\eta^2 = 0.13$] showed only one significant contrast between Years 6 and 2 ($p = 003$). Finally, the Catalan children [$F(2,113) = 62.193$, $p < 0.001$, $p\eta^2 = 0.53$] showed a steady improvement with significant contrasts between both Year 4 and Year 2 ($p < 0.001$), and Year 6 and Year 4 ($p = 008$).

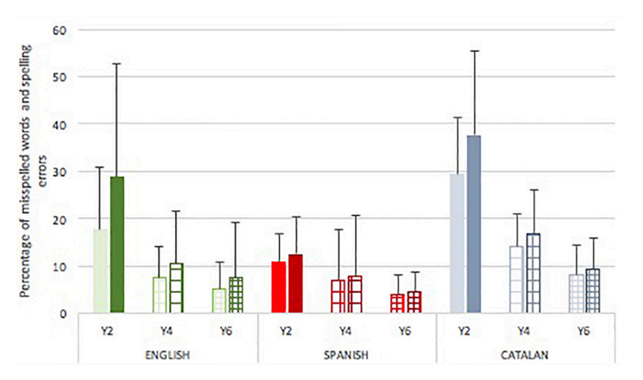

FIGURE 4 | Mean (SD) percentage of misspelled words (left column) and spelling errors (right column) by language and school grade.

Numbers of Spelling Errors in Narrative Texts

The numbers of spelling errors in the text were examined. There were main effects of language [$F(2,281)$ 22.876, $p < 0.001$, $p\eta^2 = 0.14$] and school year [$F(2,283) = 53.331$, $p < 0.001$, $p\eta^2 = 0.28$] and a school year by language interaction [$F(2,281) = 5.180$, $p < 0.001$, $p\eta^2 = 0.07$]. **Figure 4** shows that the Catalan cohort produced the highest proportion of spelling errors at all school years and Spanish the lowest. Comparisons by language in separate analysis revealed that, in Year 2 [$F(2,93) = 14.370$, $p < 0.001$, $p\eta^2 = 0.24$], the Spanish cohort produced a significantly smaller proportion of spelling errors than their English ($p = 0.004$) and Catalan ($p < 0.001$) peers, and that the language effect remained significant over time in Year 4 [$F(2,92) = 5.632$, $p = 0.005$, $p\eta^2 = 0.11$] and, marginally, Year 6 [$F(2,98) = 3.226$, $p = 0.042$, $p\eta^2 = 0.06$] between Spanish and Catalan ($p = 0.005$, $p = 0.038$, respectively). Comparisons by year group in separate analysis showed the same pattern as in number of misspelled words. Thus, the English children made a significantly lower number of misspelling [$F(2,86) = 13.846$, $p < 0.001$, $p\eta^2 = 0.25$] in Year 4 than in Year 2, $p < 0.001$, but the contrast between Years 6 and 4 was not significant. The Spanish cohort showed only one significant contrast [$F(2,84) = 5.510$, $p = 0.006$, $p\eta^2 = 0.12$] between Years 5 and 1 ($p = 0.004$). With age, the Catalan children made significantly fewer spelling errors [$F(2,113) = 56.588$, $p < 0.001$, $p\eta^2 = 0.51$] and contrasts were significant between both Year 4 and Year 2 ($p < 0.001$), and Year 6 and Year 4 ($p = 023$).

Types of Spelling Errors in Narrative Texts

The proportions of spelling errors at the root and affix level were examined (**Figure 5**). For root level errors there was a significant effect of language [$F(2,282) = 24.41$, $p < 0.001$, $p\eta^2 = 0.15$] and year group [$F(2,282) = 42.56$, $p < 0.001$, $p\eta^2 = 0.24$] and a significant interaction between language and year group [$F(4,282) = 24.41$, $p < 0.001$, $p\eta^2 = 0.09$]. The children writing in Spanish made significantly fewer spelling errors than both their English, $p < 0.001$ and Catalan, $p < 0.001$ peers. Comparisons by language in separate analyses showed that, in year 2 [$F(2,93) = 14.971$, $p < 0.001$, $p\eta^2 = 0.25$], the pupils

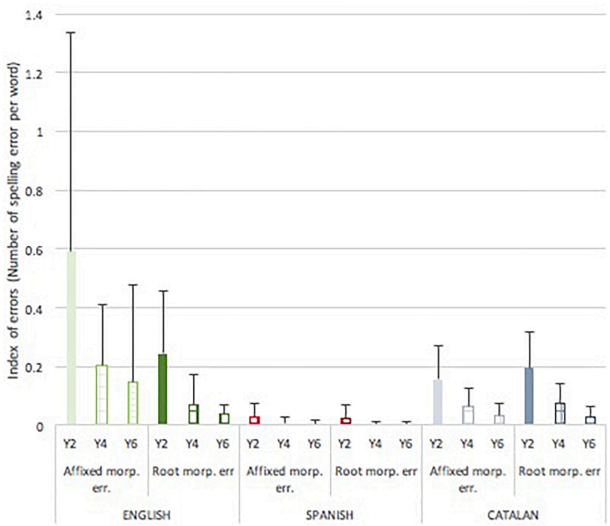

FIGURE 5 | Mean (SD) index of spelling number of spelling errors at the root level per word and at the morpheme level per morphologically complex word by language and school grade.

writing in Spanish made significantly fewer root level errors than pupils writing in English ($p < 0.001$), or Catalan ($p < 0.001$); in year 4, the difference remained significant [$F(2,92) = 4.533$, $p = 0.013$, $p\eta^2 = 0.09$] between the Spanish and the Catalan children ($p = 0.018$) but was only nearly significant between the Spanish and the English children ($p = 0.0.66$); finally in year 6, only the Spanish and the English children showed significant differences [$F(2,98) = 6.181$, $p = 0.003$, $p\eta^2 = 0.12$] ($p = 0.002$ for the post-hoc contrast). Age had a different effect depending on the language; the number of root errors decreased significantly in English [$F(2,86) = 14.648$, $p < 0.001$, $p\eta^2 = 0.26$] and Catalan [$F(2,113) = 41.439$, $p < 0.001$, $p\eta^2 = 0.43$] between Years 2 and 4 only ($p < 0.001$) (though in Catalan the decrease between Years 4 and 6 almost reached significance $p = 0.050$); whereas in Spanish [$F(2,84) = 6.260$, $p = 0.003$, $p\eta^2 = 0.13$] the decrease occurred at a slower pace and was significant between Years 2 and 6 ($p = 0.002$).

For misspelled affixes there was also significant effect of language [$F(2,279) = 28.44$, $p < 0.001$, $p\eta^2 = 0.17$] and year group [$F(2,279) = 13.92$, $p < 0.001$, $p\eta^2 = 0.09$] and a significant interaction between language and year group [$F(4,279) = 5.63$, $p < 0.001$, $p\eta^2 = 0.08$]. Comparisons by language in separate analyses showed that the children writing in English made more affix errors in Year 2 [$F(2,91) = 13.817$, $p < 0.001$, $p\eta^2 = 0.24$] and Year 4 [$F(2,92) = 19.655$, $p < 0.001$, $p\eta^2 = 0.31$] than the children writing in Spanish and Catalan (all, $p < 0.001$), and again in Year 6 [$F(2,97) = 5.208$, $p = 0.007$, $p\eta^2 = 0.10$] ($p = 0.002$ and $p = 0.032$ for post-hoc contrasts with Spanish and Catalan, respectively). Children writing in Catalan or Spanish did not differ at any age point regarding their ability to spell word affixes. For each language, performance across year groups was examined. Children significantly improved the spelling of affixes in English [$F(2,83) = 6.976$, $p = 0.002$, $p\eta^2 = 0.15$] with significant post-hoc contrast between Years 2 and 4 ($p = 0.012$), in Catalan [$F(2,113) = 26.827$, $p < 0.001$, $p\eta^2 = 0.33$] also with a significant post-hoc contrast between Years 2 and 4 ($p < 0.001$), and Spanish [$F(2,84) = 4.102$, $p = 0.020$, $p\eta^2 = 0.09$] with a significant post-hoc contrast between Years 2 and 6 ($p = 0.027$).

Omission of accents in Catalan and Spanish was compared. There was a significant effect of language [$F(1,189) = 4.34$, $p = 0.04$, $p\eta^2 = 0.02$] and year group [$F(1,189) = 29.97$, $p < 0.001$, $p\eta^2 = 0.25$] but no interaction [$F(2,189) = 0.09$ *ns.*]. Children writing in Catalan omitted more accents in comparison to students writing in Spanish, $p < 0.001$, as did children in the lower year groups (Year 2 in contrast to Year 4, $p < 0.001$ and Year 6, $p < 0.001$).

The Impact of Orthography on the Relationships Between Transcription, Reading and Writing

We first explored the zero order correlations between the writing measures of numbers of words produced and text quality with transcription (handwriting and dictated word spelling) and reading (word reading and reading comprehension) for each language cohort (see **Table 1** for *M*(SD) and **Table 2** for correlations). Bonferroni's adjustment ($p = 0.008$ for significance) was used to control for multiple correlations. As expected, in English both measures of transcription and reading comprehension were significantly associated with text productivity and text quality. For Catalan a similar pattern was evident but reading comprehension was not significantly associated with text productivity. There was a more mixed pattern for Spanish where written text productivity was only significantly associated with reading comprehension but text quality was associated with both reading and transcription skills.

Stepwise multiple linear regression analyses were used to test models for predicting written text productivity and quality in the three languages. Independent variable were age, the transcription measures (handwriting fluency and spelling) and the reading measures (decoding and reading comprehension). Significant models emerged in all languages for text quality and in Catalan and English for productivity. Significant models and predictors can be found in **Table 3**. As the table shows, both productivity and text quality were predicted by age and transcription skills in both Catalan (only handwriting was a significant predctor) and English (both spelling and handwriting reached significance), and the largest variance was evident for the text quality measures (55 and 57%, respectively). By contrast for Spanish text quality is predicted by the two reading variables accounting for 42% of the variance but text productivity was not predicted by any of the measures in the current study.

DISCUSSION

We examined patterns of spelling and narrative writing in three different age groups of Catalan, English, and Spanish speaking children. We predicted that the differences between the orthographies and morphological systems used by the children

TABLE 1 | Descriptive *M*(SD) for transcription and reading skills.

	Year 2			Year 4			Year 6		
	Eng (*N* = 31)	**Cat (*N* = 38)**	**Spa (*N* = 26)**	**Eng (*N* = 27)**	**Cat (*N* = 35)**	**Spa (*N* = 29)**	**Eng (*N* = 28)**	**Cat (*N* = 40)**	**Spa (*N* = 30)**
Hand writing fluency	26.42 (14.01)	17.03 (8.57)	25.15 (9.49)	40.15 (18.10)	43.63 (19.59)	34.55 (14.69)	47.04 (20.50)	63.15 (16.56)	54.13 (19.68)
Dictated word spelling	20.82 (9.76)	18.23 (1.91)	25.48 (2.99)	2735 (6.60)	21.46 (3.00)	29.43 (2.05)	23.71 (8.40)	25.52 (3.30)	30.59 (1.43)
Word reading	45.3 (15.70)	44.26 (18.55)	85.92 (34.31)	65.93 (11.01)	96.58 (42.19)	133.47 (32.31)	70.68 (11.73)	136.76 (40.51)	173.71 (31.01)
Reading comprehension	26.13 (11.94)	17.84 (2.96)	18.08 (4.14)	42.74 (4.84)	19.29 (5.23)	17.62 (4.59)	30.96 (10.10)	19.62 (5.46)	20.20 (3.02)

TABLE 2 | Zero order correlations between transcription, reading, and writing measures of productivity and quality by language.

Language		Handwriting fluency	Single word spelling	Word reading	Reading comprehension	Text productivity
English						
N = 86	Single word spelling	0.48**				
	Word reading	0.60**	0.72**			
	Reading comprehension	0.35**	0.71**	0.66**		
	Text productivity	0.44**	0.36**	0.42**	0.47**	
	Text quality	0.58**	0.49**	0.68**	0.43**	0.66**
Spanish						
N = 85	Single word spelling	0.50**				
	Word reading	0.67**	0.77**			
	Reading comprehension	0.21	0.38**	0.38**		
	Text productivity	0.11	0.12	0.12	0.24*	
	Text quality	0.32*	0.52**	0.61**	0.42**	0.30*
Catalan						
N = 113	Single word spelling	0.65**				
	Word reading	0.62**	0.80**			
	Reading comprehension	0.24*	0.44**	0.35**		
	Text productivity	0.48**	0.35**	0.35**	0.07	
	Text quality	0.66**	0.60**	0.60**	0.25*	0.52**

TABLE 3 | Final regression models reporting significant predictors written text measures for Catalan, English, and Spanish.

	Predictor	*B*	Std error	Beta	*t*	Sig	Model	Adjusted R^2
Productivity								
Catalan	Handwriting fluency	0.54	0.22	0.29	2.09	−0.04	$F(5,107) = 7.605$, $p < 0.001$	0.23
English	Handwriting fluency	0.48	0.18	0.31	2.68	−0.009	$F(l,85) = 7.1$, $p < 0.001$	0.26
	Reading comprehension	1.02	0.38	0.39	2.64	0.009		
Spanish	No significant predictors						$F(5,84) = 1.02$, *ns*	0.001
Text Quality								
Catalan	Age	0.03	0.007	0.49	3.84	<0.001	$F(5,107) = 27.82$, $p < 0.001$	0.55
	Handwriting fluency	0.01	0.01	0.22	2.17	0.03		
English	Age	0.03	0.01	0.37	3.89	<0.001	$F(5,85) = 23.87$, $p < 0.001$	0.57
	Handwriting Fluency	−0.02	0.01	0.23	2.59	0.01		
	Spelling	0.04	0.02	0.31	2.19	0.001		
Spanish	Word Reading	0.01	0.003	0.49	2.98	0.004	$F(5,84) = 13.12$, $p < 0.001$	0.42
	Reading comprehension	0.05	0.02	0.23	2.48	0.02		

would impact on their relative spelling performance and, as a consequence, written productivity and writing quality. As predicted Spanish children were the better spellers on both the single word spelling assessment and in their written narratives. Indeed, the Spanish children produced very few spelling errors at any age, they were the most productive writers and wrote higher quality texts than the other two cohorts. The quality, but not the productivity, of their texts was predicted by their reading skills. By contrast, and as anticipated, the English children were challenged by spelling both at the single word level and in their written narratives. Overall their written text productivity was lower than those of the Catalan and Spanish children but the quality of the texts was similar to their Catalan peers. As predicted spelling skills were a significant constraint both in terms of productivity and quality. The spelling performance of the Catalan children was, as anticipated, not as good as the Spanish children but showed steady improvement across the three year groups. The difference between English and Catalan varied by type of spelling assessment. In contrast to single word spelling where English children were the most challenged group, in the narrative task the Catalan children produced both the highest number of misspelled words and the highest number of spelling errors overall in their written texts. This pattern remained consistent across all three year groups. Only handwriting predicted the productivity and quality of their written texts for the Catalan children.

In terms of quality and productivity, different developmental patterns were evident across the three languages. In Spanish, children were more productive at younger ages and this was reflected in the higher quality of their written texts. By contrast, both children writing in English and in Catalan demonstrated a more gradual pattern of development in terms of both productivity and quality, differences were evident between the two older year groups. Nonetheless, by the time children were in the last year of elementary school (Year 6) there were no differences between the cohorts in terms of the quality of their texts but the Catalan children were most productive.

We examined the factors which predicted productivity and quality for the three languages by using a series of multilinear regressions. As predicted reading was explained a significant proportion of the variance in the performance of Spanish children, while for English children spelling accounted for the most variance. The Spanish data, as has been demonstrated for other transparent orthographies (Babayigit and Stainthorp, 2011; Arfe et al., 2016) further highlight the need to consider wider factors that impact on the quality of children's text. It is also important to note that once spelling and handwriting are fluent, at least for transparent orthographies, productivity no longer serves as a good discriminator of children's writing skills.

In contrast to models of reading, models of writing have only recently begun to consider proximal and distal factors that impact on writing products (Dockrell, in press). Proximal factors, those directly related to the production of the written text (handwriting and spelling) have dominated our understanding of writing development in English; only small amounts of variance have been accounted for by more distal factors. The data from the Spanish sample clearly indicated that once challenges by proximal factors are overcome (as in transparent orthographies) distal factors are more important. The key role of these distal factors once transcription skills are in place warrants both further research and the refinement of current models of writing. Their importance also points to the potential role of distal factors in interventions to support writing development.

Why handwriting fluency affected both text productivity and text quality across all age groups in Catalan is not clear. Graphomotor execution is thought to be automatized around nine years of age (Afonso et al., 2017) but also susceptible to orthographic and morphological effects. Single word writing studies have shown that inter letter interval duration increases both at the inter syllable boundary (Alvarez et al., 2009) and in the presence of bound morphemes (Kandel et al., 2008). Lexical variables seem to have a more evident impact on handwriting when the sublexical route is used to spell and write words. Recently, a study examining word writing in Spanish found that orthographic consistency cascades into movement production in children. However, this effect was found only for children in Year 2 when writing was not been yet automated (Suarez-Coalla et al., 2018). However, the complexities of the Catalan language where the repertoire of multi-syllabic and multi-morphemic words interplay with a moderately opaque orthography may serve as a bottle-neck captured in handwriting fluency at this stage of development. Since the relationship between spelling and handwriting has been explored in word level studies, our findings indicate that these effects are evident at the text level as well, emphasizing the need to examine this interaction at the text production level and to explore if they are consistent across different languages and orthographies.

To further explore how different writing systems pose different challenges for developing writers, we examined the distribution of spelling errors that the children produced in their narrative writing. The Catalan children produced the highest number of misspelled words and the highest number of misspellings overall. A substantial number of the spelling errors they made, however, were accounted for the omission of an accent mark. The English children produced more root errors than the Spanish children and more affix errors than both Spanish and Catalan children. They were the only group that made more morphological errors than root errors. These results are consistent with previous findings in English by Bahr et al. (2012) that spelling affixed morphemes represents an increasingly difficult task as children progress through primary school.

The Catalan children also produced significantly more root errors but not affix errors than the Spanish children. This might indicate that the Catalan children relied on sublexical approach to spelling the word root but demonstrated the ability to analyze the morphological structure of the word as an alternative strategy to spell bound morphemes. Additionally, as anticipated, the Catalan children produced significantly more errors in the omission of accents than the Spanish children. The clear advantages in spelling experienced by the Spanish children further corroborate differences found in experimental studies that have demonstrated that shallow orthographic systems (e.g., comparison between Spanish and French) in addition to transparency at the phonemic level appear to support the storage of orthographic representations more easily (Carrillo et al., 2013). As such Spanish which has a clear syllabic structure and five vocalic phonemes facilitates phonemic awareness and the development of orthographic representations resulting in few root errors and affix errors and reducing the impact of spelling on text production. The finding that Catalan children produced as many root errors as the English children but fewer affix errors would support the view that learning to spell requires that the child perceives and integrates linguistic information onto orthographic representations and that there is an interaction between the characteristics of the language and the strategies children use for spelling. Here, the more salient morphology of Catalan supported a faster development of an accurate orthographic representation of the bound morphemes in this language. For instance, apparently, a child spelling the inflected form /pərsonəs/ → <per'sones> "persons-fem-pl" faces two equivalent difficulties of phoneme-grapheme inconsistency: /ə/ spelt <e>, both in the root and the affix. Similarly, a child spelling /əßɛ/ → <haver> "(auxiliar) to have" faces the challenge of representing a phonologically empty letter both in the root, for letter <h> and in the affix, for letter <r>. Both to solve the phoneme-grapheme inconsistency in the root of "persones" or to produce the phonologically empty <h> in the root of "haver," the child will need to rely on lexical knowledge of these words. It appears, children in the early grades of primary school show capacity to analyse the word morphological, and the identification of the inflectional suffixes, here <-es>, expressing number, in <persones>, and <-er>, expressing the infinitive mode, in <haver>, provides the child with a helpful basis on which to produce the necessary spelling. These results are consistent with previous studies showing that the typological characteristic of the language affect the rate and path of development of an orthographic lexicon (Ravid and Gillis, 2006; Defior et al., 2008; Llaurado and Tolchinsky, 2016).

Our prediction that reading skills, which would arguably play a role in the development of an orthographic lexicon, would predict written text performance in Catalan was not supported by the present findings. One possible explanation is that the impact of the more distal factors cannot be seen until the transcription (handwriting) skills are consolidated. Free writing tasks provide children to choose the words in their text. As expected there was significant variability in their texts and therefore variation in the number of morphologically complex words used. This was particularly the case for derived words. Using a more controlled task such as a dictated text might provide a better way to explore this issue at this developmental point.

LIMITATIONS

This study examines the contribution of transcription and literacy skills to the writing productivity and quality in three languages that differ both in the consistency of their orthographic systems and in the prominence of their morphologies. As with all studies which aim to examine cross-linguistic differences there are limitations. Firstly, we have only addressed differences in spelling performance according to the word morpheme (stem or affix) where they occur, a more fine grained analysis accounting for the type of spelling error would further inform the challenges posed by the characteristics of each writing system. Secondly, the text writing skills of children have been assessed by means of one single written text. There is increasing evidence that multiple tasks are a more valid indicator of writing proficiency than a single writing task. Thirdly, future studies should include a measure or a range of measures of oral language. Although existing studies typically report weak to moderate correlations between measures of oral language and the length and quality of children's written products, the role of oral language in written text production should not be minimized as recent evidence suggests that oral sentence fluency supports written text generation over time and across languages (Savage et al., 2017). Fourthly, we depict development using cross-sectional data, longitudinal data are needed to fully establish the direction of the relationship between the different variables. Finally, although we statistically controlled for the small age differences between the Catalan and Spanish participants and English counterparts this is not ideal. However, this limitation is not specific to our sample, it reflects different school entry dates across systems and therefore difficult to overcome in the design of a comparative study. The limitations of the current study should inform future research.

CONCLUSION

To conclude, this study is unique in its examination of the relationships of proximal and distal factors with two key measures for written text assessment: productivity and quality in three different languages and orthographies. Our findings demonstrate that the role of transcription and reading skills to developing writing is modulated by the characteristics of the writing system. As such findings established in studies conducted only in English cannot be generalized to other languages and orthographies. These data further support the need for more crosslinguistic studies to establish models of writing development that accurately depicts the process whereby children learn to use the written language flexibly for a wide range of communicative purposes. In addition to the theoretical implications of the findings, the results of this study also have implications for educational practice too. Writing continues to be the most common means by which children are assessed and the specific characteristics of the language and its orthography will impact on the reliability and validity of different approaches to assessment of the writing product.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee of Institute of Education. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

AL organized the database. JD supervised the analysis. Both authors contributed to the design and conceptualization of the study, literature review, and discussion.

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Handwriting Legibility and Its Relationship to Spelling Ability and Age: Evidence From Monolingual and Bilingual Children

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Studies of the relationship between spelling and handwriting concur that spelling skills influence the dynamic processes of handwriting. However, it remains unclear whether variations in spelling ability are related to variations in the legibility of handwriting, how important spelling skills are relative to the amount of handwriting experience afforded by an individual's age and number of years of schooling, or to what extent this relationship may be task- and orthography-specific. We investigated these questions in a study comparing spelling and handwriting legibility in a group of N = 127 Welsh-English bilingual children matched in age and number of years of schooling to a group of N = 127 English-monolingual children, as well as to a group of N = 127 younger, English monolingual children matched to the bilingual group in spelling ability. All groups completed the Spelling and Handwriting Legibility Test (SaHLT) and a broader battery of literacy measures. The bilingual children were found to have poorer handwriting legibility than same age peers, and in some cases, than their younger, spelling-ability peers, suggesting that spelling ability, more so than amount of handwriting experience and years of schooling impacts handwriting legibility. This was corroborated in a series of multi-group path models, where all children's handwriting was predicted by spelling ability more strongly than by age, and, the effect of spelling generalized across two different spelling tasks in all groups. Finally, bilingual children seemed to draw on general (Welsh) as well as on orthography-specific (English) knowledge when handwriting in English.

Keywords: handwriting legibility, spelling, writing experience, bilingual, monolingual, predictors, orthography-specific, language-general

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INTRODUCTION

Spelling and handwriting skills, also called transcription skills (Juel et al., 1986; Berninger and Swanson, 1994), form a crucial, but to date understudied skill set in children's writing acquisition. They are temporally closely related processes of writing production, both occurring virtually simultaneously. However, models of writing production see them as separate, dissociable skills, under the control of different systems (e.g., van Galen, 1991). Spelling is a language-based skill under cognitive control, while handwriting is generally seen as a psychomotor skill under motor control. More recent elaborations of van Galen's model (e.g., Roux et al., 2013; Olive, 2014), the theoretical framework adopted for the present study, view the component processes of writing as a cascading and partially overlapping series of events, with spelling preceding, but also being modulated by handwriting processes. Despite their separate origins, the two skills are correlated (e.g., Berninger et al., 1992; Sumner et al., 2014), although the nature of the relationship between them is complex, and only beginning to be understood (e.g., Sumner et al., 2012; Kandel and Perret, 2015).

Handwriting comprises two aspects: the ability to write easily at speed, without undue effort and hesitation (fluency) and the ability to write clearly (legibility). Handwriting fluency is relatively easy to measure objectively as the number of units of writing produced per unit of time, for example, by the number of alphabet letters produced in 1 min (e.g., Jones and Christensen, 1999; Pontart et al., 2013; Alamargot and Morin, 2015). Other, more subtle, time-dependent behaviors that occur during handwriting and reveal the 'real-time handwriting dynamics' can be measured objectively thanks to technologies allowing detailed, real time tracking of pen movements (see below). Given the relative ease and measurement objectivity enabled by these tools, fluency in handwriting has been more extensively studied (Lambert and Quémart, 2019). It has been found to uniquely predict, across the developmental spectrum, the quantity and quality of text composition (Graham et al., 1997; Connelly et al., 2006; Puranik and Al Otaiba, 2012). This effect has been interpreted to indicate that when writing becomes automatic (as indexed by measures of fluency), cognitive resources are freed up for other, higher, skills of writing (Berninger and Amtmann, 2003; Berninger and Winn, 2006).

Research on handwriting dynamics has significantly moved the field forward in demonstrating how the attributes of words (such as phonology-to-orthography consistency (Roux et al., 2013; Kandel and Perret, 2015), and frequency (e.g., Delattre et al., 2006; Afonso et al., 2018) can impact processes such as the latencies (pauses prior to the onset of writing) and/or handwriting durations (time pen spent on the surface whilst creating strokes/letters/words), and pausing within words during spelling. Furthermore, studies conducted with children in various orthographies including French (e.g., Kandel and Perret, 2015), Spanish (e.g., Afonso et al., 2018), and Norwegian (e.g., Søvik et al., 1996) have focused on the influence of spelling ability on handwriting dynamics. However, these studies have used different task types (dictation vs. copying), measures of handwriting dynamics (onset latency between stimuli presentation and beginning writing, stroke duration, letter duration), and age groups, making it difficult to assess the extent and nature of the moderating effects that orthographies may have on spelling and handwriting. Studies that include direct cross-linguistic comparisons and studies of bilingualism will advance the understanding of the generalities and specifics of the spelling-handwriting relationship. The second aspect of handwriting, legibility, has been studied less extensively, in part because it is a skill more difficult to measure. Yet, the practical and educational consequences of poorly legible handwriting are arguably more pervasive than those of slow or dysfluent handwriting. Common features of poor legibility include distortions and inconsistencies in letter shape and size, poor spatial organization and spacing of letters and of words (e.g., Rosenblum, 2008). At school, children with poor handwriting are more likely to receive lower grades than those with better handwriting for comparable content, they are at greater risk of falling behind academically, and more likely to experience lower self-esteem and greater loneliness than peers with good handwriting (e.g., Feder and Majnemer, 2007). Thus, a better understanding of the development of handwriting legibility, its cognitive and motor underpinnings, as well as its relationship to spelling ability are warranted.

The complex relationship between handwriting and spelling has been the subject of a growing body of scientific investigation. In studies of skill development, a common approach is to examine how individual and group differences in spelling skills influence handwriting (e.g., Abbott and Berninger, 1993; Sumner et al., 2012). Studies comparing typically developing groups and groups with known deficits in spelling, namely children with dyslexia for whom spelling difficulties are a hallmark feature, have generally focused on the fluency and real-time dynamics of handwriting processes (Sumner et al., 2012, 2014; Kandel et al., 2017; Afonso et al., 2019; Arfé et al., 2019), but not legibility. These studies concur that, although handwriting difficulties (e.g., dysfluency due to pausing and pen movement durations) are not a core cause of dyslexia, they are concomitant reflections of dyslexic children's weaknesses in orthographic knowledge and processing during spelling. In contrast, studies reporting a link between spelling and handwriting legibility have been mainly based on anecdotal evidence (e.g., Cooke, 2002). Martlew (1992) carried out one of the few empirical studies that considered both handwriting fluency *and* legibility in their relationship to spelling ability, in comparisons of children with dyslexia to age- and younger ability-matched control groups. An interesting finding of this study was that, while the speed-related motor dynamics of handwriting seemed more dependent on amount of writing experience, such that the younger spelling-ability-matched children wrote generally more slowly than their older dyslexic and non-dyslexic counterparts, handwriting legibility seemed more closely associated to spelling ability. That is, judges could reliably categorize older typical writers in terms of their handwriting legibility, but seemed to be at chance in distinguishing between dyslexic and ability-matched children on the basis of legibility. Martlew's results must be considered as tentative, however, because the study included small sample sizes, and the relationships between spelling ability and speed versus spelling ability and legibility of handwriting were not compared directly.

The above experimental studies have compared groups with dyslexia to their typically developing chronological age mates. Such comparisons reveal, in theory, the gap between impaired performance caused by dyslexia and expected attainments in the absence of the disorder, given similar age and schooling experience of the two groups of participants. However, individuals with dyslexia tend to read and write less than their typically developing peers (Stanovich, 1986; Juel, 1988), and consequently many have relatively less experience and practice with both spelling and handwriting; this lesser experience may compound the expression of either or both of their difficulties.

This issue is partially addressed by the inclusion of typically developing comparison groups who are younger but matched for spelling ability with the dyslexic group (e.g., Sumner et al., 2012, 2014). Such younger control groups can shed light on the extent to which spelling and handwriting skills are interlinked for those without a spelling disorder but have had (as of yet) lesser experience and practice in the two skills. However, because it is difficult to quantify how much less reading and writing experience individuals with dyslexia have had, matching for spelling ability does not entail matching for the amount of writing experience of the two groups, nor does it account for probable effects of general maturation between the younger typical and older dyslexic groups.

The role of handwriting practice and experience, over and above spelling skill, may play a particularly important role in the development of handwriting, this being a skill primarily in the motor domain. Indeed, one defining characteristic of developmental co-ordination disorder (DCD), a disorder of motor functions, is persisting handwriting difficulty (Miller et al., 2001). While studies comparing the handwriting skills of typical groups and groups with DCD are informative about the proximal impacts of motor skills on handwriting development, they also involve a comparison with a group with a neurocognitive disorder. As in studies of groups with dyslexia, comparisons with such "disorder groups" do not allow for the role of practice and experience in either spelling or handwriting to be decoupled from the effects of the disorders themselves. However, the same design can be effectively used in research with bilingual (or second language – L2) learners of a language, and it may better separate overall handwriting experience (i.e., in the main language of instruction) from spelling ability. This is because the monolingual age-matched group and the typically developing bilingual group should have had comparable amounts of writing experience in their main language of instruction, but of course not in the amount of experience they have had in writing the bilingual group's L2. In contrast, while the bilingual group will have had more writing experience than the younger, monolingual spelling ability-matched control group, their spelling knowledge of the language in question will be comparable.

In the present study, we adopt such an approach to the investigation of the spelling-handwriting relationship, which is novel in two respects. First, we consider group and individual differences among children who are typically developing, and yet have lower spelling skills due to their bilingual, Welsh-English, education context. Specifically, we studied mid-primary-school-aged children in Welsh-medium schools where all instruction is provided in the Welsh language from 5 to 7 years of age (the North American equivalent of kindergarten to second grade) and only as of the third grade (age seven onward), English instruction is introduced. An interesting characteristic of this population is that most are bilingual speakers (but not readers) of English already in the early school years preceding formal English tuition. We compared the English spelling and handwriting skills of this bilingual group to age-matched peers, and to younger, spelling-ability-matched peers who were English monolinguals attending English-medium schools in the same region and under the same education authority. Thus, all groups were typically developing, and the age-matched (bilingual and monolingual) groups had the same amount of schooling under similar educational curricula and literacy skills targets across the primary years (Welsh Government, 2007). Their younger peers shared English monolingualism with one group, and English spelling level with the other.

It is useful to point out a few features of the Welsh orthography that have direct relevance to this study. The Welsh language uses an alphabetic orthography with almost full overlap of letters with the English alphabet (although Welsh additionally uses several diacritics), and thus Welsh-English learners' main challenge in acquiring written English after having acquired the rudiments of written Welsh involves learning the new orthographic patterns of English. The acquisition of written English, which most children already speak, does not entail learning a new script or a new handwriting style. There are considerable orthographic differences between the languages in terms of the typical and permissible spelling patterns (graphemes), and Welsh has a more grapho-phonemically consistent orthography than English. Thus, in terms of spelling, the bilingually educated children in the present study were learning the more complex spelling system of English after several years of learning the less complex system of Welsh. Note that, in the present study, the factor of orthographic consistency was not explored *per se*.

The second novel feature of the present study is our focus on handwriting legibility, as opposed to fluency and real-time handwriting dynamics. This was done to enrich current understanding of children's handwriting development by investigating whether, as is the case for the link between spelling and handwriting fluency, there is also a link between spelling skill and handwriting legibility, and whether this is true for learners with monolingual versus bilingual language backgrounds. Measuring handwriting legibility presents various challenges. Assessments of legibility are often globally scored, with a 'grade' awarded for whole texts (Rosenblum et al., 2003). These and even more fine-grained scales often suffer from relatively low reliability and validity, and they are difficult to replicate because there is an inherent element of subjective judgment in their evaluation. In an attempt to overcome these limitations, we developed a scale, the Spelling and Handwriting Legibility Test (SaHLT), which measures spelling and handwriting based on the same task. The handwriting component assessed four separable dimensions, recognized also by other scholars (e.g., Rosenblum et al., 2003) to contribute to legibility: letter formation, letter spacing, word spacing, and line alignment. We explain the design and psychometric properties of the test in the Methods section. Here, we highlight the main constructs assumed to be measured by each of the four dimensions. All four are related to motor skills, however, letter formation and word spacing are also likely related to spelling skills. Letter formation has been reported to be related to letter knowledge (Longcamp et al., 2008) an important spelling-related skill (Caravolas et al., 2012). Accordingly, we recently found strong correlations between letter formation, as measured by the SaHLT, and spelling ability; moreover, children with dyslexia were found to have poorer letter formation than typically developing children (Downing and Caravolas, 2018). We also found that low scores on the word spacing dimension were related, not only to visual-spatial distortions in spacing between words, but also to incorrect use of word boundaries (for example, spelling “around” as two words “a round”), suggesting that performance on this dimension may also be related to morpho-phonological knowledge in spelling. While letter formation and possibly word spacing are related to spelling, letter spacing and line alignment are assumed to be more reflective of motor skills.

Here, we attempted to disentangle the effects of handwriting experience, which we assume is reflected across groups by age and amount of schooling experience, from spelling ability, on handwriting legibility. We did so by examining typically developing, bilingual spellers in Welsh-English education in comparison to age- and spelling-ability-matched English monolingual counterparts. Thus, pupils learning in the bilingual context had comparable experience of handwriting to their age peers in monolingual English education, but were likely to have weaker English spelling skills in the mid-primary years (grades 3–6) due to the later start of formal tuition in this orthography. The bilingual group was anticipated to have comparable spelling skills to monolingual English children with approximately 1 to 2 years less schooling.

We hypothesized that if the association between spelling ability and handwriting legibility is mainly contingent on the impacts of effortful and error-prone spelling processes during handwriting production, then the bilingual and spelling ability matched monolingual groups should show concomitant handwriting weaknesses relative to older and better spellers. This pattern of results might be most strongly evident on outcomes for the letter formation dimension. If, on the other hand, handwriting legibility develops as a function of general, language-independent spelling and writing experience and practice, then the bilingual pupils should produce handwriting that is as legible as that of their monolingual age- and schooling-matched peers. The latter pattern may be more clearly evident on the handwriting dimensions of letter spacing and line alignment, thought to be more strongly indicative of handwriting components under motoric, and visuo-spatial control, and thereby be more amenable to general handwriting experience and practice, be it in Welsh or in English. To test these hypotheses, we carried out between-group analyzes on English spelling and handwriting legibility scores obtained from the SaHLT measure.

Furthermore, we were interested in examining whether previously reported associations between spelling and handwriting fluency and its dynamic processes (e.g., Kandel and Perret, 2015) also held for spelling and handwriting legibility. Moreover, to test the generality of this relationship, we also examined whether any relationship between spelling and handwriting legibility was only present when measured by the same task or whether it would hold across different measures of spelling. We also probed whether associations between spelling and handwriting among bilingual writers depended on the orthography in which they were writing (orthography-specific) or whether they reflected general spelling skill (i.e., Welsh and English). We addressed these questions in a series of multi-group path analyses, in which spelling ability, age (our proxy also for amount of writing experience), non-verbal ability and reading skills were included as potential predictors of handwriting legibility.

MATERIALS AND METHODS

Participants

The participants were selected from two larger studies of typically developing children, one of $N = 294$ pupils in primarily Welsh-medium education, and one of $N = 936$ pupils in primarily English-medium education. The two studies had partially overlapping aims and hence included a number of the same assessments. All participants came from North Wales and were schooled according to similar curricula set by the Department for Education and Skills (Wales); the main difference between the cohorts was their language profile. In Wales, children attending Welsh-medium schools are taught through the medium of Welsh throughout the Foundation Phase (3 to 7 years of age). During Key Stage 2 (7 to 11 years of age), English is introduced formally, however, children still experience up to 70% of their learning through the medium of Welsh. For the present study, 127 Welsh-English bilingual (BIL) children (69 girls) in grades 3, 4, and 5 (7.8 – 10.8 years of age) were selected from three schools of the larger Welsh-medium cohort. In addition, 254 English monolingual children were selected from across six schools in the larger English-medium cohort, of whom 127 (69 girls) were in grades 3, 4, and 5 (7.8 – 10.7 years of age) and were matched to the individuals in the bilingual group according to chronological age (± 3 months) and non-verbal reasoning ability (as close to ± 3 points as was possible); this was the chronological age (CA) control group. The remaining 127 participants (68 girls) of the 254 English monolingual children, were in grades 2, 3, and 4 (6.3 – 10.1 years of age), and were matched to the bilingual children according to spelling (binary sentence spelling) ability and non-verbal reasoning (matrix reasoning) skills; this was the spelling-ability-matched (SA) control group. Details of each group’s sample size and age by grade level are provided in **Table 1**.

Regarding language profiles, all participants were asked about their language preferences in three set questions, and confirmations about their responses were sought from teachers. These self-reports revealed that, in the bilingual group, 55% of participants identified as preferentially Welsh speakers, 46% as preferentially English speakers, and 0.8% as preferring an ‘other’ language. The subgroups did not differ in terms of their English or Welsh literacy skills, however, and therefore they were considered a single language-profile bilingual group for the purposes of the present study. The participants in English-medium schools were primarily English monolingual. In response to the language preference questions, 98% of the sample identified as preferentially English speakers, and 1.6% as preferentially speakers of an ‘other’ language.

All participants completed measures of non-verbal reasoning, reading, spelling, and handwriting legibility skills in English. In addition, the bilingually educated children completed spelling

TABLE 1 | Sample sizes, means, and standard deviations of ages in months for the bilingual, chronological-age-matched and the spelling-ability-matched groups as a function of Grade.

	Grade			
	2	3	4	5
Chronological Age				
n		35	46	46
Age (months)		100.60	110.61	123.61
SD		3.52	3.51	3.59
Bilingual				
n		35	46	46
Age (months)		101.74	110.74	123.72
SD		4.07	3.57	3.90
Spelling Age				
n	28	62	37	
Age (months)	80.54	97.48	110.68	
SD	3.18	3.66	4.06	

and reading tests in Welsh (see Materials section). None of the participants had a statement of special educational needs. Head teachers were invited to opt into the project, while the opt-out method of consent was used in seeking parental approval because the testing was carried out in classrooms as part of the children's main instruction. The study was conducted in accordance with the British Psychological Society Code of Ethics and Conduct.

Materials

Descriptive statistics of the raw and standardized scores (where appropriate) as a function of group for the measures listed below are reported in **Table 2**.

Test of Non-verbal Reasoning Ability

We adapted the Matrices subtest of the Wide Range Intelligence Test (WRIT; Glutting et al., 2000) for group administration. This measure was included as a proxy for non-verbal reasoning skill. In the adaptation, the test plates (items) that are normally presented individually on a flipchart, were presented in sequence on a screen to whole classes, and children worked with a corresponding test booklet. Children were instructed to identify in their booklet the missing 'piece' of the main pattern array from the multiple distractors that were displayed on the screen. The plates were presented for the time durations described in the WRIT manual. The first 42 WRIT items were administered, as this set surpassed the typical discontinuation zone for the age groups in this study. The Cronbach's alpha reliability was $\alpha = 0.85$ for the monolingual sample and $\alpha = 0.78$ for the bilingual sample. Given the adaptations for group administration, and because the WRIT battery is normed on a US population, grade-based normative scores were computed, based on the samples of children in the larger studies ($N = 936$ and $N = 294$). Standard scores were derived with a population mean of 100 and a standard deviation of 15.

Picture-Word Matching Test (PWM) – English Version (Caravolas et al., 2013, 2018a)

The PWM test measures children's single word reading efficiency in a 3-min silent reading format; it was completed by all groups. The test contains 62 items that are cognates across several languages, and appear in frequency corpora of child-directed school texts across the languages (e.g., English: Masterson et al., 2003; French: Lété et al., 2004; Spanish: Martínez and García, 2004; Czech and Slovak: Kessler and Caravolas, 2011). The test items were presented in a booklet in order of increasing difficulty, and according to their appearance in school texts at specific school grades from Reception Year/Kindergarten to Year/Grade 6 (see Caravolas et al., 2013 for details). For each item, children viewed a target picture and then placed a tick under the word they selected as the best match to the picture from among four different printed words, which included the target item, a phonographemic distractor, a semantic distractor, and an unrelated distractor. Following a brief training session, children completed as many items as possible in 3 min. The score was the number of words selected correctly in 3 min. Test-retest reliability was not available for this test, however, in previous studies with younger English children (Caravolas et al., 2012, 2013) we found it to have high stability with *r*s ranging from 0.60 to 0.93. Year-group-based normative scores were computed, based on the samples of children in the larger studies ($N = 936$, and $N = 294$). Standard scores were derived with a population mean of 100 and a standard deviation of 15.

Picture-Word Matching Test (PWM)-Welsh Version (Caravolas et al., 2018b)

A Welsh version of the Picture-Word Matching test, parallel to the English version, was administered to the bilingual participants. The Welsh version was presented in the same order, according to the same method of administration as the English version. All children completed the Welsh version in a first testing session, and the English version in a subsequent session.

Test of English Single Word Spelling Ability

The Spelling subtest of the Wide Range Achievement Test IV (WRAT-IV; Wilkinson and Robertson, 2006) was adapted for group administration, adhering as closely as possible to the published guidelines, to the monolingual English participants only. It was not administered to the bilingual group due to constraints on the time available for testing in the bilingual schools. All monolingual participants spelled to dictation 13 alphabet letters followed by 36 words graded in difficulty and were given approximately 30 s to write each item. The cut-off of 36 words was selected as this corresponds to a standard score of 145 in grade six, and it was expected that most of sixth graders (equivalent to Year 5 in the United Kingdom) were unlikely to exceed this score. Each correct spelling was awarded one point and scoring was discontinued after 10 consecutive errors. The maximum possible score was 49. The Cronbach's alpha reliability for this measure was $\alpha = 0.92$. For the same reasons that applied to the Matrices test, grade-based normative scores were computed,

TABLE 2 | Descriptive statistics and group comparisons on age and literacy background measures for bilingual, chronological age-, and spelling ability-matched control groups.

Measure	CA		BIL		SA		Group comparisons	
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*	η_p^2
Matching								
Age (months)	112.56	9.90	112.76	9.90	97.59	11.33	88.95***	0.32
Matrices[a]	94.99	13.94	98.93	15.33	102.52	13.41	8.16***	0.04
Sentence Spelling								
Binary	34.83	8.36	29.57	11.12	29.69	11.05	10.87***	0.05
Letter Distance	0.82	0.62	1.02	0.72	1.25	1.01	9.59***	0.05
Additional literacy								
Picture-Word Matching								
English								
Raw	37.43	9.46	44.44	11.18	31.59	10.05	55.50***	0.24
Standardized	102.30	14.29	101.46	14.06	103.79	12.74	0.81	<0.01
Language of education[a]	102.30	14.29	101.20	15.43	103.79	12.74	0.92	0.01
Word Spelling (language of education)[a]	101.59	12.54	100.65	14.04	103.96	13.12	2.19	0.01

[a]*Standard score (M = 100, SD = 15); ***p < 0.001.*

based on the samples of North Walean children in the larger study of monolingual children (*N* = 936). Standard scores were derived with a population mean of 100 and a standard deviation of 15.

Test of Welsh Single Word Spelling Ability (Caravolas et al., 2018b)

This test was created to assess Welsh word spelling ability in primary-school-aged children. It contained 36 words, graded in terms of difficulty [per Welsh literacy curricula (Welsh Government, 2008)], and embedded in sentence contexts. Each word was repeated three times: once in isolation, the second time in a sentence context, and in isolation again, with approximately 30 s writing time allowed per word; all test items were administered. Participants were instructed to write each dictated word neatly in their booklets. Scoring was binary with one point for fully correct spellings and zero points otherwise. The Cronbach's alpha reliability for this test was α = 0.82. Grade-based normative scores were computed based on the samples of children in the larger study (*N* = 294), and standard scores were derived with a population mean of 100 and a standard deviation of 15.

Spelling and Handwriting Legibility Test (SaHLT; Caravolas et al., in preparation)

Sentence spelling and handwriting legibility were measured using the SaHLT, a sentence dictation task that allows for the concurrent scoring of spelling and handwriting legibility.

Sentence Spelling

The ten sentences comprising the SaHLT are those used in Caravolas et al. (2005). For the purpose of this study, we used a shortened, eight-sentence (51 word), version of the test. The sentences varied in length from four to eight words, and within sentences, words varied from one to nine graphemes in length. Sentences increased in phonological, morphological, lexical, and orthographic complexity throughout the task. The item complexity increased in line with national spelling curriculum guidelines for England (cf. Caravolas et al., 2005). Spelling accuracy was measured in terms of binary conventional accuracy, with one point awarded for fully correct spellings, otherwise zero points; the possible maximum score was 51 points. A second, string edit distance, score was calculated for each spelling production using the computer software Ponto (Kessler, 2009). Ponto was set to apply a penalty of one point for each letter deletion, addition, and substitution within a word, thus generating a *letter distance* score (of the number of edits required to correct each spelling production). The number of penalties per word was averaged to derive a mean letter distance score per child.

Handwriting Legibility

Four separate dimensions of handwriting legibility were assessed per the guidelines in the SaHLT. The dimensions were developed based on a theoretical and empirical understanding of salient aspects of handwriting legibility (Caravolas et al., in preparation; Rosenblum et al., 2003). The dimensions are: (a) Letter Formation, which captures the child's accuracy in producing the letter's form, orientation, and consistency of its angle and size, (b) Letter Spacing, which measures the degree and consistency of the spacing between the letters within words, (c) Word Spacing, which – similarly to Letter Spacing – measures the degree and consistency of the spacing between words within a sentence, and (d) Line Alignment, which captures the degree and consistency with which the child writes the letters and words on the line. Each dimension is scored on a five-point Likert scale ranging from 1 (highly illegible) to 5 (highly legible), and an Overall Legibility score for each *sentence* is obtained by summing across the four-dimension scores, averaged over all sentences to a possible maximum of 20 points. On the abridged version of the SaHLT used in the present study, the five mean scores were generated by aggregating across the eight sentences. The SaHLT places no constraints on the type of script to be used; children are invited to write with pen or pencil and in print or cursive script, as is the norm in their schooling environment.

We have found this scale to be valid and reliable. For example, a strong correlation ($r = 0.54$) was observed between teacher responses on the Handwriting Proficiency Screening Questionnaire (Rosenblum, 2008) and SaHLT Overall Legibility, demonstrating convergent validity (Campbell and Fiske, 1959). The handwriting legibility measure showed excellent internal consistency ($\alpha = 0.97$), test-retest (intraclass correlation = 0.76), and inter-rater (intraclass correlation = 0.83) reliabilities for the written productions of the monolingual English children. Children's written productions were evaluated by trained scorers who had not scored the children's spelling accuracy and were blind to their group classification. The bilingual children's handwriting was evaluated by a different rater who received the same training as the rater of the monolingual sample. The inter-rater reliability was carried out by two trained scorers on a randomly selected sample of 25% of scripts from the bilingual group, and was found to be excellent (ICC = 0.85, $F(31, 31) = 6.70$, $p < 0.001$; Cicchetti, 1994).

Procedure

Whole classes of children completed all the measures described above in specially prepared booklets in normal classroom conditions. For ease of administration and to reduce fatigue effects, measures were delivered over two 45- to 60-min sessions. The bilingual children completed one session through the medium of Welsh and the second through the medium of English, with at a minimum 1 hour elapsing between sessions. All sessions were conducted by a team of three or four trained research assistants who maintained good oversight of children's work and of their compliance with the set instructions.

RESULTS

The data were analyzed in two main steps. First, between-group comparisons were conducted to investigate whether the bilingual children differed from their monolingual peers in literacy, and handwriting skills. Second, correlational and multi-group path analyses were conducted in order to assess the concurrent predictors of handwriting, and to test whether the predictive patterns were the same for all groups.

Between-Group Comparisons

Preliminary data checking was carried out for each group on every measure. Outlier scores, representing 0.7% to 2% of the data, were Winsorized to within 2.7 SD of the respective group's mean (Tukey, 1977). The resulting distributions were reasonably normal with the exception of the spelling measure of letter distance, which was positively skewed in all groups. Square root transformations normalized these distributions and the transformed scores were used in subsequent analyses. Descriptive statistics and analysis of variance results for group comparisons of age, non-verbal ability, and background literacy measures are reported in **Table 2**.

Group Matching Measures

Analyses of variance were carried out to test the anticipated effects on the variables used to match groups. By design, the bilingual (BIL) and chronological age-matched control (CA) groups did not differ in age, $t(252) = 0.16$, $p < 0.435$, $d = 0.02$, and both groups were significantly (on average 15 months) older than the spelling ability-matched control group (SA) (BIL vs. SA, $t(252) = 11.37$, $p < 0.001$, $d = 1.43$; CA vs. SA, $t(252) = 11.21$, $p < 0.001$, $d = 1.41$). Similarly, the analyses of spelling ability in sentence context (SaHLT), measured by binary accuracy, confirmed that the bilingual and spelling ability-matched groups did not differ from each other, $t(252) = 0.08$, $p < 0.469$, $d = 0.01$, and both groups spelled significantly less accurately than the CA controls (BIL vs. CA, $t(252) = 4.25$, $p < 0.001$, $d = 0.53$; CA vs. SA, $t(252) = 4.18$, $p < 0.001$, $d = 0.52$). Sentence spelling ability was also analyzed using the more refined measure of string edit letter distance to see whether the groups differed in the magnitude of their within-word error rates, which may have otherwise been missed by the binary scoring method. As reported in **Table 2**, this analysis replicated the pattern of results for the binary scoring method such that the CA group had the lower mean distance scores relative to bilingual, $t(252) = 2.64$, $p = 0.004$, $d = 0.33$, and SA groups, $t(252) = 4.26$, $p < 0.001$, $d = 0.53$, who in turn did not differ statistically from each other, $t(252) = 1.85$, $p = 0.066$, $d = 0.23$. No differences were found in standard scores on non-verbal ability between the bilingual and SA groups, $t(248) = 1.96$, $p = 0.975$, $d = 0.25$, or between the bilingual and CA groups, $t(237) = 2.07$, $p = 0.980$, $d = 0.27$, but the CA controls' non-verbal ability was significantly lower than that of the SA controls, $t(233) = 4.22$, $p < 0.001$, $d = 0.53$, although, all groups performed within the average range. Consequently, in ensuing analyses we controlled for the potential moderating effect of non-verbal ability on literacy and handwriting attainments.

Background Literacy Measures

For a more complete picture of the literacy skills of the three groups, and to verify that all were performing within the normal range of their respective age and language of education contexts, additional reading and spelling measures were analyzed. ANCOVAs, controlling for potential effects of non-verbal abilities, were carried out on English word reading efficiency measured by the Picture-Word Matching test (PWM). Significant main effects were followed up with Bonferroni-corrected *post hoc* comparisons between groups. Because the same test was completed by all groups, we investigated the outcomes on both the raw scores (that is, the number of words matched correctly in 3 min), and the standardized score equivalents. The analysis of covariance (covarying non-verbal ability scores) on the raw scores revealed a main effect of the covariate $F(1,357) = 25.88$, $p < 0.001$, $\eta_{\rho}^2 = 0.07$, as well as a main effect of group such that, after controlling for the effect of non-verbal ability, the bilingual group read English words more efficiently than their monolingual peers (BIL vs. CA: $t(251) = 4.78$, $p < 0.001$, $d = 0.68$; BIL vs. SA: $t(252) = 10.53$, $p < 0.001$, $d = 1.21$) – a finding to which we return in the Discussion – and in turn, the younger SA group read less efficiently than their older monolingual peers ($t(251) = -5.35$, $p < 0.001$, $d = 0.60$). However, the ANCOVA on the standardized English Picture-Word Matching scores demonstrated that, after controlling for the significant effect of non-verbal ability ($F(1,357) = 27.23$, $p < 0.001$, $\eta^2_\rho = 0.07$), the groups' performances did not differ from each other, and furthermore, all groups were reading well within the normal range relative to their normative populations. The bilingual children had also completed the Welsh version of the Picture-Word Matching test, and thus we conducted an analysis comparing reading efficiency across groups when reading in their main language of instruction (English PWM for the CA and SA groups; Welsh PWM for the bilingual group). This was mainly done to ascertain that the bilingual group's relatively strong performance on the English reading test did not reflect a group with particularly strong reading skills in their language of education. This ANCOVA on the standardized reading scores revealed that after controlling for a significant effect of non-verbal ability ($F(1,356) = 27.51$, $p < 0.001$, $\eta^2_\rho = 0.07$), the three groups did not differ from each other, and all were reading well within the normal range.

In addition to assessments of reading, it was deemed important to assess spelling ability on an independent measure that was not used for participant selection and matching. All groups had been assessed on a graded single word spelling measure in their language of education; this was the WRAT Spelling Test in English and the Test of Welsh Single Word Spelling Ability. The raw results for these tests could not be compared directly, thus, we submitted the standardized score equivalents to an ANCOVA. As was true for the reading results, after controlling for the significant effect of non-verbal ability $F(1,356) = 11.74$, $p < 0.001$, $\eta^2_\rho = 0.03$), the groups did not differ from each other in single word spelling ability, and all groups were performing well within the normal range relative to their normative population. These analyses confirmed that while in raw terms, the bilingual children spelled less well in English (SaHLT) than their monolingual counterparts, their spelling being on a par with monolingual children on average 15 months younger, all three groups represented typical readers and spellers in their educational and linguistic contexts.

Group Handwriting Legibility Profiles

To examine whether bilingual children's handwriting differed from that of monolingual children, group performance was compared on each of the handwriting legibility dimensions. Owing to the high degree of relatedness among these dimensions (see correlations) we conducted a oneway MANCOVA with the four dimensions as dependent variables and group membership as the independent variable, covarying for non-verbal ability. The resulting model revealed performance on the handwriting legibility dimensions to differ significantly between groups, Pillai's Trace = 0.20, $F(8,712) = 9.83$, $p < 0.001$.

Follow-up ANCOVAs on each dimension revealed significant group effects on letter formation, letter spacing, and line alignment, but not on word spacing (see **Table 3** for the descriptive statistics and *post hoc* group comparisons). There were, however, different patterns of performance on each of the three dimensions, which were investigated using Bonferroni-corrected *post hoc* comparisons. On letter formation (after controlling for the significant covariate of non-verbal ability, $F(1,358) = 7.51$, $p = 0.006$, $\eta^2_\rho = 0.02$), bilingual and spelling-ability-matched monolingual groups, who did not differ from each other ($t(252) = 2.09$, $p = 0.113$, $d = 0.27$), attained significantly lower scores than older monolingual controls (CA vs. BIL: $t(252) = 5.27$, $p < 0.001$, $d = 0.66$; CA vs. SA: $t(252) = 2.09$, $p = 0.005$, $d = 0.47$). On letter spacing, after controlling for non-verbal ability ($F(1,358) = 8.19$, $p = 0.005$, $\eta^2_\rho = 0.02$), the bilingual group also received significantly lower scores than both monolingual control groups (CA vs. BIL: $t(252) = 6.61$, $p < 0.001$, $d = 0.85$; SA vs. BIL: $t(252) = 4.28$, $p < 0.001$, $d = 0.51$) who did not differ from each other ($t(252) = 2.38$, $p = 0.054$, $d = 0.29$). Similarly, for line alignment bilingual children received significantly lower scores than both monolingual control groups (CA vs. BIL: $t(252) = 7.30$, $p < 0.001$, $d = 0.94$; SA vs. BIL: $t(252) = 4.24$, $p < 0.001$, $d = 0.51$) and younger monolingual children received significantly lower scores than older monolinguals, ($t(252) = 3.06$, $p = 0.007$, $d = 0.39$). Finally, group comparisons on the overall legibility scores revealed that, after controlling for non-verbal ability, $F(1,358) = 6.98$, $p = 0.009$, $x^2 = 0.10$, the bilingual group achieved a significantly lower overall score than the younger SA controls ($t(252) = 2.97$, $p = 0.010$, $d = 0.37$), and both groups had lower scores than their CA counterparts (CA vs. BIL: $t(252) = 6.18$, $p < 0.001$, $d = 0.80$; CA vs. SA: $t(252) = 3.21$, $p = 0.004$, $d = 0.43$; see **Table 3**). Overall, these analyses consistently showed the bilingual group to have poorer handwriting than monolingual children of their own age, and, in some cases, than younger children with a similar level of spelling ability.

Relationships Between Spelling and Handwriting

Correlations

It is clear from the previous analyses that, despite having adequate spelling abilities for their age and education, the bilingual children had poorer handwriting legibility when writing in English. We investigated this further by examining the relationships between the background literacy skills and handwriting in monolingual and bilingual children. First, we examined the bivariate correlations between all variables of interest for each group separately; these are reported in **Tables 4–6**.

Several noteworthy patterns emerged from these analyses. As expected, in all groups there were moderate to strong relationships between age and those literacy measures that had not been standardized, and hence already been controlled for age. Moderate correlations were also present between age and handwriting legibility measures. However, these correlations were stronger in the bilinguals and spelling-ability matched children, that is the relatively poorer spellers of English, than in older and better English speller (CA) group. Across all groups, non-verbal ability showed relatively weak associations with the handwriting legibility measures; in contrast, however, non-verbal skills associated moderately with the various literacy

TABLE 3 | Summary of performance on handwriting legibility measures for bilinguals, chronological age-, and spelling ability-matched controls.

Measure	CA		BIL		SA		Group comparisons	
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*	η_p^2
Letter formation	2.95	0.63	2.44	0.89	2.65	0.65	13.98***	0.07
Letter spacing	3.34	0.47	2.88	0.61	3.19	0.59	22.77***	0.11
Word spacing	3.40	0.53	3.29	0.65	3.27	0.64	1.60	0.01
Line alignment	3.75	0.55	3.20	0.64	3.52	0.64	26.85***	0.12
Overall legibility	13.45	1.72	11.80	2.35	12.63	2.05	19.13***	0.10

*CA = chronological age-matched; BIL = bilinguals; SA = spelling ability-matched; ***p < 0.001.*

TABLE 4 | Correlations between literacy and handwriting measures for chronological age-matched controls.

	1	2	3	4	5	6	7	8	9	10	11
(1) Age[a]											
(2) Non-verbal ability[b]	0.04										
(3) English word reading	0.48***	0.33***									
(4) L-ED word reading	0.48***	0.33***	1.00								
(5) L-ED word spelling[b]	0.03	0.25**	0.37***	0.37***							
(6) Sentence binary spelling	0.41***	0.26**	0.61***	0.61***	0.76***						
(7) Sentence letter distance	−0.45***	−0.27**	−0.63***	−0.63***	−0.72***	−0.96***					
(8) Letter formation	0.28***	0.15	0.25**	0.25**	0.30***	0.38*	−0.35***				
(9) Letter spacing	0.19*	0.20*	0.12	0.12	0.16	0.14	−0.15	0.65***			
(10) Word spacing	0.08	0.21*	0.15	0.15	0.14	0.15	−0.14	0.45***	0.43***		
(11) Line alignment	0.21*	0.12	0.26**	0.26**	0.13	0.20*	−0.23*	0.57***	0.41***	0.43***	
(12) Overall legibility	0.25**	0.21*	0.25**	0.25**	0.24**	0.29***	−0.28***	0.86***	0.78***	0.73***	0.77***

*[a]Months; [b]Standard scores. L-ED = language of education (i.e., English versions of PWM reading test and of the WRAT spelling test). ***p < 0.001, **p < 0.01, *p < 0.05.*

skills in the older (CA, BIL) but not the younger (SA) groups. As might be expected, all of the measures of reading and spelling intercorrelated relatively strongly in all the groups, however, literacy skills and handwriting dimension associations were weaker among the more advanced English spellers (CA group) than among the less advanced spellers of English (BIL and SA groups). Finally, all of the handwriting dimension scores intercorrelated relatively strongly within all groups. Looking at the individual dimensions, it is clear that letter formation had the most consistent relationships with literacy measures in all three groups. Again, these relationships were stronger in the poorer speller groups (BIL, SA) than among more advanced spellers (CA). In sum, with respect to the main question addressed in the present study, the patterns of correlations suggest that age (a proxy for amount of schooling and general writing experience) and literacy skills both seem to share variance with handwriting legibility; furthermore, their associations may be stronger among less advanced spellers (BIL, SA) than among more advanced spellers (CA).

Multigroup Path Models

We were interested in examining the extent to which spelling knowledge (task-specific and general), along with reading skills, non-verbal ability, and age, predicted handwriting legibility and whether these relationships differed in bilingual children, who were at once older but also poorer spellers of English, relative to their monolingual peers. Legibility was predicted in pairs of multigroup path models, the first always predicting *letter formation* because this measure was theoretically most likely to be related to spelling via letter knowledge (e.g., Longcamp et al., 2008), but also empirically it showed the most consistent correlations with spelling ability in the present study; the second model always predicted *overall legibility* as this captured the fuller handwriting legibility construct.

In the first pair of models, the English spelling predictor reflected the binary accuracy score from the SaHLT, and the dependent measure was the letter formation legibility score (**Figure 1A**) and the overall handwriting legibility score (**Figure 1B**). Next, to investigate whether any predictive patterns between spelling and handwriting legibility would generalize beyond measures obtained from the SaHLT and the English language (in the case of the bilinguals), another pair of models was computed where spelling ability was measured by accuracy scores from the single word spelling task in each group's language of education (English for the monolinguals and Welsh for the bilinguals), as reported in **Figures 2A,B**. These analyses were followed up by a pair of models with an additional manipulation on the predictor of reading, such that the English version of the PWM test was substituted by the Welsh version of this test (see **Figures 3A,B**).

Prior to the analyses, all variables were standardized within group. We conducted the multigroup path analyses in Mplus

TABLE 5 | Correlations between literacy and handwriting measures for bilinguals.

	1	2	3	4	5	6	7	8	9	10	11
(1) Age[a]											
(2) Non-verbal ability[b]	−0.02										
(3) English word reading	0.37***	0.37***									
(4) L-ED word reading	0.33***	0.36***	0.80***								
(5) L-ED word spelling[b]	−0.01	0.23*	0.41***	0.44***							
(6) Sentence binary spelling	0.41***	0.33***	0.73***	0.67***	0.49***						
(7) Sentence letter distance	−0.39***	−0.37***	−0.72***	−0.69***	−0.54***	−0.94***					
(8) Letter formation	0.35***	0.16	0.43***	0.35***	0.39***	0.50***	−0.49***				
(9) Letter spacing	0.33***	0.11	0.32***	0.28**	0.28***	0.40***	−0.38***	0.74***			
(10) Word spacing	0.13	0.04	0.27**	0.15	0.17	0.21*	−0.19*	0.45***	0.58***		
(11) Line alignment	0.52***	0.11	0.37***	0.28**	0.18*	0.43***	−0.41***	0.71***	0.66***	0.51***	
(12) Overall legibility	0.40***	0.13	0.42***	0.33***	0.32***	0.47***	−0.45***	0.89***	0.88***	0.74***	0.85***

*[a]Months; [b]Standard scores. L-ED = language of education (i.e., Welsh versions of PWM reading test and of the Single Word Spelling test). ***p < 0.001, **p < 0.01, *p < 0.05.*

TABLE 6 | Correlations between literacy and handwriting measures for spelling ability-matched controls.

	1	2	3	4	5	6	7	8	9	10	11
(1) Age[a]											
(2) Non-verbal ability[b]	0.07										
(3) English word reading	0.64***	0.06									
(4) L-ED word reading	0.64***	0.06	1.00								
(5) L-ED word spelling[b]	0.20*	0.09	0.53***	0.53***							
(6) Sentence binary spelling	0.65***	0.17	0.80***	0.80***	0.73***						
(7) Sentence letter distance	−0.65***	−0.16	−0.79***	−0.79***	−0.74***	−0.97***					
(8) Letter formation	0.45***	0.10	0.50***	0.50***	0.40***	0.62***	−0.61***				
(9) Letter spacing	0.39***	0.17	0.33***	0.33***	0.24**	0.41***	−0.38***	0.57***			
(10) Word spacing	0.44***	0.04	0.44***	0.44***	0.35***	0.52***	−0.54***	0.61***	0.47***		
(11) Line alignment	0.36***	0.00	0.28***	0.28***	0.16	0.34***	−0.33***	0.61***	0.43***	0.56***	
(12) Overall legibility	0.51***	0.09	0.48***	0.48***	0.36***	0.58***	−0.58***	0.86***	0.75***	0.82***	0.81***

*[a]Months; [b]Standard scores. L-ED = language of education (i.e., English versions of PWM reading test and of the WRAT spelling test). ***p < 0.001, **p < 0.01, *p < 0.05.*

(Version 8.1; Muthén and Muthén, 2018). To deal with the small amount of missing data (< 5%), we used full-information maximum likelihood estimators. To test the multigroup goodness of fit, we used an iterative approach, where we first attempted to constrain unstandardized path weights to be equal across groups, followed by constraints on the covariances between predictors. Below, we report the final, best-fitting models, using this procedure.

Models in Which the SaHLT Spelling Measure Predicted SaHLT Handwriting Legibility

The models for the prediction of letter formation and total legibility are shown in **Figure 1**. Although non-verbal ability and English reading were not statistically significant predictors of either letter formation (Model 1A) or total legibility (Model 1B), they were kept in the model due to the significant covariances they shared with other predictors and because removing them was detrimental to the overall fit. Covariances between age and non-verbal ability were fixed at zero because non-verbal ability was standardized based on age. In the final models predicting letter formation, χ^2 (16) = 9.13, p = 0.908, RMSEA = 0.000, SRMR = 0.052, CFI = 1.00, TLI = 1.05, and total legibility, χ^2 (16) = 11.72, p = 0.762, RMSEA = 0.000, SRMR = 0.056, CFI = 1.00, TLI = 1.03, all path weights were constrained to be equal across all groups, and covariances were constrained to be equal across the groups of the older children (CAs and BIL) but not SAs.

The patterns of prediction were similar across models in that both age and binary spelling accuracy, but not non-verbal reasoning and reading, were significant unique predictors of handwriting. The strength of the predictors was similar across the bilingual and monolingual groups and spelling was the strongest predictor, especially so in the prediction of letter formation. The total variance explained in handwriting was similar and relatively small, but statistically significant in each of the groups.

Models in Which Single-Word Spelling Measures in Children's Language of Education Predicted the SaHLT Handwriting Legibility

To investigate the role of children's general spelling ability, as measured in their main language of education, we repeated the models described above but replaced the SaHLT spelling

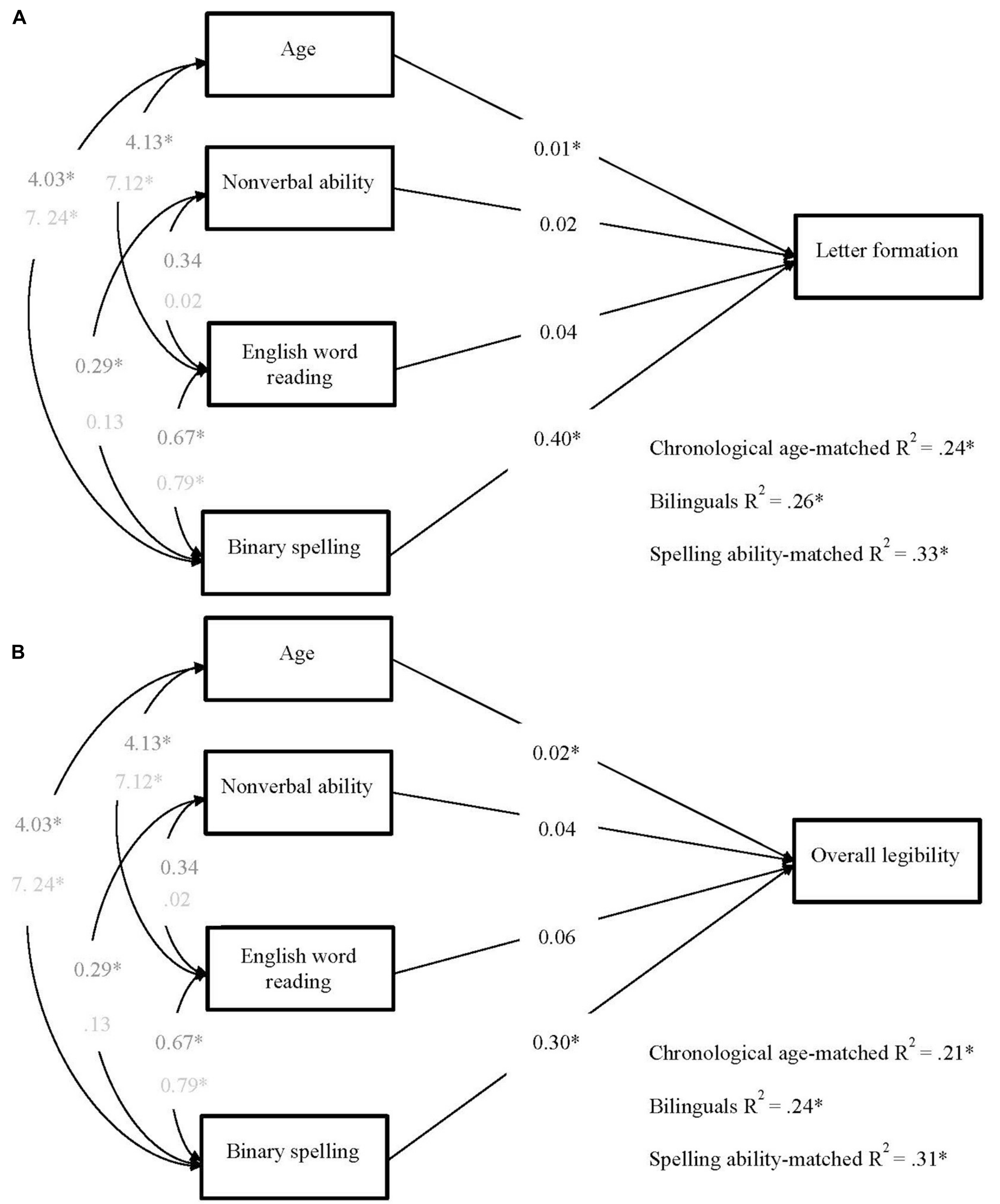

FIGURE 1 | Multigroup path models predicting **(A)** letter formation and **(B)** total legibility in bilinguals, chronological age-, and spelling ability-matched controls. Each model included four predictors: age, non-verbal ability, English word reading, and binary sentence spelling. Unstandardized values are reported (*$p < 0.05$). Covariance values in dark gray represent those for older, bilingual and chronological age-matched, children. Covariance values in light represent those for younger, spelling ability-matched children.

measure with single-word spelling measures in the group's language of education (English for CA and SA groups, Welsh for the BIL group; see **Figure 2**). Both non-verbal ability and word spelling were standardized for age and so we fixed the covariances between age and these measures to zero. The final, best fitting, models of letter formation, χ^2 (14) = 9.86, p = 0.772, RMSEA = 0.000, SRMR = 0.056, CFI = 1.00, TLI = 1.03, and total legibility, χ^2 (14) = 10.91, p = 0.693, RMSEA = 0.000, SRMR = 0.058, CFI = 1.00, TLI = 1.03, were those in which path weights were constrained to be equal across monolingual children – but not bilinguals – and covariances were constrained to be equal across older children, but not SAs.

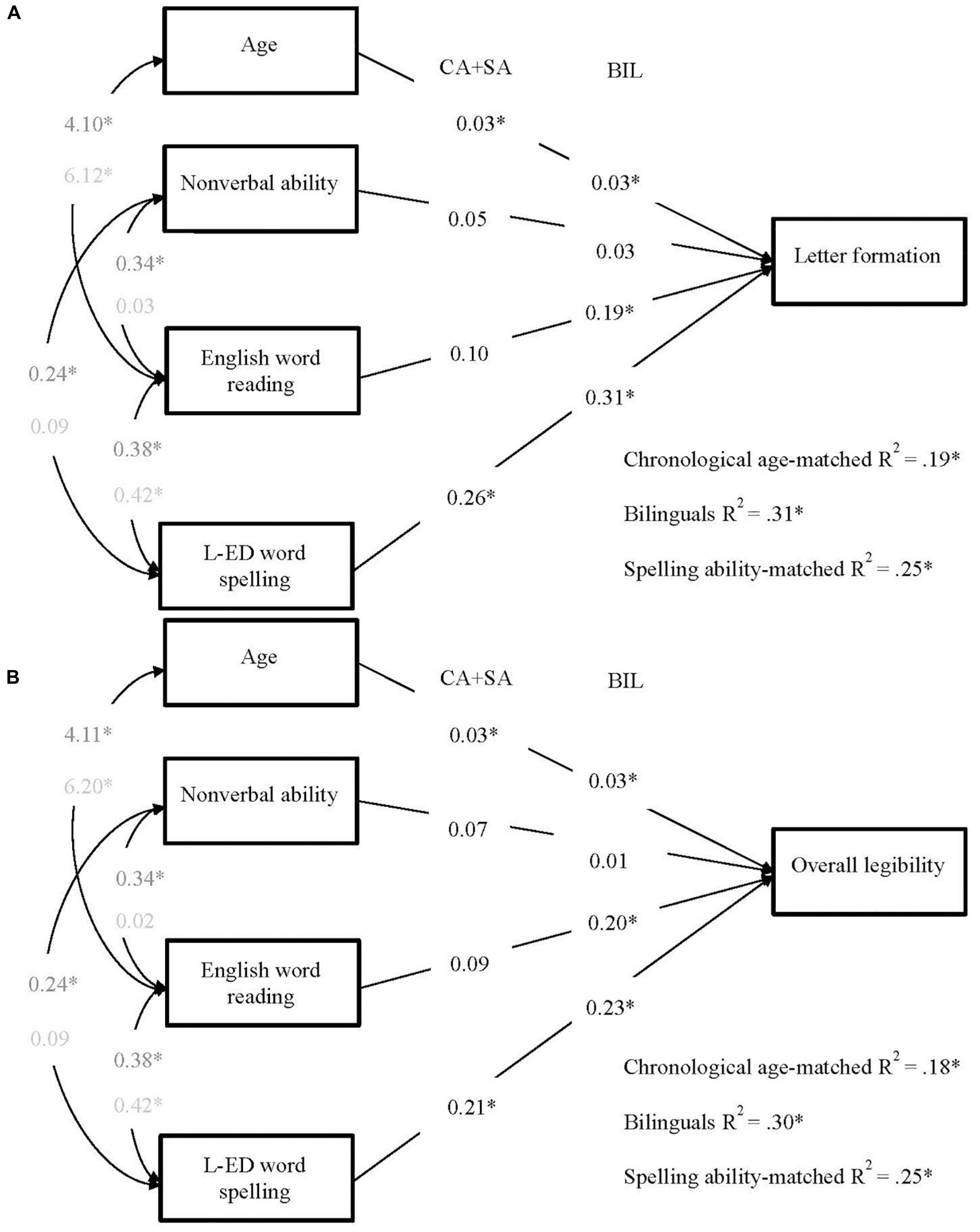

FIGURE 2 | Multigroup path models predicting **(A)** letter formation and **(B)** total legibility in bilinguals, chronological age-, and spelling ability-matched controls. Each model included four predictors: age, non-verbal ability, English word reading, and L-ED word spelling (i.e., the WRAT spelling test for the monolingual groups, and the Welsh Single Word Spelling test for the bilingual group). Unstandardized values are reported *(*p < 0.05)*. Path values on the left represent chronological age- and spelling ability-matched (CA + SA) weights and values on the right represent bilingual (BIL) weights. Covariance values in dark gray represent those for older, bilingual and chronological age-matched children. Covariance values in light represent those for younger, spelling ability-matched children. L-ED = language of education.

In these models, the patterns of predictions were the same for letter formation and overall legibility. Both age and single-word spelling accuracy were significant predictors of handwriting in all groups. While spelling remained the strongest predictor in all groups, its predictive strength was weaker than in the previous models. Interestingly, in the models of the bilingual group, when

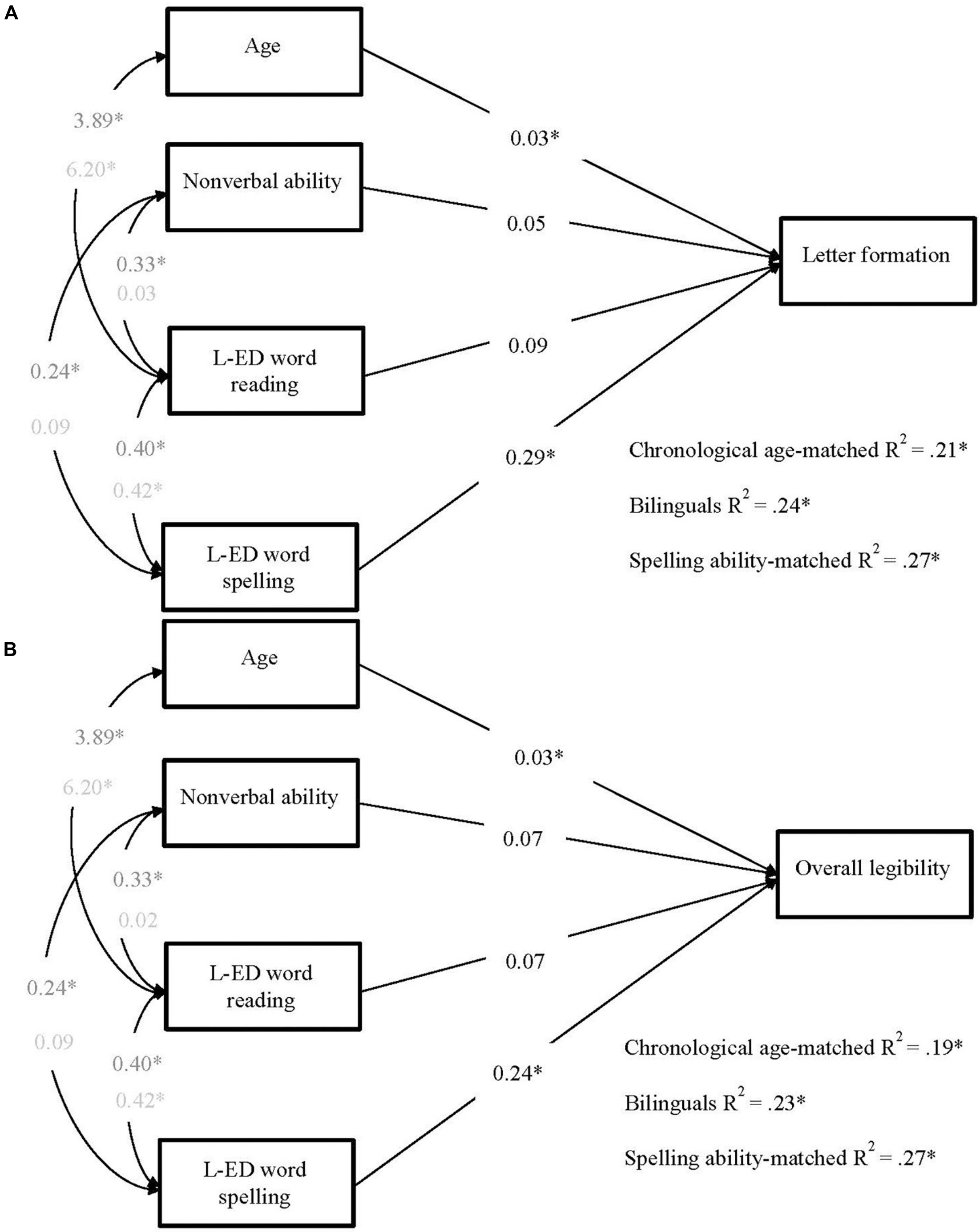

FIGURE 3 | Multigroup path models predicting **(A)** letter formation and **(B)** total legibility in bilinguals, chronological age-, and spelling ability-matched controls. Each model included four predictors: age, non-verbal ability, L-ED word reading (i.e., English version of PWM reading test for the monolingual groups, and Welsh version of the PWM reading test for the bilingual group), and L-ED word spelling (i.e., English WRAT spelling test for the monolingual groups, and Welsh Single Word Spelling test for the Bilingual group). Unstandardized values are reported (*$p < 0.05$). Covariance values in dark gray represent those for older, bilingual and chronological age-matched, children. Covariance values in light represent those for younger, spelling ability-matched children. L-ED = language of education.

the measure of spelling ability was changed to Welsh single word spelling, English word reading emerged as an additional significant predictor of letter formation and overall legibility. The total variances explained in handwriting, significant in all cases, were similar in the monolingual groups and slightly elevated in the bilingual group, reflecting the additional predictor of

English word reading. The comparison of predictive patterns across Models 1 and 2 suggested that the role of the spelling measures as predictors of handwriting legibility remained similar for all groups. Thus, when spelling was measured by the SaHLT in Model 1, its predictive strength was similar and strongest for all groups. When, in Model 2, spelling was measured by single word spelling tests (unrelated to the SaHLT), the predictive weight of spelling weakened for all groups, presumably reflecting the loss of some common method variance. To ascertain whether the English and Welsh single word spelling measures showed similar levels of association with the handwriting measures, we carried out follow-up Wald tests on the spelling path weights of the monolingual versus bilingual group. These confirmed no significant differences, in Model 2A ($W(2) = 0.303$, $p = 0.859$) and Model 2B ($W(2) = 0.03$, $p = 0.859$), suggesting that the differences in the language of the spelling tests did not bring about differences in the patterns of prediction for monolingual and bilingual children's handwriting legibility. The variable that did increase in its predictive role from Model 1 to Model 2 was reading for the bilingual group.

The previous analysis revealed that, over and above word spelling in the children's language of education, English word reading explained a significant amount of variance in handwriting in an English sentence dictation task among bilingual children but not monolingual children. The bilingual children's model suggests that while general spelling knowledge – as measured by Welsh word spelling – continues to account for individual variations in handwriting on an English writing task, the writers are additionally drawing on English-specific orthographic knowledge, as reflected by the contributing effects from the English word reading measure. To test this hypothesis further, we repeated the same models, this time replacing in the bilingual group's model, the English word reading efficiency with a parallel measure of Welsh word reading efficiency. We reasoned that if, in the former bilingual models, English reading was acting as a proxy for English orthographic knowledge, then replacing the reading measure for a Welsh one should lead to the loss of the effect of reading on handwriting.

The models predicting handwriting from age, non-verbal ability, word reading efficiency in the children's language of education, and word spelling accuracy in the children's language of education are shown in **Figure 3**. In the final models of letter formation, χ^2 (18) = 11.83, $p = 0.856$, RMSEA = 0.000, SRMR = 0.070, CFI = 1.00, TLI = 1.04, and overall legibility, χ^2 (18) = 12.79, $p = 0.804$, RMSEA = 0.000, SRMR = 0.072, CFI = 1.00, TLI = 1.04, path weights were constrained to be equal across all groups and covariances were constrained to be equal across older children, but not SAs.

Again, the same patterns of prediction held for letter formation as well as overall legibility. Like in the former models, age and word spelling were significant predictors of handwriting in all groups. However, replacing English word reading with Welsh word reading for the bilingual group led to the path between reading and handwriting to no longer be significant. Moreover, in the latter models, the relative weighting of spelling ability appeared to be weaker than in Models 1A and 1B, where spelling and handwriting measures are obtained from the same test. Similarly, the total amount of variance explained was somewhat lower than in the first two models, however, the fits between the respective Models 1 and 3 did not differ significantly (Models 1A vs. 3A χ^2 = 2.70, Δ_{df} = 2, $p = 0.259$; models 1b vs. 3b, χ^2_{diff} = 1.07, Δ_{df} = 2, $p = 0.586$) suggesting that any differences are minimal.

DISCUSSION

In this study, we sought to better understand the influences of spelling ability and amount of handwriting experience and practice (estimated by years of schooling and age), on handwriting legibility. To do so, we compared typically developing children in Welsh-English bilingual education to peers in monolingual English education using an age- and spelling-ability-matched design. Thus, the spelling and handwriting skills of bilingual children in mid-primary school (class years 3–5) were compared to those of English monolingual groups of children of similar-age, years of schooling and non-verbal ability, on the one hand, and those some 15 months younger (class years 2–4), who were spelling at the same level as their bilingual peers.

Preliminary between-group comparisons of the children's broader literacy skills, confirmed that on tests of silent word reading efficiency and of single word spelling – completed in each group's main language of education (English for the monolingual groups and Welsh for the bilingual group) – all three groups were typical readers and spellers in their own age and educational contexts. One somewhat surprising finding was that the bilingual group read English words more efficiently (Picture-Word Matching test), in raw score terms, than their monolingual peers. This finding aligns with reports of facilitatory transfer effects in bilingual populations, especially those whose first or dominant written language is more consistent in terms of letter-sound mappings (e.g., Spanish, or in this case Welsh) than their second language (e.g., English; Durgunoğlu, 2002). For example, Spencer and Hanley (2003) found that Welsh-English bilingual children read English pseudo-words more accurately than their English monolingual age classmates, although the former group had less experience of reading English than the latter. However, we must interpret the present finding with caution because the bilingual group had completed the Welsh version of the Picture-Word Matching test in an earlier test session. Thus, they may have benefited from practice effects on the English test. While this reading result awaits further investigation, the important finding here is that, in relation to their normative populations, all groups read the English words well within the average range, and there were no significant differences between the groups in terms of mean standard scores.

On the critical measures of English spelling on the sentence dictation (SaHLT), as anticipated, the CA group spelled more accurately than the bilingual and SA groups, who in turn performed similarly to each other whether spelling ability was measured in terms of binary accuracy or Levenshtein letter edit distance. In sum, the bilingual group was well matched to the

CA control group in terms of age and amount of schooling (i.e., presumably also on amount of handwriting experience), non-verbal ability and they had somewhat greater English word reading efficiency. Yet, their English spelling accuracy was significantly weaker, and on a par with 15-month younger English monolingual pupils.

Against this backdrop, we examined the mean ratings on the four handwriting legibility dimensions of the SaHLT (letter formation, letter spacing, word spacing, line alignment, as well as the aggregated overall legibility). With the exception of word spacing scores, which did not differentiate between groups, the bilingual group had consistently poorer legibility than their age mates, despite having otherwise comparable general and literacy skills. In comparison to their spelling ability peers, the bilingual group produced comparably legible letter forms, the dimension of handwriting that is likely most strongly related to spelling (Martlew, 1992; Longcamp et al., 2008; Caravolas et al., in preparation). However, on the remaining dimensions, they scored significantly less well, than their spelling-ability peers. This finding was contrary to our expectations that the dimensions of letter spacing and line alignment may be more indicative of handwriting components under motoric, and visuo-spatial control, and thereby be more amenable to the variations in handwriting experience and practice, reflected by age and number of years of schooling, be it in Welsh or in English. A possible explanation for the generally weak handwriting profile of the bilingual children is that handwriting legibility is to some extent dependent on orthography-specific practice and experience. That is, perhaps it is not experience with handwriting in general, but with the graphic/motor sequences of specific spelling patterns of words in an orthography.

We pursued this line of investigation in a series of multigroup path models. In the first model, we asked whether, over and above performance differences in the skills of interest, the predictors of handwriting vary as a function of spelling ability, age (a proxy for amount of handwriting experience), reading ability, and non-verbal reasoning. Importantly, we investigated whether the predictive patterns hold across age, ability, and language groups. In the first set of models, the measure of spelling was binary accuracy on the words of the SaHLT, and the measures of letter formation (Model 1A) and overall legibility (Model 1B) were also derived from the SaHLT. We found that spelling and to a lesser extent age predicted letter formation and overall legibility similarly across ability and language profiles, even when accounting for non-verbal reasoning and English reading abilities. This finding extends the well reported view that variations in spelling skills influence variations in handwriting fluency (e.g., Abbott and Berninger, 1993; Sumner et al., 2014; Afonso et al., 2018) and confirm that this relationship holds also for handwriting legibility. Turning to language profiles, these models explained performance in monolingual and bilingual children similarly which suggests that bilinguals use their English spelling skills in a similar way to their monolingual peers when handwriting in their second orthography. However, from this set of models, it remained unclear whether the effect of spelling was restricted to the SaHLT task, where the spelling and handwriting performance were derived from the same task. Also, this analysis was not informative about the generality of the spelling-handwriting relationship across different orthographies.

In the second set of models, we therefore replaced the binary sentence spelling score with a word spelling score of the child's language of education (Welsh for bilinguals and English for monolinguals). These models (2A and 2B) revealed a slightly different picture. In both monolingual groups, single word spelling and – to a lesser extent – age were the only significant predictors of letter formation and overall legibility, thus replicating the first set of models. However, among the bilingual group, English word reading abilities emerged as a predictor of letter formation and overall legibility, in addition to age and Welsh word spelling. The prediction of handwriting from a separate spelling measure further strengthens the view that the influence of spelling ability on handwriting legibility generalizes beyond specific tasks – although the influence of spelling in the first analysis tended to be stronger than in the second, suggesting that common method variance accounted for additional variance when both spelling and handwriting were measured by the same test. Furthermore, these models suggest that bilingual writers' handwriting is influenced by some general spelling ability, as demonstrated by the significant path between Welsh spelling knowledge and legibility. In addition, the significant path between English reading and legibility – which was only significant in the bilingual group – suggests that bilinguals were utilizing some English orthography-specific knowledge to shape the legibility of their English handwriting.

In the final set of models (3A and 3B), we further tested the hypothesis that bilingual children were drawing on some orthography-specific knowledge when writing in their second orthography by replacing the English word reading measure with its Welsh analog, thus removing any measure of English orthography knowledge in the bilingual group's model. This manipulation led to the loss of the significant path between word reading and handwriting, present for the bilingual group in models 2A and 2B. This finding strengthens our interpretation of Models 2A and 2B and suggests that when Welsh-English bilingual children handwrite in English, they rely on general spelling knowledge as well as orthography-specific spelling, and orthographic knowledge. This interpretation, in line with current theorizing about the organization of the bilingual lexicon (e.g., Kroll et al., 2005; de Groot, 2011), implies that during handwritten spelling production, bilingual writers may rely on orthographic (spelling) knowledge specific to the language in use (i.e., English or Welsh), in addition to relying on a language-general or integrated construct of "general orthographic knowledge" and both of these sources of knowledge may then have a downstream effect on the quality of handwriting legibility. Thus in our Model 2, the effect of the language-general/integrated knowledge may be estimated by the path from spelling to handwriting legibility for the bilingual group, whereas any residual orthography-specific knowledge may be estimated by the path from reading to handwriting legibility in Models 2 and 3 for all groups. For the monolingual groups, language-specific spelling knowledge completely overlaps with our putative "language-general or integrated spelling/orthographic knowledge" construct, and for this reason English reading ability does not contribute to handwriting over and above English spelling ability.

In sum, the present study of group and individual differences indicates that spelling ability, more so than variables related to the amount of practice in handwriting, such as age and hence the amount of schooling experience, exerts a relatively strong and stable influence on handwriting skills, including legibility. However, variations in age did additionally make consistent contributions to handwriting legibility skills. These results were obtained in comparisons of more and less advanced spellers, all of whom were typically developing. The finding that the bilingual group had weaker spelling skills and handwriting skills in English, on a par with 15-month-younger monolingual children suggests that the contingency between spelling ability and handwriting is to a large extent driven by the amount of experience and practice in writing a *specific* orthography, and not only by spelling disorder. It could be argued that despite their otherwise adequate reading and spelling skills in their main language of education (Welsh), the bilingual children were simply worse at handwriting than their monolingual counterparts. To follow up this possibility, we used the method and criteria of the SaHLT for all but the word spacing dimension, to evaluate the handwriting legibility of 57 randomly selected participants on the 36 words of Welsh Single Word Spelling test, and we compared these to their scores on the English SaHLT. The analysis showed superior handwriting scores on the Welsh test for every dimension. Certainly, this last finding requires replication with fully analogous measures, including a Welsh version of the SaHLT as well as an English single word spelling test; but, this initial analysis is suggestive of the orthography-specific writing experience hypothesis. Finally, it is important to note that the total amount of variance was significant and consistent across all models but was relatively small in size (R^2 = 0.19–0.33). We expect that the inclusion of measures of other skills believed to affect handwriting ability, such as motor- and attention-related skills (e.g., Adi-Japha et al., 2007; Prunty and Barnett, 2019), as well as more direct measures of the amount of handwriting experience of the participants would substantially increase the amount of variance explained. These extensions to the present work await further research.

Our study has some implications for educational practice. The legibility of children's writing impacts their educational experiences and outcomes (e.g., Feder and Majnemer, 2007), and thus it is important for educators to understand the causes and possible steps to remediating poor legibility. The present study shows clearly that handwriting legibility improves with spelling ability more so than with the handwriting practice that accrues with years of schooling and maturation. Moreover, our study suggests that it is learning to write the specific orthographic patterns of a given language that is particularly beneficial to handwriting development. Thus, it seems advisable for educators to focus on handwriting legibility, not only in dedicated handwriting lessons, but also during spelling instruction, and for bilingually educated children, and second language/orthography learners, handwriting should be a focus during spelling instruction in both taught languages. In addition, during dedicated handwriting practice, it would be beneficial to include spelling patterns of the language(s) of education. That is, taking the Welsh-English example, while handwriting skills acquired in the context of Welsh literacy lessons should generalize to some extent to handwriting quality in English, our results suggest that English spelling practice may confer even stronger benefits on handwriting in English. Finally, when children present with poor handwriting, this may be a signal to teachers of underlying spelling difficulties.

DATA AVAILABILITY STATEMENT

The datasets for this article are not publicly available because the data set is new, part of a larger data set, and still being exploited by the authors. The data will be made available in the future. Requests to access the datasets should be directed to MC, m.caravolas@bangor.ac.uk.

ETHICS STATEMENT

The studies underpinning this article were reviewed and approved by Ethics Committee of the School of Psychology, Bangor University, United Kingdom. Written informed consent was provided by headteachers. Participants' legal guardian/next-of-kin gave opt-out consent in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

MC conceptualized the aims, design of the study, and led the write-up of the manuscript. CD contributed to all aspects of the manuscript development and was the main contributor to the data analysis. CH, CW, and CD performed data collection and scoring. CH and CW contributed to specific sections of the manuscript. All authors read and approved the submitted version.

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Non-phonological Strategies in Spelling Development

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This paper investigated the role that types of knowledge beyond phonology have on spelling development, such as knowledge of morpheme-to-grapheme mappings, of orthographic patterns, and of word-specific orthographic patterns. It is based on the modern view that children do not learn spelling in discrete stages but, rather, they apply different types of strategies from early on. The goals of the paper were threefold: (1) to determine the relative difficulty of different types of non-phonological spelling strategies, (2) to examine the contribution of non-phonological strategies (specifically, morphological, morphophonological, orthographic, and lexical) to conventional spelling scores, and (3) to determine the role of children's educational level and population type (first- vs. second-language learners) on spelling strategy use. A large sample of 982 children (497 boys), speakers of Catalan (a Romance language similar to Spanish but with a less consistent orthography), participated in the study. They were administered a bespoke dictation task aimed to test their conventional and phonographic accuracy skill, as well as to determine their ability to use different types of non-phonological strategies for the spelling of ambiguous phonemes. Data were analyzed with a series of multigroup, multilevel SEMs. Results showed that (1) children across groups found morphological and lexical strategies harder to apply than orthographic and morphophonological strategies and (2) all types of non-phonological strategies contributed greatly to spelling accuracy scores, even after controlling for children's phonographic skills. Efficient strategy use increased as a function of schooling level, while second-language learners had a worse performance throughout, but no group showed a specific pattern of results. In conclusion, the paper offers substantial evidence that non-phonological strategies are paramount to learning to spell at least during the early and intermediate elementary school years. It is suggested that the teaching of writing should therefore be multidimensional in nature and target particularly the strategies with which children struggle the most: knowledge of morpho-graphemic mappings and word-specific lexical representations. Theoretical implications are also discussed.

Keywords: spelling, morphology, orthographic constraints, orthographic representations, Catalan

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INTRODUCTION

Learning to spell is a process of a phonological nature (Read, 1971; Treiman, 2004). There is substantial evidence, however, that accurate spelling also requires accessing and applying other types of knowledge beyond phonology, such as knowledge of morpheme-to-grapheme mappings (e.g., Nunes et al., 1997a; Pacton and Deacon, 2008) and of orthographic patterns (e.g., Treiman, 1994; Cassar and Treiman, 1997; Pacton et al., 2002; Deacon et al., 2008). This holds true particularly in highly inconsistent orthographies, like English (Borgwaldt et al., 2004; Caravolas et al., 2012), that often need to resolve the ambiguities generated by the multiple alternative spellings for a single phoneme. Nonetheless, users of more consistent orthographies have also been shown to apply non-phonological strategies during spelling (e.g., Defior et al., 2008; Carrillo et al., 2013; Alegría and Carrillo, 2014; Carrillo and Alegría, 2014; Rothe et al., 2014; Marinelli et al., 2017; Angelelli et al., 2018; Zarić et al., 2020). In this paper, we examined the use of non-phonological spelling strategies in Catalan-speaking children in the early and intermediate elementary school years.

Models of Spelling Development

Early models of spelling were concerned with identifying the various phases in its development. A common trait in stage-like theories of spelling was that the various stages were articulated around the role of phonology. For example, most models distinguished between a pre-phonological phase (i.e., pre-literate), where the nature of the link between language and graphemes is unknown to the child; a phonological phase, where the child has grasped the alphabetic principle (Byrne, 1998) and becomes increasingly more able to represent the phonological structure of words; and a "beyond phonology" phase, in which the child recruits the necessary (non-phonological) knowledge to arrive at the conventional spelling of words (e.g., Gentry, 1978; Henderson and Beers, 1980; Frith, 1985). By collapsing all non-phonological aspects into a single, later stage, these theories did little to accommodate their precise nature and their role in learning to spell.

Currently, the widely accepted view on spelling development is that children are sensitive to non-phonological information right from the start of the learning process and that different spelling strategies overlap throughout development (Rittle-Johnson and Siegler, 1999; Treiman, 2017). What is more, sensitivity to non-phonological aspects of spelling, such as the "outer form" of words, actually precedes phonological processes (Treiman, 2017, p. 4). For example, even pre-phonological spellers develop ideas about the number of graphemes that words have, which are consistent with the average word length in the language to which they are exposed (e.g., Ferreiro and Teberosky, 1979). They have also been found to develop orthographic awareness skills prior to their understanding of the alphabetic principle; for instance, they are sensitive to the positions at which the orthography allows letter doubling and those at which it does not (Cassar and Treiman, 1997).

Children appear to be sensitive to morpho-graphemic regularities in spelling as well (e.g., Nunes et al., 1997a,b; Sénéchal, 2000; Deacon et al., 2008). Treiman and Cassar (1996) showed that young children, aged 5–9 years, were more prone to spelling complex consonant clusters correctly when one of the consonants involved a past tense morpheme (e.g., *passed* > *past*). Although it could be argued that complex spelling strategies, such as morphological knowledge, are mostly applicable in highly inconsistent orthographies, such as French or English, there is evidence of the use of morphological strategies in highly consistent orthographies, such as Spanish (e.g., Defior et al., 2008: Suárez-Coalla et al., 2017), Italian (e.g., Angelelli et al., 2014, 2017), or Finnish (e.g., Lehtonen and Bryant, 2005). Defior et al. (2008), for example, studied the spelling strategies of children who speak a regional dialect of Spanish (Andalusian) in which some consonant endings are not pronounced (e.g., /s/ in coda position). They asked children in grades 1–3 to spell words in two conditions: one in which the final /s/ belonged to a verbal morpheme, as is the case with the <s> in *tienes* "have_2nd person singular" and a control condition in which the /s/ did not have any morphological bearing, as is the case with the <s> in *lunes* "Monday." Children across grades were more prone to spelling the silent <s> in the morphologically bound condition than the reverse.

In sum, there is abundant evidence that children are sensitive to regularities beyond phonology and that they apply them from very early on. However, only a few studies have addressed the extent to which these strategies are applied successfully at different educational levels. Moreover, a majority of studies on the use of non-phonological spelling strategies has been conducted in English or French, both languages with highly inconsistent phonographic mappings (Borgwaldt et al., 2004; Caravolas et al., 2012), which could arguably make such strategies indispensable, in contrast to more consistent orthographies that could rely on phonological representations to a much larger degree. In this study, we examined the use of non-phonological spelling strategies in early- (grade 2) and intermediate-level (grade 4) speakers of Catalan, a Romance language spoken in Barcelona (Spain), with a semi-transparent orthography (Llauradó and Tolchinsky, 2016).

Spelling Development in a Second Language

Literacy skills have often been regarded as transferable across the languages spoken by an individual (e.g., Cummins, 1979). However, research on second-language (L2) spelling has reported conflicting findings. On the one hand, L2 learners show low spelling accuracy levels and appear to develop at a slower rate, in comparison with their L1 peers, but their spelling performance appears to be driven by similar skills (Geva et al., 1993; Verhoeven, 2000). Moreover, L2 spelling can be explained, to a great extent, by L1 spelling skills (Sparks et al., 2008), in line with Cummins' (1979) assertion. Conversely, some studies reported that the skills underlying L1 and L2 spelling differ over time (Jongejan et al., 2007), where at least part of the differences may be related to the characteristics of the L1 writing system (Martin, 2017). Importantly, studies of brain dynamics have shown varying patterns of EEG activity as a function of population type (i.e., L1 vs. L2), especially during the spelling of words that require non-phonological strategies (Weber et al., 2013). In this study, we compared children with (L1) and without (L2) exposure to Catalan, the language of instruction, outside school.

Assessing Spelling

The analysis of misspellings allows understanding the type of strategies that children apply during spelling. Several schemes have been proposed that have different outcomes and goals. One type of assessment focuses on giving children (partial) credit for misspellings that to some extent reflect the underlying phonological structure of the target words. For example, some schemes evaluate whether children's written productions represent all phonemes in the target word, using a letter or grapheme that could represent the intended phonemes in some context, even if the resulting production is unconventional, such as writing *<fait> for *fight* (e.g., Ritchey et al., 2010; Treiman et al., 2019). Other assessment schemes evaluate the degree of phonological proximity of the misspelling to the target word. Caravolas et al. (2001) scored each sound segment and their corresponding grapheme on a 0–4 scale, so that any plausible spelling of a specific sound got the maximum score, and close approximations (e.g., graphemes that represent a phoneme that differs from the target one in a single feature) were scored lower, while omissions were given a score of 0 (Caravolas et al., 2001, p. 758). Phonology-centered assessments of spelling have been particularly insightful when evaluating children in the early stages of learning to spell, when they are expected to use a phonological strategy to spell both known and unknown words. Even most spelling instruction programs recommend beginning with phonologically based strategies [e.g., National Reading Panel, 2000; Alves et al., 2018]. Typically, these assessment schemes do not penalize misspellings for not observing orthographic constraints, since the aim is to determine the extent of children's phonographic skills.

As reviewed above, there is abundant evidence of children's early sensitivity to orthographic regularities. Therefore, assessment proposals that focus on evaluating children's knowledge of orthographic patterns or their familiarity with the "outer-form" of words are highly valuable (Treiman, 2017). Letter-based schemes are characterized by giving children credit for partial success in representing the conventional form of printed words. One of such attempts, for example, consists in awarding points for each two-letter sequence that is accurately (i.e., conventionally) represented, plus points for conventionally represented initial and final letters (Frisby, 2016). This type of schemes is useful to tap into children's knowledge of orthographic patterns and to test the strength of their orthographic representations in greater detail than a simple correct/incorrect spelling measure.

Other spelling assessment proposals evaluate a combination of phonological and orthographic knowledge. For example, Treiman et al. (2016) assessed children's spelling considering both phonographic and orthographic skills. Words spelled with all conventional letters received more points than productions that were spelled with phonologically plausible, but unconventional, letters.

Yet other spelling assessment schemes pay attention to children's use of knowledge sources beyond phonology and orthography (e.g., Masterson and Apel, 2010; Bahr et al., 2012; Lee and Al Otaiba, 2017). Bahr et al. used a framework for assessing spelling rooted on triple word-form theory, which takes into account phonological, orthographic, and morphological strategies, the Phonological, Orthographic, and Morphological Assessment of Spelling (POMAS; Silliman et al., 2006; Bahr et al., 2009, 2012). Investigations using the POMAS scheme classify misspellings as phonological when they omit, add, or replace a letter, so that the resulting word does not preserve the phonological structure of the target word, as in *<borked> for *worked.* Orthographic errors are those in which the misspelling does not observe orthographic patterns or constraints, such as *<worcked> for *worked*; they may also include ambiguous letters, such as writing *<worced> for *worked.* Finally, when the child's production has ignored a morpho-graphemic mapping that could resolve an ambiguity, such as *<workt>for *worked*, the error is classified as morphological. Morphological errors are evaluated on both inflectional and derivational morphemes, as well as in word roots (Bahr et al., 2012). Besides the classification of spelling errors under these three categories, the POMAS allows further specifications within categories, identifying specific mistakes of each kind. In the examples above, <borked> would be further classified as a problem with an initial obstruent (Silliman et al., 2006, p. 111). In the case of <worced>, it would be classified as an error that uses an ambiguous letter: both <c> and <k> can represent /k/, as in *cattle* and *kettle*. The case of <workt> is a morphological error that would be further classified as a problem with (past tense) inflections (Bahr et al., 2012, p. 22).

One of the advantages of a framework such as the POMAS is that it allows for a comprehensive analysis of both the phonological and non-phonological strategies that children use for spelling. Another advantage is that it allows using fine-grained analysis criteria as much (or as little) as the research requires. For these reasons, the POMAS should be helpful in accumulating data from different languages, given that the definition of the main categories should be applicable and comparable cross-linguistically, while the specific phenomena evaluated within each category may be adjusted to each language.

Adapting POMAS to Assess Catalan Spelling

In this study, we made two adaptations to the POMAS scheme to suit the specific characteristics of Catalan, as well as to answer specific research questions. Catalan is a Romance language spoken in the region of Catalonia, Spain, where the vast majority of people are speakers of, at least, Spanish and Catalan. Catalan is also the language of instruction throughout preschool, primary, and secondary education. It is also used in most university education. Catalan's morphosyntax is similar to Spanish, in that they both have a rich morphological system, particularly in verbs, and relatively free word order with subject elision (*pro-drop* nature, Bel, 2003). Syllable structure allows, like Spanish, only up to two consonants in onset position, and it is slightly more complex in coda position than Spanish, allowing up to three consonant sounds, as in *boscs*/bosks/"forests." In the region where the data were collected, Barcelona, Catalan uses eight vowel sounds (three more than Spanish) and has vowel-reduction processes, such that in unstressed syllable position only three vowel sounds may occur: /ə, i, u/(Prieto, 2004). This leads to several spelling ambiguities, because there are multiple possible representations for each of these three phonemes. In addition, some consonants are silent: <h> is always silent, <t> is silent after a nasal sound at the end of words, as in *vent*, "wind"; *caminant*, "walking"; and *estudiant*, "student." The letter <r> is also silent when word final, as in *primer*, "first," or *cantar*, "sing." Several consonant sounds may be represented by two or more graphemes. For example, /b/may be written as <b> or <v>, as in *vaixell*, "boat," and *bèstia*, "beast"; likewise, the palatal, fricative, voiced sound/ʒ/may be represented by <g>, as in *albergínia*, "aubergine," and as <j>, as in *jove*, "young." Some of these inconsistencies can be resolved by applying morphological strategies; for example, the silent <t> in *caminant* indicates that the word is a verb in gerund form. Therefore, if the speller is aware of the link between this morpheme, /-an/, and its spelling, <-ant>, the ambiguity disappears. Other inconsistencies can be resolved by applying orthographic knowledge, that is, knowledge of orthographic patterns and constraints. For example, the use of <g> or <j> to represent phoneme /ʒ/ can be disambiguated by taking into account the following vowel sound: front vowel sounds /e, i, ɛ/ combine only with <g>, while all other vowel sounds, combine only with <j>. Thus, the correct spelling of /ʒ/ in *albergínia* and *jove* requires accessing and applying knowledge of orthographic patterns. Finally, certain words or parts of words require a full orthographic representation that, often, may need to be paired with a semantic representation. As such, they require memorizing word-specific spellings, since they are not governed by a morphological or an orthographic rule, and phonographic knowledge is necessary but insufficient to arrive at the conventional spelling. This is the case of <v> in *vaixell*, of <b> in *bèstia*, the first <a> in *cantar*, and many others.

Previous studies using POMAS collapsed irregular or word-specific spelling knowledge together with knowledge of orthographic patterns into a single category of "orthographic knowledge" (e.g., Silliman et al., 2006; Bahr et al., 2012). A first adaptation of the present study is, thus, to differentiate between these two types of knowledge sources. We will classify as "orthographic" those errors in which the ambiguity in the representation of a phoneme can be resolved by resorting to knowledge of legal orthographic patterns, and of context-dependent rules. We will classify errors as "lexical" when the ambiguity in the representation of a phoneme cannot be resolved by resorting to rules that can be generalized to several tokens and, rather, the speller needs to resort to word-specific spelling patterns. Often, this will involve an association between the semantics or the lexical representation of a word and its spelling. For example, /hi:l/ associated with the meaning, "to become healthy," is spelled <heal>, while associated with the meaning "back part of the human foot" is spelled <heel>. A similar distinction was used in another study, also on Catalan (Llauradó and Tolchinsky, 2016). In short, our adaptation entails that the "orthographic" category in POMAS is subdivided into "orthographic" and "lexical" strategies, where the former are characterized by context-dependent rules and knowledge of legal sequences of letters, whereas the latter require rote memorization of words or parts of words, with or without association to a semantic representation.

Our second adaptation of POMAS in the present study is the addition of a new category of *morphophonological* knowledge. This category has been proposed in previous studies of spelling in Dutch and Hebrew (Gillis and Ravid, 2006). Morphophonological representations occur in languages that have productive phonological processes that are triggered as a result of a morphological change. In Catalan, some words include a final occlusive phoneme that is dropped from pronunciation (i.e., it has a zero-realization allophonic variant) only in the case of masculine, singular nouns and adjectives, but that *is* pronounced in other forms of the word. For example, *vent* "wind" is pronounced [ben] in its masculine, singular form, although it is spelled with a silent <t>. In other, usually derived, forms of the word, such as *ventós*, "windy," or *ventet*, "wind.small," the <t> is pronounced. This means that the phonological representation of the masculine, singular word must carry the final stop phoneme, /bent/, which is dropped only in this version of the word, but that resurfaces in every other word form. This category entails both access to phonological representations, in combination with knowledge of morphological processes; thus, because it involves the recruitment of strategies beyond phonology, we included it in the present study.

Previous Research on Spelling Strategies

Some studies using POMAS or evaluating both phonological and non-phonological spelling strategies have examined the relative difficulty of applying them. In general, all strategy types are used even by the youngest participants (e.g., first graders), but there are differences in the rate and developmental route for each type of strategy. Orthographic errors, such as <worcked> or <worced> for *worked*, predominate across grades, while morphological and phonographic errors are the least frequent (e.g., Bahr et al., 2012; Benson-Goldberg, 2014; Llauradó and Tolchinsky, 2016; Joye, 2019). Llauradó and Tolchinsky (2016), who analyzed the spelling errors of 225 Catalan-speaking children in grades 1–5, found that, from grade 2 onward, orthographic (<worcked>) and lexical (<worced>) mistakes were the most frequent and were produced at a similar rate, while they differed significantly from both phonographic (<borked>) and morphological (<workt>) mistakes, which were the least frequent and did not differ from each other. A recent study that developed a pseudo-word spelling task based on triple word-from theory reported that phonographic strategies showed little variation over time, while there were significant differences across grades for orthographic and morphological errors, which decreased over time. This general pattern, according to which error rate is highest for orthographic errors, and lowest for morphological and, especially, phonographic errors, has received support from cross-linguistic studies (e.g., Joye, 2019) and from investigations comparing dyslexic to typically developing controls (e.g., Baseki et al., 2016).

A common trait of previous research using POMAS is that most studies analyzed naturalistic or semi-naturalistic text production data (e.g., Bahr et al., 2012, 2015; Llauradó and Tolchinsky, 2016). While ecologically valid, this procedure has the disadvantage that children may choose less complex or more familiar words (Graham and Harris, 2005), and a different number of opportunities may be created for each type of strategy to be applied. In addition, analyzing misspellings in such a context also poses the challenge of having to determine whether one or more categories apply to a specific error (Bahr et al., 2012, p. 8). For this reason, this study used a bespoke dictation task, in which an equal number of opportunities were created for using each of the non-phonological strategies, while the internal characteristics of the word items (frequency, syllabic complexity, length) were counterbalanced.

To the best of our knowledge, previous research using POMAS has not been used to determine the relative contribution of each type of knowledge source or strategy (i.e., phonographic, orthographic, morphological) to conventional spelling. This is an important point, not only because spelling is paramount to writing quality (e.g., Berninger and Winn, 2006) but also because conventional spelling is the most sensitive measure to predict later literacy gains (Treiman et al., 2019). Arguably, then, understanding the impact that different types of strategies have on children's spelling skills should be instrumental in determining their importance across a key developmental stage (beginning and intermediate elementary grades) and to orient teaching practices into which strategies require the most attention from practitioners.

This Study

The present study improves on previous ones in a number of ways. First, it uses a controlled elicitation procedure, a dictation test, instead of naturalistic or semi-naturalistic text production, so that an equal number of opportunities for using each type of strategy were created. In addition, our test measure allowed us to counterbalance word frequency and complexity. Second, it distinguished between rule-bound non-phonological strategies from those that involve memorizing word-specific patterns, not generalizable to other words. Third, in order to truly assess the contribution of non-phonological spelling strategies to spelling development, all analyses were carried out controlling for each child's phonological accuracy skills. We also included some key demographic variables, sex and parents' socioeconomic status (SES), as control variables, so as to determine their potential effect (Allred, 1990; Aram and Levin, 2001) and examine the unique contribution of spelling skills and strategies. Fourth, we investigated a relatively unexplored language, Catalan, which has a spelling system much more consistent than English, although it is not exempt from complexities. Finally, we examined spelling-strategy use as a function of children's exposure to the language of instruction, in order to contribute to the field of second-language spelling and, more specifically, to the development and teaching of spelling in different learning contexts.

The study was articulated around three main research questions: (RQ1) What is the relative difficulty in the application of non-phonological spelling strategies? We hypothesized that morphophonological strategies would be easiest, because they require accessing a productive process that is triggered very frequently both in speech and spelling. We also expected morphological strategies to be among the easier ones, given that previous studies found that morphological errors were the least or second least frequent error type across grades (Bahr et al., 2012; Llauradó and Tolchinsky, 2016). In addition, it has been suggested that speaking a morphologically rich language, as is the case of Catalan, would facilitate the use of morphological strategies (Gillis and Ravid, 2006). In contrast, we expected that the application of context-dependent rules (i.e., orthographic strategies) would be harder, because their overall incidence is lower than both morphological and morphophonological processes. Finally, we expected that word-specific spellings (i.e., lexical strategies) would be the type of strategy that would be used less successfully across grades and population types, given that they are, by definition, only learned through rote memorization.

Our second research question was (RQ2), what is the relative contribution of non-phonological spelling strategies to conventional spelling scores? In this sense, we expected that all strategy types would have a significant contribution, in line with modern views of spelling development that pose that children are sensitive to various sources of knowledge from early on (e.g., Treiman, 2017).

Our third research question was (RQ3), does the use of non-phonological spelling strategies differ for L2 learners or as a function of children's educational level? With regard to L2 spelling, we expected that children with no exposure to Catalan outside of school would have poorer linguistic and orthographic representations and, therefore, would show more difficulty across all categories. Although the available evidence comparing L1 to L2 spelling is conflicting, we sided with previous literature that poses that, despite differences in performance, a similar pattern of spelling mechanisms underlies both L1 and L2 spelling (e.g., Geva et al., 1993; Verhoeven, 2000). Given that both linguistic and orthographic representations would be less strong in L2 than in L1 children, no single strategy type stood out as more problematic for our L2 participants. Finally, we expected that fourth graders would use all non-phonological spelling strategies more successfully than second graders, but that a similar pattern of difficulty would emerge in both grade levels, in light of previous studies on a similar population (Llauradó and Tolchinsky, 2016).

MATERIALS AND METHODS

Participants

Students were 982 children (497 boys), attending second (494) and fourth (488) grade at schools in the province of Barcelona (Spain). All students were speakers of Catalan, and they were all assumed to be bilingual. Barcelona is a bilingual community, where Catalan is the main language of instruction in elementary education. All students were administered a sociolinguistic questionnaire, which they completed with the help of their teachers. We were particularly interested in the extent to which children used Catalan outside school, so they were asked to declare the language(s) they used with each of their parents, with siblings, and with friends. Based on this information, we classified children as being exposed to Catalan outside of school or not. **Table 1** provides the demographic information and distribution of the sample.

The study belongs to a larger project on writing development that had obtained full clearance by the Ethics Committee of the

TABLE 1 | Participants' distribution and demographic information.

Group	Number of participants	Mean age (SD)	Boys/girls	Mean SES (SD)
Cat0-G2	238	7;5 (0;4)	113/125	41.24 (11.91)
Cat0-G4	214	9;3 (0;8)	118/96	39.70 (10.50)
Cat1-G2	256	7;4 (0;4)	125/131	52.10 (15.38)
Cat1-G4	274	9;4 (0;4)	141/133	53.05 (14.59)

G2, grade 2; G4, grade 4; Cat0, no Catalan exposure outside school; Cat1, some degree of Catalan exposure outside school (e.g., child speaks Catalan with mother).

University. Children were recruited from 13 public schools. All children in the classroom were approached, and we collected data only from those whose parents returned signed consent forms. No children were excluded from the study on the basis of learning disorders.

Task Design and Coding

All the children completed the same bespoke task, which involved spelling 34 words that were dictated orally by the administrator. Only 32 items were used here, as two items targeted stress-mark spelling, which was outside the scope of the present study. The items were selected from a corpus of Catalan children's spelling (Llaurado et al., 2012), available online at http://clic.ub.edu/corpus/en/cesca-en. This corpus includes the words that a sample of more than 2000 children aged 5–16 wrote in response to a semantic category (e.g., clothes, traits of character, natural phenomena, food). Words are lemmatized and can be looked up according to their overall frequency, the educational level of the writer, and they are moreover listed according to the number of alternative (mis)spellings produced. Words that appeared in the 90th percentile or higher were considered high-frequency words, and words in the 10th percentile or lower were considered low-frequency words, as long as they belonged to the corresponding category within which they were produced[1].

The task was designed as follows: 32 items were selected so that at least one phoneme was ambiguous (i.e., it had two or more alternative spellings). A single phoneme was targeted in each item, whose ambiguity could be eliminated by resorting to one of four different sources of knowledge: morphological, morphophonological, orthographic, or lexical. There were eight items per category. In addition, all items were scored as correct or incorrect in terms of their phonographic plausibility, that is, whether the spelling was an accurate phonological representation of the intended word, regardless of positional or other orthographic constraints. Finally, items were scored as correct or incorrect in terms of conventional accuracy (i.e., as they would appear in a dictionary). Items were counterbalanced for frequency: 16 low-frequency items, 16 high-frequency items; for length, with *short* words consisting of one or two syllables and *long* words consisting of three to four syllables; and for syllabic complexity: *simple* words typically consisting of open syllables, usually CV in structure, while *complex* words had, at least, two closed (e.g., CVC) syllables or at least one consonant cluster (e.g., CCV, VCC). All items were validated by two experienced elementary-school teachers, who confirmed the perceptions of frequency and difficulty.

In the morphophonological category, all eight items had a silent <t> that could be recovered in derived words. In the morphological category, four items tested the silent <t> in the gerund form of verbs, and the other four items tested the spelling of the plural of feminine nouns, which contains an ambiguous vowel sound, /ə/, that is always spelled <e>. In the orthographic category, seven items tested <g> vs. <j> alternation, which is regulated by the following vowel, and one item tested knowledge that the spelling of the sound /z/ after a consonant sound is always <z>. Finally, the lexical category tested some of the most common homophonous letters, when they are not governed by other rules: <b, v>, <h, ->, <a, e>, <s, ss, ç>.

Several scores were obtained from the task: (1) a conventional spelling accuracy score, (2) phonographic plausibility, (3) use of morphological strategies, (4) use of morphophonological strategies, (5) use of orthographic strategies, and (6) use of lexical knowledge. Each score was determined independently of the rest, in a binary fashion. Conventional accuracy and phonological plausibility scores were determined for all 32-word items, whereas for each type of non-phonological strategy, the score was the total correct out of the eight items in the category. Cronbach alpha reliability for the test was 0.92. An external research assistant, uninvolved in the present research, scored all words, and the author rescored 28% of a random sample. Inter-rater reliability [intra-class correlation (ICC)] was excellent: 0.989.

Procedure

Children were tested in their regular classrooms. They were given a lined paper, with a dot next to which they had to write each word, one below the other. The administrator explained that they were going to do a dictation task and that they would hear each word three times: first in isolation, then in a carrier sentence, which would help identify the word used in context. Finally, they would hear it one final time, again in isolation. For example, the administrator said, "*Vent. Si fa vent, podrem anar a navegar. Vent.*" "Wind. If there's wind, we can go sailing. Wind." Children were given a few seconds to spell each word. They were encouraged to write them as best they could, even if they were unsure, and told not to worry if they did not know how to spell correctly. Testing lasted between 20 and 30 min, a time that all teachers reported they were used to engaging in writing activities.

All test administrators received training as to how to deliver the sentences in terms of speed, rhythm, and emphasis. They practiced several times until it was clear that they were all reading the items using a similar, natural tone, and without specifically emphasizing any of the words.

[1] Sometimes children would produce a word in response to, for example, traits of character, that had an overall low frequency, such as *beautiful*. These instances were ignored, as the resulting word may not necessarily be a low-frequency token in absolute terms. Rather, they seem to be productions that failed to capture the semantic field that was required.

RESULTS

An inspection of the data showed that they were normally distributed, with skewness values below 3, and kurtosis values under 10 (Kline, 2011). We conducted a series of analyses dividing children into four groups: grade 2 without Catalan exposure, grade 2 with Catalan exposure, and analogous grade 4 groups.

Development of Non-phonological Spelling Strategies

We first addressed the difficulty of applying the various non-phonological spelling strategies in each group. We ran preliminary one-way, repeated-measures ANOVAs to determine whether the type of spelling strategy that needed to be applied in each group of eight words affected performance. Results showed that the type of strategy did have a significant effect on its successful application, with moderate effect sizes across groups (**Table 2**). In general, application of a morphophonological or an orthographic strategy was easier, whereas lexical and morphological strategies were harder strategies across groups. It was apparent, however, that there were differences between groups.

We next conducted a more comprehensive two-level structural-equation model (SEM), in which students were repeatedly measured on the four types of words. Thus, the level 1 data were the item-level performance and the level 2 data were the students. Moreover, this modeling strategy was run within a multiple-group comparison framework, where we used the division of children into the four groups specified above and tested the effect of Strategy Type on performance. The model included sex, parents' SES, and each child's phonographic accuracy score as control variables. The overall unconstrained model goodness of fit was excellent, $Chi^2(8) = 6.96$, $p = 0.541$; RMSEA = 0.000; CFI = 1.00; TLI = 1.00; $SRMR_{within} = 0.000$; and $SRMR_{between} = 0.019$. In each group, we were able to show pairwise comparisons between effects (**Table 3**). For both grades 2 and 4 with no Catalan outside of school, the order of difficulty was the same reported in the ANOVAs (from easiest to hardest): morphophonological, orthographic, morphological, and lexical. All comparisons between each pair of strategies were significant across grade levels. In the case of children with exposure to Catalan outside school, there were only subtle variations. For second graders, letters that required a morphophonological or an orthographic strategy were equally difficult; similarly, applying a morphological or lexical strategy was equally hard. These two pairs of strategies, orthographic and morphophonological, on the one hand, and lexical and morphological, on the other, were significantly different from each other. In the fourth grade, the situation was similar, except that these children found that applying a morphophonological strategy was significantly easier than applying an orthographic one.

TABLE 2 | Comparison between performance measurements of different word types by grade level and exposure to Catalan.

Group	Lexical	Morph	MPhon	Ortho	df	*F*	η_p^2
G2 Cat0	0.35[a] (0.23)	0.31[a] (0.29)	0.53[c] (0.29)	0.42[b] (0.35)	3633	44.32***	0.17
G2 Cat1	0.32[a] (0.22)	0.35[a] (0.28)	0.55[b] (0.30)	0.56[b] (0.32)	3726	79.77***	0.25
G4 Cat0	0.51[a] (0.22)	0.48[a] (0.29)	0.74[c] (0.24)	0.62[b] (0.31)	3579	72.12***	0.27
G4 Cat1	0.53[a] (0.22)	0.55[a] (0.28)	0.78[c] (0.23)	0.67[b] (0.28)	3783	96.98***	0.27

*G2, grade 2; G4, grade 4; Cat0, no Catalan exposure outside school; Cat1, some degree of Catalan exposure outside school (e.g., child speaks Catalan with mother); Ortho, proportion of correct use of orthographic knowledge; MPhon, proportion of correct use of morphophonological knowledge; Morph, proportion of correct use of morphological knowledge; Lex, proportion of correct use of lexical knowledge; Small Latin letters for mean ranking, from the lowest (a) to the highest. ***p < 0.001.*

TABLE 3 | SEM comparative coefficients between types of strategies.

Group	L-O	M-O	MP-O	L-M	L-MP	M-MP
G2 Cat0	−0.07* (0.02)	−0.10* (0.02)	0.13* (0.03)	0.04* (0.02)	−0.19*** (0.02)	−0.23*** (0.02)
G2 Cat1	−0.27* (0.02)	−0.21* (0.02)	−0.01 (0.02)	−0.03 (0.02)	−0.23*** (0.02)	−0.20*** (0.01)
G4 Cat0	−0.11* (0.02)	−0.14* (0.02)	0.12* (0.02)	0.04* (0.02)	−0.22*** (0.02)	−0.26*** (0.02)
G4 Cat1	−0.14* (0.02)	−0.11* (0.02)	0.12* (0.02)	−0.02 (0.02)	−0.25*** (0.01)	−0.23*** (0.01)

*G2, grade 2; G4, grade 4; Cat0, no Catalan exposure outside school; Cat1, some degree of Catalan exposure outside school (e.g., child speaks Catalan with mother); O, proportion of correct use of orthographic knowledge; MP, proportion of correct use of morphophonological knowledge; M, proportion of correct use of morphological knowledge; L, proportion of correct use of lexical knowledge. ***p < 0.001 and *p < 0.05.*

As the SEM model was built of two-level data, we estimated the impact of students' characteristics on performance. The ICCs of the success rate of Strategy Type were above 0.30, which emphasized the potential of variability across students. In all four groups separately, students' sex and parents' SES did not have a significant effect on performance. Phonographic accuracy, in contrast, did have a significant effect, so that children with higher scores on phonographic accuracy tended to apply non-phonological spelling strategies more successfully. Adding Strategy Type as an independent variable considerably improved the explanatory power of the model, as shown by the notable increase pseudo R^2 values of the final model vs. the model without level 1 indicators, from a.14 to a.21 increment (**Table 4**). These findings were consistent across the four groups. Students' demographic characteristics did not impact their performance, while complementary indicators did.

Because there were remarkable similarities across groups in terms of (1) the pattern of relative difficulty for each spelling strategy; (2) the influence of demographic variables; and (3) the role of phonological accuracy, we ran alternative, more parsimonious models in which we constrained either Educational level or Exposure to Catalan to be equal across groups. These models, however, were a significantly worse fit to the data, $Chi^2(6) > 30.21$, $p > 0.05$, supporting the between-group differences reported above.

TABLE 4 | Structural equation modeling results for level 2 student's effects by grade and exposure to Catalan.

			Unconditional model		Conditional model with no strategy type			Final model				
Group	**Sex**	**SES**	**Phono. Acc.**	**ICC**	**Within variance**	**Between variance**	**Within variance**	**Between variance**	**Pseudo R^2**	**Within variance**	**Between variance**	**Pseudo R^2**
G2 Cat0	0.03 (0.02)	−0.002 (0.001)	0.84*** (0.06)	0.383	0.057 (0.003)	0.035 (0.005)	0.056 (0.003)	0.013 (0.003)	0.26	0.046 (0.003)	0.015 (0.003)	0.40
G2 Cat1	−0.02 (0.02)	0.000 (0.001)	0.77*** (0.06)	0.297	0.065 (0.003)	0.027 (0.004)	0.064 (0.003)	0.010 (0.002)	0.20	0.049 (0.002)	0.014 (0.002)	0.38
G4 Cat0	0.01 (0.02)	0.00 (0.001)	0.97*** (0.07)	0.367	0.051 (0.003)	0.030 (0.004)	0.052 (0.003)	0.006 (0.002)	0.28	0.038 (0.003)	0.010 (0.002)	0.49
G4 Cat1	−0.02 (0.02)	0.001 (0.001)	0.93*** (0.06)	0.336	0.050 (0.002)	0.025 (0.004)	0.050 (0.002)	0.004 (0.002)	0.28	0.037 (0.002)	0.008 (0.002)	0.48

*G2, grade 2; G4, grade 4; Cat0, no Catalan exposure outside school; Cat1, some degree of Catalan exposure outside school (e.g., child speaks Catalan with mother); SES, socioeconomic status; Phono. Acc., phonological accuracy. ***p < 0.001.*

The Contribution of Non-phonological Strategies to Conventional Spelling

A second series of models examined the contribution of non-phonological spelling strategies to explaining conventional accuracy scores. We ran a one-level, multigroup SEM, in which conventional accuracy was the dependent variable and each group was defined, as in previous analyses, according to the educational level (grade 2 or 4) and exposure to Catalan outside school (exposure, no exposure). A baseline model that included sex and SES, as well as phonological accuracy, was an excellent fit to the data $Chi^2(8) = 7.10$, $p = 0.530$; RMSEA = 0.000; CFI = 1.000; TLI = 1.002; SRMR = 0.027, and explained a significant proportion of the variance, with R^2 values ranging from 0.430 to 0.583. A model in which children's performance on each type of non-phonological spelling strategy was added as an independent variable was also a great fit to the data, $\Delta Chi^2(26) = 25.1$, $p > 0.05$, and it explained a much larger proportion of variance: $Rs^2 = 0.848$ and 0.865, for grades 2 and 4 without Catalan exposure outside school, and $Rs^2 = 0.841$, and 0.866 for grades 2 and 4 with Catalan exposure outside school, respectively. Finally, a model in which the influence of non-phonological spelling strategies on conventional accuracy was constrained to be equal across all four groups was an excellent fit to the data as well, $Chi^2(46) = 42.05$, $p = 0.638$; RMSEA = 0.000; CFI = 1.000; TLI = 1.001; SRMR = 0.036; $\Delta Chi^2(12) = 9.95$, $p > 0.05$. This final model indicated that, above and beyond the significant effect of phonographic accuracy, conventional accuracy was affected by children's ability to apply non-phonological strategies. In contrast, children's sex or their parents' SES did not exert a substantial influence. Moreover, our results show that morphological and lexical skills contributed more to conventional accuracy scores than either orthographic or morphophonological skills (**Table 5**).

TABLE 5 | Unstandardized estimates, standard errors, and significance values of SEM on conventional spelling accuracy scores (final model†).

Variable	Estimate[2]	SE	p-Value
Lexical[1]	0.320	0.021	<0.001
Morphological[1]	0.326	0.020	<0.001
Morphophonological[1]	0.157	0.020	<0.001
Orthographic[1]	0.180	0.020	<0.001
Phonological accuracy	0.213	0.029	<0.001
Sex	−0.002	0.028	0.087
SES	0.026	0.036	0.232

[1]Strategy type; [2]standardized estimates; SE, standard error. †Model in which all groups were constrained to be equal.

DISCUSSION

This study set out to examine the role of non-phonological strategies in spelling development. A large number of children in grades 2 and 4, speakers of Catalan, completed a dictation task that included words containing a target inconsistent phoneme. Words were grouped according to the type of non-phonological strategy that was required to resolve an inconsistency: morphological, morphophonological, orthographic, and lexical. In addition, children's production of each word was assessed in terms of conventional and phonographic accuracy. We aimed to ascertain the relative difficulty of applying different types of non-phonological strategies, and the contribution of each strategy to conventional accuracy scores, above and beyond the effect of children's phonographic skills.

Development of Non-phonological Spelling Strategies

Our first research question involved the relative difficulty with which children applied the various non-phonological strategies, controlling for their phonographic spelling skills. Our findings showed that, generally speaking, strategies that required morphophonological or orthographic knowledge were mastered earlier than those requiring morphological or lexical knowledge. These results partially confirmed our initial hypotheses. We had expected morphophonological strategies to be on the easier side of the continuum, given that we hypothesized that even our youngest age group, the second graders, would succeed in efficiently accessing the full phonological representation of words. In addition, the phenomenon that creates the inconsistency, namely, the zero-realization of the final stop phoneme, although triggered by a morphological process, is extremely common in everyday speech. Indeed, children seemed to be able to extend their knowledge of phonological representations to represent silent letters and to take advantage of the phonology–morphology interface, in line with previous studies (Gillis and Ravid, 2006).

We had also expected that the lexical strategy would be among the hardest to apply, given that it involves word-specific knowledge, so children would only be able to produce the correct spelling if they already had an orthographic representation of the word. Our findings for the lexical category supported this hypothesis. This means that, even in semi-consistent orthographies like Catalan, strong orthographic representations are needed to spell words that are not entirely rule-bound (e.g., Carrillo et al., 2013; Marinelli et al., 2017; Angelelli et al., 2018). It is likely that vocabulary knowledge and strong semantic representations are advisable teaching strategies to enhance this source of knowledge to improve children's spelling skills.

As for orthographic strategies, we had expected that they would be relatively easy to apply across groups. Results supported this hypothesis. Previous studies using POMAS had found this category to be among the least successful (e.g., Bahr et al., 2012; Llauradó and Tolchinsky, 2016; Daffern and Ramful, 2020). However, we expected a different result based on the fact that, in contrast to most previous research using POMAS, we had distinguished between types of misspellings, reserving this category only for spelling mistakes that involved overlooking orthographic patterns and constraints, while word-specific strategies were under the "lexical" category. Given the fact that our orthographic category required applying constraints to which children have been found to be sensitive from early on (Cassar and Treiman, 1997), our expectation was that our participants would readily choose between homophonous letters using orthographic knowledge. It should be noted, however, that one study, also on Catalan, made the same distinction between orthographic and lexical errors (Llauradó and Tolchinsky, 2016) and found orthographic strategies to be harder than phonographic and morphological strategies. We would speculate that the differences with this previous study are due to the fact that Llauradó and Tolchinsky (2016) analyzed words that children had produced in a relatively free writing context, while we analyzed only a specific segment (phoneme) in a closed group of words, targeting a single ambiguous phoneme, /ʒ/. The orthographic rules that need to be applied to choose between homophonous letters in our case are taught at school, and, although children do make substitution mistakes involving <g> and <j>, it is reasonable to think that a lot of them were aware of the rule. Future studies should test a more comprehensive set of orthographic-bound inconsistencies to determine whether orthographic knowledge is indeed easier to apply than other types of strategies or whether it is highly dependent on the particular context chosen.

The most striking finding concerns our results for morphological strategies. We expected children to be quite adept at using morpho-graphemic regularities to resolve very common spelling inconsistencies, such as plural or gerund formation. Our expectation was based on (1) the results from other studies using POMAS, which reported morphological errors to be one of the least frequent (e.g., Bahr et al., 2012; Llauradó and Tolchinsky, 2016; Daffern and Ramful, 2020) and (2) the fact that children are speakers of a morphologically rich language, which is a key factor in determining their sensitivity to morphological information (e.g., Gillis and Ravid, 2006; Dressler, 2010). Nevertheless, in the present study, morphological strategies were one of the hardest to be applied across educational levels and population types. This was a surprising result, especially because we only tested regular inflectional morphology (plural formation and gerunds), which has been reported to be the easiest context for the application of morphological knowledge in spelling (e.g., Llauradó and Tolchinsky, 2016; Daffern and Ramful, 2020). We believe that the differences with past research are essentially methodological. Most previous studies did not control for the occurrences of morphologically bound spellings. Particularly in studies that analyzed free writing samples (e.g., Bahr et al., 2012), each text will have created a different number of opportunities in which application of a morpho-graphemic mapping was relevant (e.g., regular past tenses, derivates, plurals, and so on). Therefore, the low rates of morphological mistakes found in those studies might be merely reflecting instances in which morphological spellings were applicable (and, certainly, not resolved successfully). The current study arguably provides a more reliable result, given that children encountered the exact same number of opportunities for the application of each strategy. Our findings thus indicate that, even in a language with rich morphology like Catalan, children struggle to mobilize this aspect of their linguistic knowledge to use it for spelling. Previous research on morphological awareness indicated that it is, indeed, a protracted development (e.g., Green et al., 2003), although intervention studies to improve it are generally successful (e.g., Devonshire and Fluck, 2010; Devonshire et al., 2013; Bowers and Bowers, 2017). A key educational implication is, thus, that children need to be taught about the way words are formed and how these forms map onto the orthography.

Contribution of Non-phonological Strategies to Conventional Spelling

A second research question concerned the impact of the various non-phonological spelling strategies on spelling accuracy scores, over and above that of children's phonographic skills. A major novel outcome of the present study was the finding that all non-phonological strategies had a significant and unique contribution to spelling conventionally across educational levels and population types. In this way, we have provided substantial support to theories that pose that learning to spell requires mobilizing various types of linguistic knowledge besides phonological skills (e.g., Rittle-Johnson and Siegler, 1999; Bahr et al., 2009; Treiman, 2017).

Learning to spell involves phonological skills and knowledge of letter-sound correspondences (e.g., Caravolas et al., 2012), but it also requires knowledge of orthographic constraints, of morpho-graphemic regularities, and word-specific orthographic representations of tokens whose spelling cannot be ascertained by generalizable patterns.

The fact that the impact of non-phonological spelling strategies on conventional spelling accuracy was unaffected by children's educational level indicates that these various types of knowledge sources are operative over a wide developmental span. Similarly, the lack of an educational-level effect questions phonology-first approaches to literacy development [e.g., National Reading Panel, 2000] and calls for further research on the importance of mobilizing all levels of linguistic representations relevant for spelling from the earlier grades.

These findings are in line with previous studies claiming that non-phonological spelling strategies are necessary also in orthographies more transparent than English or French (e.g., Lehtonen and Bryant, 2005; Defior et al., 2008; Carrillo and Alegría, 2014; Rothe et al., 2014; Angelelli et al., 2017, 2018). It could be argued that users of orthographies with very consistent phoneme-to-grapheme mappings would rely to a great extent on these simple associations, rather than apply a host of different strategies to spell accurately. However, spellers appear to take advantage of additional knowledge sources that may help to disambiguate between alternative, homophonous spellings regardless, in principle, of how inconsistent the system is. Future research should strive to compare efficacy in strategy use (both phonological and non-phonological) across languages.

Use of Non-phonological Strategies and Grade

As expected, fourth graders outscored second graders in all strategy types, but the general pattern of difficulty applied across grades: morphophonological and orthographic strategies were generally easier to apply than both morphological and lexical strategies. These findings contradict stage-like views of spelling that consider non-phonological strategies a later development (e.g., Frith, 1985). On the contrary, the present study provides further support to spelling development theories that claim that non-phonological spelling strategies are used from very early on (e.g., Rittle-Johnson and Siegler, 1999; Treiman, 2017).

The current study also has clear educational implications. On the one hand, since all non-phonological strategies are paramount for spelling accurately, the teaching of spelling should strive to mobilize all relevant linguistic levels from very early on (e.g., Devonshire et al., 2013). On the other hand, at least from grade 2 onward, teachers should target lexical and morphological strategies in particular, in an overall multidimensional approach to spelling instruction. This is because it was precisely these strategies that not only proved to be the hardest but also were the ones that made the largest contribution to spelling conventionally. Morphological strategies could be taught by raising children's levels of morphological awareness, explicitly teaching them about word formation, while showing the specific (and consistent) way in which morphemes map onto the orthography (Alves et al., 2018). Lexical strategies should be promoted by calling children's attention to word-specific spellings in meaningful contexts, with the overarching goal of facilitating the creation of robust orthographic representations filled with semantic information (Treiman and Kessler, 2014; Treiman, 2017).

L1 and L2 Non-phonological Spelling Strategies

Second-language learners who do not have at-home support of the language of instruction found it harder to apply all spelling strategies, as expected. However, they did not show a unique pattern of strategy use and, just as the L1 participants, found it easier to apply morphophonological and orthographic knowledge, than to apply morphological or lexical knowledge. Despite not showing a unique developmental route, we did not find support for a common model of spelling strategy use (that is, one that did not distinguish between these two population types), suggesting that performance differences were substantial, in line with previous studies (e.g., Geva et al., 1993; Verhoeven, 2000). Notably, this was true for children in grade 2 as for children in grade 4, indicating that having little or no contact with the language of instruction outside school has a long-lasting impact on these children's literacy development. This means that L2 learners require extra support for spelling development beyond phonology (e.g., Bar-Kochva and Hasselhorn, 2017; Bowers and Bowers, 2017), though such training can be similar in nature to training aimed to their L1 peers (e.g., Devonshire and Fluck, 2010; Devonshire et al., 2013; Alves et al., 2018). Without adequate support, however, these children could be at risk of academic failure, in view of the key role that spelling has on writing development (e.g., Juel, 1988; Salas and Silvente, 2019).

The similarities found across L1 and L2 spelling strategies were even clearer in the contribution of the various non-phonological strategies to conventional spelling, above and beyond the contribution of phonographic strategies and demographic factors. Results were consistent with studies reporting that L1 and L2 spelling have similar drivers of performance (Geva et al., 1993; Verhoeven, 2000), given that all non-phonological strategies contributed greatly to explaining conventional spelling accuracy across population types. The lack of qualitative differences in the underpinnings of spelling development as a function of language status (i.e., L1 vs. L2) extends previous assertions about potentially universal factors driving (early) literacy development, at least in alphabetic writing systems (Caravolas et al., 2012).

Limitations

As with virtually every other developmental study, it would have been ideal to test the same hypotheses on longitudinal, rather than cross-sectional data. Future studies should try to inquire whether the same pattern of results is replicated in longitudinal datasets, particularly encompassing a larger developmental span. Another shortcoming of the present study is that it included a limited number of use cases within each strategy type. This affects particularly the application of orthographic knowledge, in view that some orthographic patterns might be more difficult to learn than others. Similarly, research on morphological spelling strategies would benefit from investigations that include a larger set of contexts, with not just inflectional but also derivational morpho-graphemic correspondences. Finally, the present findings may only be applicable to the language under examination, Catalan, although they can be accumulated to previous studies that used a similar error-analysis approach. Cross-linguistic studies should be able to shed light on whether the trends presented are part of a language-general pattern of spelling development.

CONCLUSION

Spelling is a multidimensional skill that involves phonographic knowledge, but to which non-phonological strategies make a large contribution early on in development. We have shown that, even in a relatively consistent orthography, strategies beyond phonology that involve morphophonological, morphological, orthographic, and lexical knowledge are instrumental to spell accurately. In particular, knowledge of morpho-graphemic correspondences and word-specific orthographic representations made the largest contribution to conventional spelling scores in early and intermediate elementary school levels. L2 learners had more difficulty to apply all strategy types than peers who have target language exposure outside school, but they seem to follow the same developmental route. Across population types and regardless of children's sex or their parents' SES, applying morphological and lexical strategies was more challenging than applying morphophonological and orthographic regularities. Spelling instruction should therefore strive to adopt a multidimensional approach from the earlier grades and provide extra support to children without exposure to the language of instruction outside school.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Comissió d'Ètica en l'Experimentació Animal i Humana, UAB. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

NS designed and conducted the study, analyzed the spelling samples, carried out statistical analyses, and wrote the manuscript in its entirety.

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English Word and Pseudoword Spellings and Phonological Awareness: Detailed Comparisons From Three L1 Writing Systems

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Spelling is a fundamental literacy skill facilitating word recognition and thus higher-level reading abilities via its support for efficient text processing (Adams, 1990; Joshi et al., 2008; Perfetti and Stafura, 2014). However, relatively little work examines second language (L2) spelling in adults, and even less work examines learners from different first language (L1) writing systems. This is despite the fact that the influence of L1 writing system on L2 literacy skills is well documented (Hudson, 2007; Koda and Zehler, 2008; Grabe, 2009). To address this shortcoming, this study collected data on real word spelling, pseudoword spelling, and phonological awareness (elision) abilities from 70 participants (23 native speakers; 47 ELLs with alphabetic, abjad, and morphosyllabic L1s). Analyses compared performance on real word and pseudoword spelling between L1 English speakers and ELLs, and additionally among the non-native-speaker L1 groups (categorized into alphabet, abjad, and morphosyllabary groups). Similar comparisons were made across groups for performance on phonological awareness. Further, correlations were calculated between phonological awareness and real word spelling and between phonological awareness and pseudoword spelling, separately for L1 English speakers and the various ESL groups. Spelling accuracy on real words and pseudowords as well as phonological awareness skill differed between native speakers and ESL speakers, and also varied by the ESL speakers' L1 writing system. Theoretically interesting patterns emerged in the spelling data. For example, the morphosyllabic L1 speakers had strong real word spelling (better than the other ESL groups) but greatly decreased pseudoword accuracy (a drop of 59% in accuracy). Although alphabetic L1 speakers had low spelling accuracy in terms of strict scoring, they had lower rates of errors per item, highlighting the importance of scoring approach for shaping the conclusions that are drawn. Error rates also revealed vowels to be more problematic than consonants, particularly in abjad L1 speakers. The results demonstrate that L2 spelling abilities, phonological awareness, and the relationships among them vary by L1 writing system, and that differing approaches to scoring and analysis may lead to varying conclusions.

Keywords: spelling, phonological awareness, ESL, cross-linguistic influence, abjad, morphosyllabary, alphabet

INTRODUCTION

Literacy is widely recognized as a foundational educational skill (e.g., Snow and Strucker, 1999; Gomez and Gomez, 2007). Although it has received somewhat less attention than other critical literacy skills such as phonological awareness, decoding, and word recognition (Treiman, 1997; Joshi et al., 2008), a number of models of first language (L1) spelling development have been articulated (e.g., Chall, 1983; Frith, 1985; Ehri, 1989; Nunes et al., 1997); the relationships between spelling ability and other components of literacy have been examined (Gill, 1989; de Manrique and Signorini, 1994; MacDonald and Cornwall, 1995; Yeung et al., 2011; Graham and Santangelo, 2014), and best approaches for spelling instruction have been established (e.g., Graham, 1999; Moats, 2005; Joshi et al., 2008; Bear et al., 2019).

In contrast, spelling ability has received relatively little attention in second language (L2) learners. Existing research shows evidence both for overlap with L1 spelling (Wade-Woolley and Siegel, 1997; Durgunoğlu, 1998; Figueredo, 2006; Jongejan et al., 2007) and L1-based differences (Koda, 2004, 2008; Dixon et al., 2010; Dich and Pedersen, 2013). In particular, L2 spelling is influenced by the characteristics of learners' L1 writing system (Ziegler and Goswami, 2005; Koda and Zehler, 2008; Frost, 2012; Perfetti and Verhoeven, 2017). However, much of this research has focused on young bilingual students, not adult L2 users, and cross-linguistic comparisons with the same tasks and materials are limited. Further, little is known about how L2 spelling ability relates to other L2 literacy skills, and how these relationships vary in learners from different L1s.

To address these gaps, the current study analyzed English spelling data from adult ESL users in three L1 groups (based on L1 writing system: alphabet, abjad, or morphosyllabary), as well as a native speaker comparison group. Data were additionally collected on phonological awareness ability to facilitate cross-linguistic comparisons of not only spelling ability, but also how spelling is related to other key literacy skills.

SPELLING AS A CENTRAL COMPONENT OF LITERACY

Although spelling ability frequently gets only secondary attention in literacy research (Treiman, 1997; Joshi et al., 2008), it is in fact strongly interrelated with overall literacy skills. Rather than being simply a peripheral, rote, memory-based skill, spelling is fundamentally connected to overall reading and writing abilities (Ehri and Wilce, 1987; Ehri, 1997, 2000; Joshi et al., 2008). Much of this connection is due to the fact that both word recognition and spelling ability draw on the same underlying lexical representations (Snow et al., 2005; Russak and Kahn-Horwitz, 2015). Thus, stable and fully-specified spellings (orthographic forms) within lexical representations support rapid, automatic word recognition during fluent reading (Perfetti and Hart, 2002; Ehri and Snowling, 2004; Perfetti, 2007). Without such robust lexical representations, additional cognitive resources must be allocated to decoding and bottom-up word recognition and retrieval, thus limiting the cognitive resources that can be dedicated to higher-level reading skills such as text integration and inferencing (Ehri, 2005; Mehta et al., 2005; Perfetti, 2007).

Spelling is also a key component of writing. The Simple View of Writing (e.g., Berninger et al., 2002; Berninger and Amtmann, 2003) describes four components of writing skill: transcription (including handwriting and spelling), executive functions (including attention, planning, and reviewing), working memory, and text generation. If one component, such as transcription (i.e., spelling), requires extra attentional resources, the cognitive capacity available for the other components of writing decreases (Wollscheid et al., 2016). In fact, students with poor spelling skills typically write less, with more restricted vocabulary, and at an overall lower level of quality than students with good spelling skills (Graham et al., 1997; Singer and Bashir, 2004; Moats et al., 2006; Re et al., 2007).

Further evidence for the interconnectedness of spelling with word recognition, reading comprehension, and writing comes from research examining the impact of instructional interventions. Targeted spelling instruction improves not only spelling and phonological awareness (e.g., Graham et al., 2002; Berninger and Amtmann, 2003; Graham and Santangelo, 2014) but also word recognition (Post et al., 2001; Graham et al., 2002; Graham and Hebert, 2011), reading fluency (Graham and Hebert, 2011), and writing fluency (Graham et al., 2002). Thus, spelling ability provides a window onto the underlying lexical representations that serve as a foundation for readers' general literacy skills, both productive and receptive, and can also provide an avenue for improving overall literacy.

One perennial point of contention in literacy research is whether word recognition is best modeled via a single-route, connectionist approach (e.g., Seidenberg and McClelland, 1989; Plaut et al., 1996) or a dual-route approach, with one route progressing via assembling grapheme-phoneme correspondences and one progressing via direct lexical look-up (e.g., Coltheart et al., 1993, 2001). However, this debate is not limited to word recognition. Spelling ability may also draw on multiple component skills, including phonological awareness, recoding, and multiple aspects of orthographic knowledge. These can include knowledge of both whole-word orthographic forms, also known as mental graphemic representations (Apel, 2011) or lexical orthographic knowledge (e.g., Deacon et al., 2012; Conrad et al., 2013; Apel et al., 2019); as well as restrictions on allowable letter combinations and placements, also called graphotactics (e.g., Verhoeven et al., 2006; Deacon et al., 2008), orthotactics (e.g., Masterson and Apel, 2007; Georgiou et al., 2009), or sublexical orthographic knowledge (e.g., Cunningham et al., 2001; Loveall et al., 2013).

Cross-linguistic research on spelling development suggests that the degree to which individuals rely on these two major sources of knowledge – phonological and visual/orthographic – varies across languages, and in particular across writing systems. As has been widely discussed in the literature on cross-linguistic literacy, the varying phonological and morphological characteristics of different languages are typically associated with particular approaches to encoding the language in writing, such that "every language gets the writing system it deserves" (Frost, 2012, p. 266).

Although there are different approaches to classifying writing systems (e.g., compare Daniels and Bright, 1996; Perfetti and Dunlap, 2008; Sampson, 2015), a relatively comprehensive approach uses five general categories: alphabet, abugida, abjad, syllabary, and morphosyllabary. An alphabet is a writing system in which all sounds – both consonants and vowels – have full, independent graphic forms representing them. Languages such as Spanish, Russian, and Greek use alphabets. An abugida (or alphasyllabary) is similar to an alphabet in that it is a segmental system (each spoken sound is represented by a distinct graphic form); however, it differs in that the main forms represent consonants. Vowels are also written but are generally represented by small diacritics or modifications to the main consonant graphs. Many Brahmic languages (including Hindi, Marathi, Nepali, Sanskrit, and Thai), Ethiopic languages (including Ge'ez, Amharic, and Harari), and Cree languages (including Ojibwe and Algonquian) use abugidas. An abjad is similar to an abugida in that it is a consonant-central writing system, with vowels written as diacritics above or below the main line of text; the primary difference is that these vowel graphs are *optional* in abjads, and in fact are frequently omitted in texts written for fluent adult readers (e.g., Share and Levin, 1999; Abu-Rabia, 2001, 2002; Frost, 2006). Arabic and Hebrew are both written with an abjad. In a syllabary, each graph represents a distinct combination of consonant(s) and vowel(s) (a syllable), with additional graphs available for syllable codas as relevant. Japanese uses three different writing systems, two of them (hiragana and katakana) with syllabaries; Cherokee, Vai, and the Yi languages of China also use syllabaries. Finally, in a morphosyllabary (or logography) the written graphs represent whole morphemes, the smallest meaningful unit of language. Similar to a syllabary, morphemes are typically monosyllabic in such languages, meaning that the written graphs correspond to single spoken syllables. However, in a syllabary the number of graphemes is limited to the number of spoken syllables and there is an established relationship between written and spoken forms. In contrast, in a morphosyllabary, there are many more graphemes than spoken syllables, and written forms typically indicate only minimal information about pronunciation. Chinese languages such as Mandarin and Cantonese use a morphosyllabary.

Using a similar classification scheme, Frost (2012, pp. 267–270) describes a variety of ways in which the linguistic characteristics of languages (e.g., phonological limitations on syllable structures, the number of possible syllables, the richness of morphological paradigms) have resulted in pairings between spoken and written language systems with optimal information encoding. For example, in Mandarin and Cantonese, most words comprise only one morpheme (with very little inflection or derivation), most morphemes are monosyllabic, and syllables are typically restricted to four or fewer sounds. This results in a very small number of spoken syllables, and thus a large number of homophones (Chao, 1968). Although many homophones can be distinguished phonetically by tone, the use of additional graphs indicating semantics (i.e., semantic radicals) must be used in written text to disambiguate meaning – pushing Mandarin and Cantonese toward the use of a morphosyllabic writing system (DeFrancis, 1989; Wang et al., 2009). In contrast, Finnish makes extensive use of derivational and inflectional suffixes, resulting in words that are frequently 14 letters or longer (e.g., *kirjastokortti* 'library card,' *perhetapahtuma* 'family event') (Kuperman et al., 2008). However, it uses a highly regular (i.e., shallow) alphabet, with near-perfect consistency between graphemes and phonemes; this high degree of regularity is necessary for such long, morphologically complex words to be read effectively.

In conjunction with these linguistic variations in languages using different writing systems, the approaches to text processing that develop in fluent readers of different languages are strongly influenced by such L1 characteristics (e.g., Ziegler and Goswami, 2005; Tolchinsky et al., 2012). For example, in shallow writing systems such as German or Spanish, knowledge of phoneme-grapheme correspondences and phonological segmentation abilities are sufficient to accurately spell or read most words (e.g., Frith et al., 1998; Ziegler and Goswami, 2005). However, in deeper orthographies such as English, readers and spellers must have knowledge not only of single sound-form mappings but also more complex mappings between phonological units of varying sizes (e.g., phonemes, rhymes, and syllables) and orthographic sequences of varying lengths (e.g., single letters, digraphs such as < th > or < ck >, non-linear spelling patterns such as VCe, e.g., *hope*, and rimes such as *-ough*) (Goswami et al., 1998; Ziegler and Goswami, 2005).

Research has also indicated that individual spellers may take somewhat different approaches to spelling – either lexical (whole-word) or sub-lexical (based on phoneme-grapheme correspondences) (e.g., Baron, 1979; Treiman, 1984; Castles et al., 1997). These individual tendencies for spelling strategies also pattern with reading skills. For example, Lennox and Siegel (1993, 1996) examined the types of spelling errors produced by children with different profiles of reading and spelling skills. They found that children with reading disabilities and other poor spellers tended to produce less phonologically accurate misspellings and relied on phonological correspondence information to spell words less frequently than normally achieving children and good spellers (see also Bruck and Treiman, 1990; Lennox and Siegel, 1998; Cassar and Treiman, 2004). Thus, literacy research has established the impact of L1 linguistic structure, L1 writing system, and individual differences in overall literacy skills on individuals' spelling abilities.

UNDERSTANDING L2 SPELLING

Given the importance of high-quality lexical representations to support word recognition and overall reading skill, surprisingly few studies have included a detailed consideration of L2 spelling skills. This is true even for English as a second/foreign language (ESL/EFL), despite the international prevalence of this second language (e.g., Crystal, 2003). However, the broad themes and findings that have been established are described below to provide a framework for ESL spelling as examined in the present study.

A number of studies on ESL spelling have found substantial overlap between L1 (English) spelling development and L2 (ESL/EFL) spelling development. For example, ESL spelling ability relies on largely the same component literacy skills (e.g., phonological awareness, orthographic knowledge, auditory perception) as does monolingual L1 English spelling ability (Wade-Woolley and Siegel, 1997; Durgunoğlu, 1998; Figueredo, 2006; Jongejan et al., 2007; Russak and Kahn-Horwitz, 2015). In addition, L2 spellers may, in principle, rely on both or either of phonological and orthographic knowledge for spelling in L2. However, research on L2 text processing and spelling suggests that the type of knowledge used most frequently varies based on learners' L1 background and the literacy processes that develop as attuned to their L1 language and writing system. In other words, the L1-specific text processing approaches that develop along with initial literacy acquisition frequently transfer to and influence L2 text processing approaches (Durgunoğlu, 2002; Wang et al., 2003; Koda and Zehler, 2008). More specifically, learners from shallow, alphabetic L1 backgrounds tend to rely more on phonological skills and decoding/recoding for word-level literacy (including word recognition and spelling), whereas learners from deeper, opaque, and non-alphabetic L1 backgrounds tend to rely more on visual and orthographic information for the same literacy skills (e.g., Holm and Dodd, 1996; Nassaji and Geva, 1999; Wade-Woolley, 1999; Akamatsu, 2003; McBride-Chang et al., 2004; Mayer et al., 2007; Martin and Juffs, in press).

These general tendencies also influence the types of spelling errors or misidentifications that are made most frequently by learners from different L1 backgrounds. For example, Wang and colleagues (Wang et al., 2003; Wang and Koda, 2005) examined the word identification and phonological awareness skills of university-level L1 Chinese and L1 Korean ESL students. They found that the L1 Korean speakers had greater accuracy on a word naming task (dependent on phonological skills) and had more frequent regularization errors in their pronunciations of irregular words than the L1 Chinese speakers. On the other hand, the L1 Chinese speakers were more accurate in a semantic categorization task involving differently spelled homophones (demonstrating an ability to rely on orthographic over phonological form) but had more difficulty making judgments to words with similar spellings. Similarly, in work examining L1 English and L1 Chinese learners of L2 Japanese, Li and Martin (Li and Martin, 2017; Martin and Li, 2017) found that L1 Chinese speakers produced substantially fewer errors overall, and that the types of orthographic errors produced revealed L1 influence. For example, the L1 English speakers tended to produce phonologically based errors, in particular errors resulting from maintaining the English (L1) pronunciation of words borrowed into Japanese, whereas the L1 Chinese speakers tended to transfer in (simplified) Chinese characters in place of the target Japanese kanji characters.

Another well-established domain of L1 influence on L2 spelling is L1 phonology: when examining the specific misspellings produced by L2 spellers, errors frequently appear for the spellings of sounds that do not exist or are not contrastive in learners' L1. For example, Wang and Geva (2003a,b) examined the ability of L1 Cantonese-speaking children to spell words with /θ/ < th > and /ʃ/ < sh > – phonemes not present in Cantonese. The L1 Cantonese speakers had substantially more errors than matched L1 English speakers in spelling these non-native phonemes as well as lower overall pseudoword spelling accuracy, though they had stronger overall performance on a confrontation spelling task (dependent on orthographic knowledge).

The two groups with the most available research demonstrating an effect of L1 phonology on L2 spelling are L1 Spanish speakers (Cronnell, 1985; Zutell and Allen, 1988; Ferroli and Shanahan, 1992; Fashola et al., 1996; Cook, 1997) and L1 Arabic speakers (Ibrahim, 1978; Cook, 1997; Fender, 2008; Allaith and Joshi, 2011; Saigh and Schmitt, 2012). In Spanish, for example, spellers have been found to frequently confuse < b > and < v > (e.g., < bery > for *very*) and < s > and < z > (e.g., < eazy > for *easy*), as well as the spellings of /i/ and /ɪ/ (e.g., < it > for *eat*). Similarly, in L1 Arabic speakers, spelling errors frequently involve confusion between graphemes representing sounds present in Arabic (e.g., /b/ and /f/) and their voicing pairs, representing sounds absent from Modern Standard Arabic (e.g., /p/ and /v/); examples include < cabable > for *capable* and < habet > for *habit*. Similar evidence of L1 phonological influence on L2 spelling has been documented for L1 German (James and Klein, 1994) and L1 Japanese (Cook, 1997).

Another area of L1 influence on L2 spelling, and L2 text processing in general, is the differential levels of attention that readers and spellers from some L1s have for vowels versus consonants. More specifically, individuals from an abjad L1 (e.g., Arabic, Hebrew) show less awareness of, lower sensitivity to, or less robust representations of vowels compared to consonants – "vowel blindness" (Ryan and Meara, 1996). Early studies with L1 Arabic speakers showed that they process Roman letters much differently from L1 English speakers (Randall and Meara, 1988) and have reduced awareness of vowel letters in English words (Ryan and Meara, 1991; partially replicated by Hayes-Harb, 2006). More recent studies have shown that L1 Arabic speakers use only minimal phonological information in text processing (Fender, 2003; Martin and Juffs, in press). In terms of spelling ability, L1 Arabic speakers also show greater difficulties spelling vowels, particularly short vowels (which are typically not represented in their L1 writing system) than other ESL students (Fender, 2008; Saigh and Schmitt, 2012). A similar pattern has also been found for L1 Hebrew speakers (Martin, 2017).

In sum, the limited research on ESL spelling abilities indicates that there is substantial overlap with L1 spelling development, including the reliance on phonological versus orthographic information. However, ESL spelling is also influenced by both L1 phonology (often leading to difficulties spelling non-native phonemes or distinguishing spellings for non-native phonemic contrasts) and the L1 writing system (e.g., reduced sensitivity to vowels in abjad L1 speakers; greater reliance on phonological skills in alphabetic L1 speakers and greater reliance on visual-orthographic skills in morphosyllabic L1 speakers).

THE CURRENT STUDY

As detailed above, despite the centrality of spelling ability to overall literacy skill, relatively little research has examined ESL spelling abilities. Most of the research that has been conducted – like L1 spelling studies (Arndt and Foorman, 2010) – has focused on younger learners, not adults (Allaith and Joshi, 2011), and has not always included a comparison group of L1 English speakers. This makes the patterns of ESL spelling errors difficult to interpret (Fender, 2008; Saigh and Schmitt, 2012). In addition, this research has typically investigated only single L1 groups at a time (Figueredo, 2006), leading to difficulties in making accurate cross-linguistic comparisons of ESL spelling skills due to differences in task characteristics, target words, and lexical and learner characteristics (Ziegler and Goswami, 2005). Finally, little research has examined L2 spelling in relation to other key component literacy skills, such as phonological awareness, despite the fact that phonological awareness is a fundamental literacy skill for English and is closely connected with spelling ability in L1 English readers (Fender, 2008).

The current study was conducted in an effort to begin filling in these gaps. In contrast to much of the existing research, the target participants were adult learners of ESL at the university level (rather than children in elementary or middle school). Data were collected from learners with a range of L1 backgrounds; these were grouped into three main categories on the basis of L1 writing system: alphabet, abjad, or morphosyllabary. Collecting data from this range of L1 backgrounds facilitates cross-linguistic comparisons using uniform task items and procedures. In addition, data were collected from a comparison group of L1 English speakers, so that ESL performance (across L1 groups) could be understood in the context of native-level performance. Finally, participants also completed a phonological awareness task, so that spelling ability could be examined in relation to this key literacy skill. Phonological awareness was chosen because it is a critical component skill for literacy, particularly in the opaque orthography employed in English (e.g., Adams, 1990; Hanley et al., 2004; Ziegler and Goswami, 2005). It also has a reciprocal, mutually supportive relationship with spelling and reading ability (e.g., Read et al., 1986; Perfetti et al., 1987; Goswami and Bryant, 1990; Huang and Hanley, 1995; Burgess and Lonigan, 1998), and may provide insight regarding the strength of participants' general phonological skills and the degree to which they rely on such skills for their L2 English spelling.

MATERIALS AND METHODS

Participants

Data were collected from 70 participants: 47 ESL learners and 23 L1 English speakers (serving as a native speaker reference group). All participants were adult (18 years or older) students recruited from the intensive English program, undergraduate, and graduate student populations at a mid-sized regional university in the midwestern United States. The 47 ESL learners (23 female, 21 male, 3 with no data; average age 22.18 years) were either preparing for or enrolled in undergraduate or graduate studies. They were classified into three groups based on the type of writing system employed in their L1: 27 alphabetic L1 participants (24 L1 Spanish speakers, 1 L1 French speaker, 1 L1 Korean speaker, and 1 L1 Efik speaker); 7 abjad L1 participants (all L1 Arabic speakers); and 13 L1 morphosyllabary participants (all L1 Mandarin Chinese speakers). Specific age data were not available for the 23 L1 English speakers (19 female, 4 male), though all participants fell within the typical undergraduate student age range of 18–25 years old.

For the ESL learners, L2 proficiency information was available in the form of a score from one or both of two different standardized English proficiency tests: the Test of English as a Foreign Language (TOEFL) or the Oxford Online Placement Test (OOPT). Because there is no established, validated method of converting scores from one of these two assessments to an equivalent score on the other, the scores on each assessment were instead converted to the corresponding level of proficiency as described in the Common European Framework of Reference (Council of Europe, 2001): A1, A2, B1, B2, or C1 + (see **Table 1** for detailed descriptions). Due to limited sample sizes for each L1 at each proficiency level, these CEFR levels were further combined into two main proficiency levels: lower proficiency (A1 through B1 levels) and higher proficiency (B2 through C1 + levels). This cut-off, of B1 vs. B2 levels as distinguishing higher versus lower proficiency, is consistent with the cut-offs used for undergraduate (B2) or graduate (C1) admissions at the institution where data were collected. There were 22 lower-proficiency and five higher-proficiency alphabetic L1 speakers, five lower-proficiency and two higher-proficiency abjad L1 speakers, and five lower-proficiency and eight higher-proficiency morphosyllabic L1 speakers.

Materials and Procedure

The first task completed by participants was a brief survey that elicited participants' L1. Following this, participants completed two spelling dictation measures: one comprising 34 real English words and one comprising 16 English pseudowords (see the **Supplementary Material** for items and details of item characteristics). The 34 real word items were a subset of the items used by Fender (2008). They included 12 items targeting within-word spellings, 11 targeting syllable juncture spellings, and 11 targeting derivational spellings. The specific items chosen were selected to include a variety of orthographic features (e.g., consonant and vowel digraphs, silent < e >), syllable structures (e.g., single consonants and consonant clusters in onsets and rhymes), and number of syllables (2–4; average 2.12). Words had an average of 7.18 letters and 1.50 morphemes, and across all items there were 71 judgments of consistent syllables and 73 judgments of inconsistent syllables[1]. The 16 pseudoword items were taken from a variety of published studies examining pseudoword spelling in ESL/EFL learners (Liow and Poon, 1998; Wang and Geva, 2003b; San Francisco et al., 2006). These specific items were again chosen to represent a variety of orthographic features and syllable structures. Pseudowords were all monosyllabic and had an average of 4.31 letters and 3.50 phonemes. Across all items there were 14 judgments of consistent syllables and 18 judgments of inconsistent syllables.

[1]Both feedback (spelling) and feed-forward (reading) consistency information was obtained from Ziegler et al. (1997), giving each syllable two consistency judgments. For words with more than one syllable, feedback and feed-forward consistency were determined for each syllable separately. This was done as a proxy for consistency in multisyllabic words, given that objective statistics for the consistency of such words are not available.

Participants were tested in a group setting. Each participant was seated at an individual Macintosh computer in a computer lab. Participants completed the real word spelling dictation measure first. They were told that they would hear an English word pronounced aloud twice, with a pause in between, and given approximately 10–12 s to write down the word with the most accurate spelling they could. Following this, participants completed the pseudoword spelling dictation measure. For this task, they were told that they would hear a made-up word that was not a real English word, and that they should write down how they thought the word should be spelled if it were a real English word. Again participants heard each item pronounced aloud twice and were given approximately 10–12 s to write down the spelling. All items were pronounced carefully by a female native English speaker trained in ESL.

The final task completed by participants was a computer-adapted version of the Elision task from the Comprehensive Test of Phonological Processing (Wagner et al., 1999) to measure their phonological awareness. This task comprised six unscored practice items (with feedback), involving the deletion of a whole syllable from a disyllabic word (3), the deletion of the initial phoneme from a monosyllabic word (2), and the deletion of the final phoneme from a monosyllabic word (1). The initial unscored items were completed as a group, following the standard procedure describe in the Examiner's Manual for the CTOPP. These were followed by 20 scored items (without feedback), completed individually by each student on their computer. The 20 scored items targeted the deletion of a variety of units: whole syllables from disyllabic words (3), single consonants in word-initial (3), medial (3), or final (2) positions, and consonants from within a consonant cluster in word initial (5), medial (2), or final (2) positions. Total testing time took approximately 30–60 min.

Scoring and Analyses

Spelling responses were first typed verbatim into a digital spreadsheet for scoring and analysis. Any doubts about the written responses (e.g., due to unclear handwriting) were resolved through discussion between a trained research assistant and the first author. A strict scoring procedure (implemented via an Excel formula) was used to determine accuracy: if the participant's production was spelled exactly correct it was marked as correct, and any deviations from the correct spelling resulted in an incorrect marking.

Responses to the Elision items were also transcribed into a digital spreadsheet for scoring and analysis. All responses to the Elision task were transcribed by a minimum of two trained research assistants; inter-rater reliability was initially 89% and items for which there was disagreement were resolved after consulting a third coder.

Pearson correlations and generalized linear mixed effects models with random intercepts for participants and items (implemented via the lme4 package in R, Bates et al., 2015) were used to analyze the data. A range of participant and item characteristics and the two-way interactions among them were initially considered for inclusion during model building: participants' age and gender; spelling items' length (in letters), consistency, and orthographic neighborhood; and real words' frequency and mean bigram statistics. However, neither age nor gender had a significant relationship with any of the outcome variables (age: $r = 0.17$, $p = 0.30$ with word accuracy, $r = 0.24$, $p = 0.15$ with pseudoword accuracy, $r = 0.21$, $p = 0.23$ with elision accuracy; gender: $r = 0.09$, $p = 0.47$ with word accuracy, $r = 0.18$, $p = 0.15$ with pseudoword accuracy, $r < 0.01$, $p = 0.98$ with elision accuracy) and were thus not included in any of the mixed effects models.

Correlations were also used to guide the selection of item characteristics to consider in modeling word and pseudoword spelling accuracy. Although no item characteristics were significantly associated with pseudoword spelling accuracy (length in letters, $r = -0.18$, $p = 0.50$; number of orthographic neighbors, $r = 0.34$, $p = 0.20$; frequency of orthographic neighbors, $r = -0.14$, $p = 0.61$; positional biphone frequency, $r = -0.05$, $p = 0.85$, positional letter frequency, $r = -0.06$, $p = 0.84$; consistency, $r = -0.17$, $p = 0.54$), a number of item characteristics were significantly associated with real word spelling accuracy (length in letters, $r = -0.52$, $p = 0.002$; number of orthographic neighbors, $r = 0.39$, $p = 0.02$; number of phonological neighbors, $r = 0.34$, $p = 0.049$; age of acquisition, $r = -0.52$, $p = 0.002$). Thus, length and number of orthographic and phonological neighbors were considered in model building. Log frequency ($r = 0.23$, $p = 0.20$ with real word accuracy) was also considered due to its substantial influence in general lexical processing; however, age of acquisition was not included in models because of its high correlation with length ($r = 0.81$, $p < 0.001$) and concerns regarding issues with multicollinearity.

Finally, Pearson correlations were calculated to examine the relationships among real word spelling accuracy, pseudoword spelling accuracy, and phonological awareness skills; these correlations were calculated separately for each L1 background group in order to determine whether the different groups showed similar patterns of interrelatedness among these skills. For the ESL groups, two-step hierarchical regressions (blockwise entry with proficiency level dummy-coded as lower-proficiency vs. higher-proficiency entered first) were used to calculate semi-partial correlation coefficients between real word spelling accuracy, pseudoword spelling accuracy, and elision accuracy, controlling for L2 English proficiency.

RESULTS

Accuracy

Relationship Between Spelling and Phonological Awareness Accuracy

Pearson correlations (zero-order for L1 English speakers, semi-partial for ESL groups) among real word spelling accuracy, pseudoword spelling accuracy, and elision accuracy are in **Table 2**. As can be seen, the patterns of interrelationships among these three tasks differed across all participant groups. The L1 English speakers had significant positive correlations between real word spelling accuracy, pseudoword spelling accuracy, and elision accuracy. Similar to the L1 English speakers, the alphabetic L1 speakers showed a significant correlation between

TABLE 1 | Common European Framework of References (CEFR) proficiency level descriptions.

General description	*Proficiency level*	*Description*
Proficient User	*C2*	*Can understand with ease virtually everything heard or read. Can summarize information from different spoken and written sources, reconstructing arguments and accounts in a coherent presentation. Can express him/herself spontaneously, very fluently and precisely, differentiating finer shades of meaning even in more complex situations.*
	C1	*Can understand a wide range of demanding, longer texts, and recognize implicit meaning. Can express him/herself fluently and spontaneously without much obvious searching for expressions. Can use language flexibly and effectively for social, academic and professional purposes. Can produce clear, well-structured, detailed text on complex subjects, showing controlled use of organizational patterns, connectors and cohesive devices.*
Independent User	*B2*	*Can understand the main ideas of complex text on both concrete and abstract topics, including technical discussions in his/her field of specialization. Can interact with a degree of fluency and spontaneity that makes regular interaction with native speakers quite possible without strain for either party. Can produce clear, detailed text on a wide range of subjects and explain a viewpoint on a topical issue giving the advantages and disadvantages of various options.*
	B1	*Can understand the main points of clear standard input on familiar matters regularly encountered in work, school, leisure, etc. Can deal with most situations likely to arise whilst traveling in an area where the language is spoken. Can produce simple connected text on topics which are familiar or of personal interest. Can describe experiences and events, dreams, hopes and ambitions and briefly give reasons and explanations for opinions and plans.*
Basic User	*A2*	*Can understand sentences and frequently used expressions related to areas of most immediate relevance (e.g., very basic personal and family information, shopping, local geography, employment). Can communicate in simple and routine tasks requiring a simple and direct exchange of information on familiar and routine matters. Can describe in simple terms aspects of his/her background, immediate environment and matters in areas of immediate need.*
	A1	*Can understand and use familiar everyday expressions and very basic phrases aimed at the satisfaction of needs of a concrete type. Can introduce him/herself and others and can ask and answer questions about personal details such as where he/she lives, people he/she knows and things he/she has. Can interact in a simple way provided the other person talks slowly and clearly and is prepared to help.*

Descriptions are taken from the official site of the Council of Europe (https://www.coe.int/en/web/common-european-framework-reference-languages/table-1-cefr-3.3-common-reference-levels-global-scale).

TABLE 2 | Correlations among spelling and phonological awareness accuracy by L1 background.

	L1 English (*n* = 23)	
	Real word accuracy	**Pseudoword accuracy**
Pseudoword accuracy	0.43*	– –
Elision accuracy	0.50*	0.66**
	Alphabetic L1 (*n* = 27)	
	Real word accuracy	**Pseudoword accuracy**
Pseudoword accuracy	0.17	– –
Elision accuracy	0.36*	0.04
	Abjad L1 (*n* = 7)	
	Real word accuracy	**Pseudoword accuracy**
Pseudoword accuracy	–0.29	– –
Elision accuracy	–0.38	0.79*
	Morphosyllabic L1 (*n* = 13)	
	Real word accuracy	**Pseudoword accuracy**
Pseudoword accuracy	–0.16	– –
Elision accuracy	0.41	0.10

$^*p < 0.05$; $^{**}p < 0.01$. Correlations for the L1 English group are zero-order; correlations for the ESL groups are semi-partial (controlling for L2 English proficiency).

real word spelling accuracy and phonological awareness. However, unlike the L1 English speakers, the alphabetic L1 speakers did not have significant correlations between pseudoword spelling accuracy and phonological awareness, or between real word and pseudoword spelling accuracy. The abjad L1 speakers had a different pattern: a significant correlation between pseudoword spelling accuracy and phonological awareness, but not between real word spelling accuracy and phonological awareness (though they also showed no significant correlation between real word and pseudoword

TABLE 3 | Mean word and pseudoword spelling accuracy and elision accuracy (% correct) by L1 background and ESL proficiency level.

	Real word spelling	Pseudoword spelling	Elision
L1 English	94.25 (7.18)	66.11 (15.32)	78.91 (23.50)
Alphabetic L1	59.63 (19.80)	12.96 (15.84)	36.49 (22.53)
Higher proficiency	84.71 (10.89)	32.50 (24.37)	63.33 (13.59)
Lower proficiency	53.94 (16.71)	8.52 (9.27)	30.39 (19.56)
Abjad L1	67.65 (21.94)	23.21 (10.02)	60.00 (20.82)
Higher proficiency	82.35 (12.48)	28.13 (13.26)	77.50 (31.82)
Lower proficiency	61.76 (23.07)	21.25 (9.48)	53.00 (13.51)
Morphosyllabic L1	76.85 (16.72)	18.10 (12.38)	64.62 (14.21)
Higher proficiency	84.93 (11.17)	22.37 (13.88)	70.63 (15.22)
Lower proficiency	63.92 (16.77)	11.25 (5.23)	55.00 (3.54)

Standard deviations are given in parentheses.

spelling accuracy). The morphosyllabic L1 speakers, on the other hand, showed no significant correlations between any of these three tasks.

Phonological Awareness Accuracy

The means and standard deviations for Elision accuracy are given in **Table 3**. There was a significant overall effect of L1 writing system, $\chi^2(df = 3) = 35.86$, $p < 0.001$, and the L1 English speakers were significantly more accurate than all three ESL groups: alphabetic L1 speakers ($\beta = -3.27$, $z = -6.50$, $p < 0.001$), abjad L1 speakers ($\beta = -2.11$, $z = 2.85$, $p = 0.004$), and morphosyllabic L1 speakers ($\beta = -1.45$, $z = -2.48$, $p = 0.01$). Next, the ESL speaker groups were examined in more detail to explore the influence of both L1 writing system and L2 English proficiency on Elision accuracy. The overall effect of L1 writing system was significant, $\chi^2(df = 2) = 8.11$, $p = 0.02$. Specifically, the abjad L1 and morphosyllabic L1 speakers were both significantly more accurate than the alphabetic L1 speakers ($\beta = 1.04$, $z = 2.07$, $p = 0.04$; $\beta = 1.08$, $z = 2.57$, $p = 0.01$, respectively). However, the difference between the abjad L1 and morphosyllabic L1 speakers was not significant, $\beta = 0.04$, $z = 0.07$, $p = 0.94$. The effect of L2 English proficiency was also significant, $\beta = 1.60$, $z = 3.97$, $p < 0.001$, such that higher proficiency participants were significantly more accurate than lower proficiency participants. However, the interaction between L1 writing system and proficiency was not significant, $\chi^2(df = 2) = 2.21$, $p = 0.33$, suggesting that the effect of proficiency is the same regardless of L1 writing system.

Spelling Accuracy

The means and standard deviations for real word and pseudoword spelling accuracy are given in **Table 3**. Overall spelling accuracy was first examined as a function of participant and item characteristics that were relevant for all participants and items: lexicality (real words vs. pseudowords), item length (in letters), orthographic neighborhood size; L1 writing system (alphabet, abjad, morphosyllabary, or L1 English), and elision accuracy. The effect of lexicality was significant, $\beta = 3.18$, $z = 6.01$, $p < 0.001$; the effect of length was marginally significant, $\beta = -0.24$, $z = -1.80$, $p = 0.07$; and the effect of orthographic neighborhood size was not significant, $\beta = -0.004$, $z = -0.08$, $p = 0.93$. The effect of elision accuracy was significant, $\beta = 2.77$, $z = 5.71$, $p < 0.001$, as was the overall effect of L1 writing system, $\chi^2(df = 12) = 69.51$, $p < 0.001$. Critically, L1 writing system also interacted significantly with lexicality, $\chi^2(df = 3) = 13.50$, $p = 0.004$. Therefore, further analyses were conducted for real words and pseudowords separately.

For real word spelling, model building initially considered all participant characteristics (L1 writing system, elision accuracy) and item characteristics (length, number of orthographic neighbors, and phonological neighbors) that correlations had suggested may be relevant, as well as log frequency. The overall effect of L1 writing system was significant, $\chi^2(df = 3) = 25.11$, $p < 0.001$, as were the effects of elision accuracy ($\beta = 3.19$, $z = 4.63$, $p < 0.001$) and word length ($\beta = -0.51$, $z = -2.81$, $p = 0.01$). In addition, there were two significant interactions involving comparisons between the L1 English speakers and the alphabetic L1 speakers (by orthographic neighborhood size, $\beta = -0.29$, $z = -2.47$, $p = 0.01$, and by phonological neighborhood size, $\beta = -0.15$, $z = -2.46$, $p = 0.01$) as well as two marginally significant interactions involving comparisons between the L1 English speakers and the abjad L1 speakers (by orthographic neighborhood size, $\beta = -0.26$, $z = -1.89$, $p = 0.06$, and by log frequency, $\beta = 0.38$, $z = 1.72$, $p = 0.08$). Thus, the final models of real word spelling accuracy examined L1 English speakers and the ESL speakers separately, and L2 English proficiency was also added as a factor for the ESL model.

These final models are given in **Table 4**; these models were selected as the final models because they each had significantly better model fit (determined using the log-likelihood ratio test and AIC values) than alternative models that included non-significant predictors. For L1 English speakers, there were only two significant predictors: elision accuracy and item length. Specifically, participants with higher phonological awareness scores had higher spelling accuracy, and longer words were spelled less accurately than shorter words. For the ESL speakers, several factors significantly impacted real word spelling accuracy. The overall effect of L1 writing system was not significant, $\chi^2(df = 2) = 0.20$, $p = 0.91$ (though it was maintained in the model due to significant interactions with other variables). There were significant effects of proficiency and elision accuracy, such that participants with higher L2 English proficiency and with

TABLE 4 | Final linear mixed effects models predicting real word spelling accuracy in L1 English speakers and ESL speakers.

	L1 English speakers			ESL speakers		
	β	*SE*	*z*	β	*SE*	*z*
Intercept	6.19	1.88	3.30***	2.31	1.65	1.40
Fixed effects						
Abjad L1[a]				2.75	1.16	2.38*
Morphosyllabic L1[a]				1.39	1.39	1.00
Higher proficiency[b]				1.29	0.39	3.40***
Elision accuracy	2.77	1.17	2.36*	2.51	0.97	2.58*
Length	−0.53	0.20	−2.71**	−0.12	0.28	−0.43
Orthographic neighborhood				−1.00	0.40	−2.52*
Phonological neighborhood				−0.62	0.24	−2.57*
Log frequency				0.13	0.20	0.67
Abjad L1[a]*Elision accuracy				−4.82	1.93	−2.50*
Morphosyllabic L1[a]*Elision accuracy				2.24	2.29	0.98
Orthographic neighborhood* Elision accuracy				0.35	0.16	2.21*
Phonological neighborhood* Elision accuracy				0.19	0.07	2.64**
Orthographic neighborhood*Length				0.14	0.08	1.78‡
Phonological neighborhood*Length				0.09	0.05	1.99*
Orthographic neighborhood*Log frequency				−0.36	0.15	−2.41*
Phonological neighborhood*Log frequency				−0.18	0.08	−2.40*

Random effects	Variance Component	*SD*	Variance Component	*SD*
Participants Intercept	0.99	1.00	0.57	0.76
Items Intercept	2.53	1.59	0.79	0.89

[a]*Alphabetic L1 is the reference group.* [b]*Lower proficiency is the reference group.* ‡$p < 0.10$; *$p < 0.05$; **$p < 0.01$, ***$p < 0.001$.

higher phonological awareness had significantly higher spelling accuracy than participants with lower L2 English proficiency and with lower phonological awareness. There were also significant effects of orthographic and phonological neighborhood size, with lower spelling accuracy for words with larger orthographic or phonological neighborhoods.

There were also a number of significant interactions that qualified these overall effects. The interaction between L1 writing system and elision accuracy was significant, $\chi^2(df = 2) = 7.82$, $p = 0.02$; follow-up analyses within each L1 writing system group were used to examine this further. For the alphabetic and morphosyllabic L1 participants, the effect of phonological awareness was significant and positive: participants with higher elision accuracy had higher real word spelling accuracy (alphabetic L1: $\beta = 2.60$, $z = 2.28$, $p = 0.02$; morphosyllabic L1: $\beta = 7.91$, $z = 2.63$, $p = 0.01$). In contrast, for the abjad L1 participants, the effect of phonological awareness was marginally significant, but in the opposite direction: abjad speakers with higher elision accuracy had *lower* real word spelling accuracy, $\beta = -4.60$, $z = -1.89$, $p = 0.06$.

The interactions between elision accuracy and orthographic neighborhood size and phonological neighborhood size were also significant. In each case, participants who had higher phonological awareness experienced a larger effect of both orthographic neighborhood size and phonological neighborhood size. Finally, the interactions between word frequency and orthographic neighborhood size and phonological neighborhood size were significant. These interactions indicate that higher-frequency words were associated with smaller effects of both orthographic neighborhood size and phonological neighborhood size.

For pseudoword spelling, model building considered the same participant characteristics (L1 writing system, elision accuracy) and applicable item characteristics (length, number of orthographic neighbors) that were considered with real word accuracy so that the results could be directly compared. The overall effect of L1 writing system was significant, $\chi^2(df = 3) = 50.97$, $p < 0.001$, as was the main effect of elision accuracy, $\beta = 2.22$, $z = 4.36$, $p < 0.001$. In addition, there were two significant interactions involving comparisons between the L1 English speakers and the abjad L1 speakers (by length, $\beta = 3.24$, $z = 3.45$, $p < 0.001$, and by orthographic neighborhood size, $\beta = -0.21$, $z = -2.41$, $p = 0.02$) as well as two significant interactions involving comparisons between the L1 English speakers and the morphosyllabic L1 speakers (again by length, $\beta = 1.97$, $z = 2.94$, $p = 0.003$, and by orthographic neighborhood size, $\beta = -0.23$, $z = -3.67$, $p < 0.001$). Thus, the final models of pseudoword spelling accuracy again considered L1 English speakers and the ESL speakers separately, and L2 English proficiency was added as a factor for the ESL model.

These final models are given in **Table 5**; these models were again selected as the final models because they each

TABLE 5 | Final linear mixed effects models predicting pseudoword spelling accuracy in L1 English speakers and ESL speakers.

	L1 English speakers			ESL speakers		
	β	*SE*	*z*	β	*SE*	*z*
Intercept	−0.81	0.43	−1.88‡	−2.39	2.90	−0.83
Fixed effects						
Abjad L1[a]				12.73	4.76	2.67**
Morphosyllabic L1[a]				7.23	3.49	−2.07*
Higher proficiency[b]				1.00	0.42	2.39*
Elision accuracy	1.99	0.50	3.95***	1.11	1.04	1.07
Length				0.12	0.65	0.85
Orthographic neighborhood				−0.05	0.07	−0.73
Abjad L1[a]*Length				2.97	1.06	2.82**
Morphosyllabic L1[a]*Length				1.53	0.78	1.96*
Abjad L1[a]*Orthographic Neighborhood				−0.17	0.10	−1.81‡
Morphosyllabic L1[a]*Orthographic Neighborhood				−0.20	0.07	−2.67**
	Variance Component		***SD***	**Variance Component**		***SD***
Random effects						
Participants Intercept	0.004		0.06	0.41		0.64
Items Intercept	0.40		0.64	0.77		0.88

*[a]Alphabetic L1 is the reference group. [b]Lower proficiency is the reference group. ‡$p < 0.10$; *$p < 0.05$; **$p < 0.01$, ***$p < 0.001$.*

had significantly better model fit (determined using the log-likelihood ratio test and AIC values) than alternative models that included non-significant predictors. For L1 English speakers, there was only one significant predictor: elision accuracy. As with real word spelling, participants with higher phonological awareness had higher pseudoword spelling accuracy. Also similar to the results for real word spelling, there were several factors that significantly impacted pseudoword spelling accuracy for the ESL speakers. The overall effect of L1 writing system was not significant, $\chi^2(df = 2) = 2.91$, $p = 0.23$ (though it was again maintained in the model due to significant interactions with other variables). There was also a significant effect of proficiency, such that participants with higher L2 English proficiency had significantly higher pseudoword spelling accuracy than participants with lower L2 English proficiency.

There were two significant interactions that qualified these overall effects: between L1 writing system and length, $\chi^2(df = 2) = 12.09$, $p = 0.002$; and between L1 writing system and orthographic neighborhood size, $\chi^2(df = 2) = 9.58$, $p = 0.01$. Follow-up analyses within each L1 writing system group were used to examine these interactions further. For the alphabetic L1 participants, neither the effect of length ($\beta = 0.002$, $z = 0.002$, $p > 0.99$) nor the effect of orthographic neighborhood size ($\beta = -0.05$, $z = -0.65$, $p = 0.52$) were significant. However, within this alphabetic L1 model, the effect of proficiency was significant, $\beta = 1.50$, $z = 1.98$, $p = 0.048$, with higher pseudoword spelling accuracy among higher proficiency participants. For the abjad L1 participants, the effect of length was significant ($\beta = 2.77$, $z = 2.33$, $p = 0.02$), with longer pseudowords being spelled more accurately than shorter pseudowords. The effect of orthographic neighborhood size was marginally significant ($\beta = -0.18$, $z = -1.71$, $p = 0.09$), with larger orthographic neighborhoods associated with somewhat lower pseudoword spelling accuracy, but the effect of proficiency was not significant and was dropped from the final abjad L1 model. Finally, for the morphosyllabic L1 participants, the effect of length was significant ($\beta = 1.65$, $z = 2.03$, $p = 0.04$), again with longer pseudowords being spelled more accurately than shorter pseudowords. The effect of orthographic neighborhood size was also significant ($\beta = -0.24$, $z = -3.02$, $p = 0.002$), again with larger orthographic neighborhoods associated with lower pseudoword spelling accuracy, though the effect of proficiency was not significant and also dropped from the final morphosyllabic L1 model.

Error Analyses

Following the quantitative analysis of overall (strict) accuracy described above, a more in-depth investigation into the *types* and *quantities* of spelling errors committed by participants was conducted. First, the spelling of each grapheme in each item was examined to determine whether it was correct or incorrect. Generally following Masterson and Apel (2010), graphemes were defined as the letter or sequence of letters representing each spoken phoneme in the target items. For example, *dress* was divided into the following graphemes corresponding to phonemes: d| r| e| ss; *separate* was divided into s| e| p| a| r| aCe| t (with aCe representing the non-linear sequence of vowel + consonant + < e > indicating long vowel); and *knowledge* was divided into kn| ow| l| e| dge.

Incorrect spellings of graphemes were further categorized in terms of whether the particular sound was misspelled or missing or whether additional sounds were represented in the spelling that were not present in the dictated word. More specifically, the categories were as follows (with examples drawn directly from the data): incorrect consonant grapheme (the wrong letter(s) representing a consonant phoneme in the word, e.g., < napcen > for *napkin*); incorrect vowel grapheme (the wrong letter(s) representing a vowel phoneme in the word, e.g., < seperate > for *separate*); missing consonant grapheme (no letter(s) present to represent a consonant phoneme in the word, e.g., < resonsible > for *responsible*); missing vowel grapheme (no letter(s) present to represent a vowel phoneme in the word, e.g., < decsion > for *decision*); extra consonant grapheme (additional letter(s) representing a consonant phoneme not present in the word, e.g., < grownd > for *grown*); or extra vowel grapheme (additional letter(s) representing a vowel phoneme not present in the word, e.g., < recoganize > for *recognize*). Inter-rater reliability was initially 91% for real words and 63% for pseudowords; items for which there was disagreement were resolved through discussion among coders.

Similar to the main analyses examining overall accuracy, linear mixed effects analyses were used, this time to examine the *rate of errors per item* (rather than strict accuracy) as a function of L1 background, L2 English proficiency, and phonological awareness. The average number of errors per item of different types are given in **Table 6**; errors per item was used as the dependent variable in order to make error rates comparable between real words and pseudowords, given the different number of each type of item (34 real words versus 16 pseudowords).

Errors to Real Words Versus Pseudowords

The first error analysis examined the errors made to real words versus pseudowords (lexicality). The effect of lexicality was significant $\beta = -0.36$, $t = 4.40$, $p < 0.001$, with significantly fewer errors made to real words than pseudowords. The overall effect of L1 writing system was also significant, $\chi^2(df = 3) = 34.50$, $p < 0.001$, as was the effect of phonological awareness, $\beta = -0.44$, $t = -3.17$, $p = 0.002$, with higher phonological awareness associated with fewer errors. The interaction between L1 writing system and item type was also significant, $\chi^2(df = 3) = 9.66$, $p = 0.02$. Thus, L1 English speakers and ESL speakers were further examined separately, with L2 English proficiency also added as a factor for the ESL model.

For the L1 English speakers, the effect of phonological awareness was significant, $\beta = -54$, $t = -0.19$, $p < 0.001$, with higher phonological awareness associated with fewer errors. The effect of lexicality was also significant, with fewer errors made to real words than pseudowords, $\beta = -0.61$, $t = 4.07$, $p < 0.001$. The interaction between phonological awareness and lexicality was only marginally significant, $\beta = 0.31$, $t = 1.70$, $p = 0.096$; the trend was such that the effect of phonological awareness was slightly stronger for real words than it was for pseudowords.

For the ESL speakers, the overall effect of L1 writing system was not significant, $\chi^2(df = 2) = 3.28$, $p = 0.19$. In addition, the effect of proficiency was not significant, $\beta = -0.03$, $t = -0.30$, $p = 0.77$. However, the effect of lexicality was significant, $\beta = -0.74$, $t = -6.59$, $p < 0.001$, with fewer errors made to real words than to pseudowords. The interaction between lexicality and proficiency was also significant, $\beta = 0.49$, $t = 3.55$, $p < 0.001$, with more errors made to real words than pseudowords among lower proficiency speakers, but more errors made to pseudowords than to real words among higher proficiency speakers.

Errors Involving Consonants Versus Vowels

For the second error analysis, the incorrect, missing, and additional consonant errors and vowel errors were summed together by phoneme type to calculate the total number of consonant-related errors and vowel-related errors for each participant. These were then examined across L1 groups and L2 English proficiency to determine whether there were any differential accuracies by segment type (consonant versus vowel sounds), as has been demonstrated in previous research with abjad L1 speakers (e.g., Fender, 2008; Saigh and Schmitt, 2012; Martin, 2017).

There was a significant overall effect of L1 writing system, $\chi^2(df = 3) = 27.58$, $p < 0.001$. The main effect of lexicality was not significant, $\beta = 0.10$, $t = 1.42$, $p = 0.16$, though the main effect of segment type was marginally significant, $\beta = 0.05$, $t = 1.66$, $p = 0.099$, with a slight trend toward more vowel errors than consonant errors. However, these main effects were qualified by a number of significant interactions, including between L1 writing system and lexicality, $\chi^2(df = 3) = 18.38$, $p < 0.001$ and between L1 writing system and segment type, $\chi^2(df = 3) = 15.44$, $p = 0.001$. Due to these significant interactions with L1 writing system, as with previous analyses, the L1 English speakers and ESL speakers were examined in more detail separately.

For the L1 English speakers, only phonological awareness and lexicality were significant predictors: phonological awareness, $\beta = -0.12$, $t = -3.08$, $p = 0.01$; lexicality, $\beta = -0.15$, $t = -9.30$, $p < 0.001$. Specifically, higher phonological awareness and real words were associated with fewer errors than were lower phonological awareness and pseudowords. Notably, the effect of segment type was not significant.

For the ESL speakers, the overall effect of L1 writing system was again significant, $\chi^2(df = 2) = 7.26$, $p = 0.03$. However, a number of main effects were not significant: proficiency, $\beta = -0.02$, $t = -0.33$, $p = 0.75$; phonological awareness, $\beta = 0.07$, $t = 0.52$, $p = 0.60$; lexicality, $\beta = 0.01$, $t = 0.10$, $p = 0.92$; and segment type, $\beta = 0.04$, $t = 1.11$, $p = 0.27$. Importantly, these main effects were qualified by a significant interaction between L1 writing system and segment type, $\chi^2(df = 2) = 14.44$, $p < 0.001$. Thus, each L1 writing system group was examined separately.

For alphabetic L1 speakers, most main effects were not significant: proficiency, $\beta = -0.05$, $t = -0.53$, $p = 0.60$; phonological awareness, $\beta = 0.04$, $t = 0.23$, $p = 0.82$; and lexicality, $\beta = -0.04$, $t = -0.40$, $p = 0.69$. The main effect of segment type was marginally significant, $\beta = 0.11$, $t = 1.97$, $p = 0.05$, with somewhat more errors made involving vowels than consonants. However, there were a number of significant interactions among these variables. Proficiency interacted with lexicality, $\beta = 0.20$, $t = 2.63$, $p = 0.01$, such that there was no lexicality effect in higher proficiency participants, but there were

TABLE 6 | Error analyses - mean error rates (per item) to different item types (real words, pseudowords) and segment types (vowels, consonants) by L1 background and ESL proficiency level.

	Real words	Pseudowords	Vowels	Consonants
L1 English	0.07 (0.09)	0.43 (0.22)	0.12 (0.12)	0.10 (0.11)
Alphabetic L1	0.59 (0.37)	0.87 (0.31)	0.23 (0.18)	0.24 (0.19)
Higher proficiency	0.21 (0.21)	0.93 (0.33)	0.28 (0.25)	0.16 (0.16)
Lower proficiency	0.68 (0.35)	0.86 (0.31)	0.22 (0.16)	0.26 (0.20)
Abjad L1	0.66 (0.68)	1.06 (0.23)	0.45 (0.28)	0.29 (0.22)
Higher proficiency	0.30 (0.10)	0.94 (< 0.001)	0.32 (0.18)	0.18 (0.11)
Lower proficiency	0.81 (0.77)	1.11 (0.26)	0.51 (0.30)	0.33 (0.24)
Morphosyllabic L1	0.41 (0.40)	1.12 (0.28)	0.38 (0.27)	0.23 (0.20)
Higher proficiency	0.25 (0.28)	1.03 (0.30)	0.32 (0.25)	0.20 (0.18)
Lower proficiency	0.66 (0.46)	1.24 (0.21)	0.46 (0.28)	0.29 (0.23)

Standard deviations are given in parentheses. Error rates per item were calculated by summing the total number of errors to real words or to pseudowords, and the total number of errors involving vowels or involving consonants, and dividing this total by the number of items of that type (total number of real words, total number of pseudowords, or total number of items overall).

more errors per item to real words than to pseudowords in lower proficiency participants. Proficiency also interacted with segment type, $\beta = -0.15$, $t = -2.39$, $p = 0.02$, such that higher proficiency participants made somewhat more errors involving vowels than consonants, but there was essentially no difference in lower proficiency participants. Lastly, phonological awareness interacted with lexicality, $\beta = -0.35$, $t = -2.55$, $p = 0.01$, such that phonological awareness was not related to the error rate among pseudowords, but higher phonological awareness was associated with a lower error rate among real words.

For abjad L1 speakers, the effect of lexicality was marginally significant, $\beta = -0.13$, $t = -1.88$, $p = 0.08$, with a lower error rate among real words than pseudowords. The effects of proficiency and phonological awareness were not significant and thus removed from the final model. However, the effect of segment type was significant, $\beta = 0.16$, $t = 2.45$, $p = 0.02$: abjad L1 speakers made significantly more errors involving vowels than consonants.

For morphosyllabic L1 speakers, the effect of lexicality was significant, $\beta = -0.17$, $t = -2.66$, $p = 0.01$, with a lower error rate among real words than pseudowords. The main effect of segment type was also significant, $\beta = 0.24$, $t = 3.72$, $p < 0.001$, with more errors involving vowels than consonants. As with the abjad L1 speakers, the effects of proficiency and phonological awareness were not significant and thus removed from the final model. However, the interaction between lexicality and segment type was also significant, $\beta = -0.18$, $t = -2.05$, $p = 0.047$; there were substantially more errors involving vowels than consonants among pseudoword items, but this difference was minimal among real words.

Summary of Results

The correlations among real word spelling accuracy, pseudoword spelling accuracy, and phonological awareness accuracy showed different patterns in each L1 group. For the L1 English speakers, all three tasks were significantly positively correlated with one another, whereas for the morphosyllabic L1 speakers, there were no significant correlations among these three tasks. The alphabetic and abjad L1 speakers fell somewhere in the middle: phonological awareness accuracy was significantly correlated with real word spelling accuracy for the alphabetic L1 speakers and was significantly correlated with pseudoword spelling accuracy for the abjad L1 speakers, though these were the only significant correlations in these groups.

Regarding spelling accuracy, the native speaker comparison group (L1 English speakers) had substantially higher real word and pseudoword spelling accuracy than the three ESL groups. Interestingly, the L1 English speakers had relatively few predictors of spelling accuracy: only phonological awareness (for both real words and pseudowords) and length (real words only). No other lexical characteristics influenced L1 English speaker spelling accuracy.

The picture was much more complex among the ESL participants. L2 English proficiency was consistently related to both real word and pseudoword spelling accuracy, such that spelling accuracy increased along with increasing L2 proficiency. Similarly, higher phonological awareness scores were associated with higher real word spelling accuracy in the alphabetic and morphosyllabic L1 speakers, but the opposite pattern was found for the abjad L1 speakers: higher phonological awareness was associated with lower real word spelling accuracy. In contrast, higher phonological awareness scores were associated with higher pseudoword spelling accuracy across L1 groups. Lexical characteristics also influenced ESL spelling accuracy: higher phonological awareness scores were associated with larger effects of orthographic and phonological neighborhood size in real words, whereas higher word frequency was associated with smaller effects of orthographic and phonological neighborhood size in real words. Among pseudowords, the abjad and morphosyllabic L1 speakers had more accurate pseudoword spelling for *longer* pseudowords and for those with smaller orthographic neighborhoods.

Considering the phonological awareness scores themselves, the L1 English speakers had higher accuracy than all ESL groups on the elision task. Among the ESL participants phonological awareness accuracy increased along with higher L2 English proficiency across L1s. However, the alphabetic L1 speakers were significantly less accurate in their elision performance than the abjad and morphosyllabic L1 speakers, who did not differ from one another.

Finally, the L1 English speakers and ESL speakers also showed different patterns regarding the rates at which they made specific types of spelling errors. Among L1 English speakers, the only two patterns that emerged were that higher phonological awareness was related to a significantly lower error rate, and that the error rate was lower to real words than pseudowords. Once again, the pattern of results was more complex when considering the ESL speakers. Considering error rates to real words versus pseudowords, there was no overall effect of L1 writing system or L2 English proficiency level, but there was an unexpected interaction between lexicality and proficiency, such that lower proficiency ESL speakers had a higher error rate to real words than pseudowords, whereas higher proficiency ESL speakers had a higher error rate to pseudowords than real words. Considering error rates involving vowels versus consonants, there was a general tendency for a higher error rate to vowels than consonants. This was found among higher proficiency alphabetic L1 speakers, with pseudowords in morphosyllabic L1 speakers, and in abjad L1 speakers regardless of proficiency level or item type.

DISCUSSION

The current study examined real word and pseudoword spelling accuracy in adult learners of ESL from a variety of L1 backgrounds. To facilitate cross-linguistic comparisons, these ESL speakers were grouped by L1 writing system: alphabetic L1s, abjad L1s, and morphosyllabic L1s. Participants also completed the Elision subtest from the CTOPP to measure their phonological awareness. Analyses focused on the relationships among real word and pseudoword spelling and phonological awareness skills, detailed analyses of the types of errors made by participants, and the variations in these patterns across L1 groups.

As a whole, the results were largely consistent with the findings from previous research on ESL spelling abilities. The comparison group of L1 English speakers consistently had higher spelling accuracy (for both real words and pseudowords), fewer errors per item, and higher phonological awareness accuracy than all three ESL groups. Considering the three ESL groups, previous research has generally found that ESL speakers from a morphosyllabic L1 typically have relatively strong real word spelling skills, particularly for irregular/exception words, but have substantial difficulties reading and spelling pseudowords, whereas ESL speakers from an alphabetic L1 typically have stronger phonological skills and rely on them for word reading and spelling, resulting in a substantial number of overregularization errors (e.g., Wang and Geva, 2003b; Wang et al., 2003; Wang and Koda, 2007; Hamada and Koda, 2008; Leong, 2011). The results from the current study are partially consistent with these previous findings. Among the ESL groups, the morphosyllabic L1 group did have the highest real word spelling accuracy (77%), and very low pseudoword spelling accuracy (18%). In comparison, the alphabetic L1 speakers had the lowest real word spelling ability (60%), though they also had the lowest pseudoword spelling accuracy (13%) and phonological awareness accuracy (36%).

Given the relatively strong phonological skills that are typically found in learners with an alphabetic L1, it may initially seem surprising that the alphabetic L1 speakers in this study had such low pseudoword spelling and phonological awareness performance. However, there are a number of factors that can help explain this result. First, as discussed further below, the distribution of participants with different L1 writing systems was not even across proficiency levels, and there were more alphabetic L1 speakers at the lowest levels of proficiency (A1, A2) than in the other ESL groups. Given that spelling accuracy was also significantly related to L2 English proficiency, it is likely that the overall lower proficiency level of the alphabetic L1 speakers contributed to their lower raw scores. This interpretation is supported by the fact that, when L2 English proficiency was considered, the differences among the ESL groups were much smaller and real word spelling accuracy did not differ between the alphabetic and morphosyllabic L1 speakers.

Another contributing factor is likely the nature of phonological skill development in L1 Spanish (by far the largest L1 group among the alphabetic L1 speakers). Due in part to the highly consistent nature of the Spanish orthography, fine-grained phonological awareness skills (e.g., below the syllable level) are not needed for Spanish literacy and thus may not develop readily (e.g., Anthony et al., 2003, 2011). In addition, previous research has shown that readers of a consistent L1 orthography, such as Spanish, may transfer this expectation of consistency to their L2 (Haggan, 1993; Sun-Alperin and Wang, 2008; see also Branum-Martin et al., 2012). This expectation can hamper such individuals' ability to adjust to the highly inconsistent nature of English, resulting in lower word recognition and spelling skills than may otherwise be expected – as was found in the current study.

It must also be noted that, although the alphabetic L1 speakers had low strict spelling accuracy, a different picture emerges if error rates per item are considered. In word spelling, the alphabetic L1 speakers frequently had low overall rates of errors per word, particularly on pseudowords. Thus, although their spellings may not have been accurate in terms of strict coding, the spellings produced by the alphabetic L1 speakers were relatively more target-like than those produced by the other ESL groups. This finding also highlights another important point: the conclusion that is reached from research results may be heavily dependent on the format of the task (e.g., Anthony et al., 2003, 2011), the types of items included (e.g., McBride-Chang, 1995; Juffs and Martin, 2014), and the way that responses are scored (e.g., Masterson and Apel, 2010; Clemens et al., 2014). Given the increasing recognition that the same tasks and items that have been developed for L1 research are not necessarily valid for ESL users and adult readers (Greenberg et al., 1997, 2002, 2009; Grant et al., 2012; Pae et al., 2012; Nanda et al., 2014), directly examining the influence of different scoring approaches will be critical for L2 literacy research going forward.

Examination of the results for error rates also highlights another initially unexpected pattern in the findings: a higher error rate to real words than to pseudowords, particularly in lower proficiency learners. Given that real words may be known, but pseudowords by definition are unknown, it might be expected that spellings, regardless of scoring approach, would be more accurate for real words than pseudowords. However, a closer examination of the characteristics of English words and pseudowords themselves helps illustrate why this may not always be the case. English spelling is notoriously opaque (Ziegler and Goswami, 2005; Share, 2008; Frost, 2012), meaning that real words naturally have wide variability in their consistency (see also Ziegler et al., 1997), and multimorphemic words in particular may have spellings that differ noticeably from expectations based on phoneme-grapheme correspondences alone (Helman et al., 2012; Bear et al., 2019). On the other hand, pseudowords may vary in the consistency of their component graphemes, but by the nature of their being pronounceable pseudowords, follow patterns that are already attested elsewhere in English. Thus, real words – including the multisyllabic and derived words used in the current study – may actually appear *less* consistent than pseudowords. If these items are not well-known words for participants (as may be the case for those with lower levels of proficiency), they are likely to be more difficult to spell and to result in an increased error rate. However, with increased proficiency (and increased vocabulary knowledge), this effect should diminish or disappear – as is attested in the current data.

The differential relationships between spelling and phonological skills found in the current study are also consistent with previous research. In the L1 English speakers, both real word and pseudoword spelling accuracy were significantly related to phonological awareness skills. This is consistent with the continuing importance of phonological skills for literacy in the opaque English orthography, compared to other languages in which the importance of phonological awareness decreases rapidly with increasing reading proficiency (e.g., Ziegler and Goswami, 2005). Consistent with previous findings that alphabetic L1 speakers rely relatively more on phonological skills for spelling and that non-alphabetic L1 speakers rely on phonological skills relatively less (e.g., Holm and Dodd, 1996; Wade-Woolley, 1999; McBride-Chang et al., 2004; Mayer et al., 2007), the alphabetic L1 speakers from this study showed a significant relationship between real word spelling accuracy and phonological awareness. In contrast, the abjad L1 speakers did not show a significant association between real word spelling accuracy and phonological awareness, and the morphosyllabic L1 speakers did not show any significant correlations between spelling accuracy and phonological awareness.

Examining the varying relationships between spelling and phonological skills is also an area where additional research with a larger number of participants at both lower and higher proficiency levels would be beneficial. In the current results there was an unexpected finding of a *negative* beta weight for elision accuracy as a predictor of real word spelling accuracy among the abjad L1 speakers, in contrast to the positive beta weights for the alphabetic and morphosyllabic L1 speakers. Based on a reviewer recommendation, we examined whether proficiency was a significant predictor of elision accuracy, and whether this relationship was different among the ESL groups. This is in fact what we found: there was a significant positive relationship between proficiency and elision accuracy for the alphabetic L1 ($\beta = 2.22$, $z = 3.32$, $p = 0.001$) and morphosyllabic L1 speakers ($\beta = 1.20$, $z = 2.28$, $p = 0.02$) but not for the abjad L1 speakers ($\beta = 0.87$, $z = 0.91$, $p = 0.37$). Thus, larger and more detailed datasets would be beneficial in future research to more directly explore these interactions and what they can tell us about L1 differences in literacy skills.

The results from the current study do provide new data to contribute to an unresolved issue in L2 spelling research: whether (L1-specific) errors decrease with increasing L2 proficiency, or whether they persist over continued L2 development. Some previous studies have found that such errors do decrease with increasing L2 proficiency (e.g., Fashola et al., 1996; Wang and Geva, 2003a), whereas others have found that spelling errors persist across grades (e.g., Zutell and Allen, 1988; Allaith and Joshi, 2011). The results from this study indicated a strong relationship between L2 English proficiency and spelling accuracy, measured via both strict accuracy and error rates per item. Further, after controlling for proficiency, L1 writing system differences persisted, considering both real word and pseudoword strict spelling accuracy and error rates. Thus, this study provides evidence for the continued influence of L1 literacy experiences on L2 (English) literacy skills across the development of L2 (English) proficiency.

Another question addressed by the current study was whether there would be significant L1 differences in accuracy spelling consonant versus vowel phonemes, as has been found for both L1 Arabic and L1 Hebrew speakers in prior research (e.g., Fender, 2008; Saigh and Schmitt, 2012; Martin, 2017). Broadly, this finding was confirmed: the error rate involving vowels was significantly higher than the error rate involving consonants, and this pattern was most widespread among the abjad L1 speakers. The alphabetic L1 speakers showed this pattern, but only among higher proficiency learners, whereas the morphosyllabic L1 speakers showed this pattern, but only with pseudowords. In contrast, the abjad L1 speakers showed a significantly higher error rate involving vowels, regardless of proficiency level or item type. Thus, the results of the current study confirm this pattern from previous research, and also show that other L1 groups may experience similar difficulties in at least some conditions (see also Martin, 2017).

Although this study makes important contributions toward our understanding of adult ESL spelling abilities, there are still a number of limitations that must be acknowledged. First, although data were collected from a wide range of L2 English proficiency levels and three representative L1 writing systems, there were relatively small sample sizes in some combinations of L2 English proficiency and L1 writing system. In addition, the number of participants from each L1 writing system was not consistent across all levels of proficiency, with somewhat more alphabetic L1 speakers at lower levels of proficiency compared to the abjad L1 and morphosyllabic L1 groups. Future research would benefit from a larger sample size, including targeted recruitment of a balanced sample of participants across L1 writing systems and proficiency levels; this was unfortunately not possible given the current context of data collection. Such research will be useful for confirming the specific findings from this study.

Another improvement that could be made by future research would be to include a wider variety of target items, both real words and pseudowords, and to specifically consider lexical characteristics during item selection. The items chosen for the current study were based on items previously used successfully in published research on ESL spelling abilities, but were not chosen with regard to their frequency, orthographic neighborhood size, or phonological neighborhood size. However, modeling the results for spelling accuracy suggested that these three lexical characteristics in particular may influence ESL spelling abilities, and are thus deserving of dedicated attention in future research.

A strength of the current study was the use of a dictation task to assess spelling ability. Although this type of assessment is common in L1- and child-focused literacy research, it is much lesson common in adult L2 research, and using it in this study eliminated the influence of learner avoidance found in studies of spelling errors from naturalistic writing samples (Allaith and Joshi, 2011). However, the words were not selected to target specific (or representative) phonemes, as has been done in some previous research (e.g., Wang and Geva, 2003a,b; Allaith and Joshi, 2011; Saigh and Schmitt, 2012). Thus, the particular difficulties that learners had may have been somewhat an artifact of the particular items that were included, and thus not fully representative of overall spelling abilities. A final limitation that we would like to highlight is the challenge of using standardized assessments, such as the Elision task from the CTOPP, with L2 speaker populations (see also Greenberg et al., 2009; Pae et al., 2012; Nanda et al., 2014; Winke et al., 2018). For example, when coding spoken responses to such assessments, it can be challenging to determine accuracy while accounting for L2 accents in a consistent – and fair – way. As the substantial difference between L1 alphabetic speakers' spelling performance – measured via strict spelling accuracy versus error rates per item – demonstrates, issues of test validity and scoring reliability need to be more widely examined in L2 research.

CONCLUSION

Although spelling is a critical literacy skill it has received relatively little attention, especially in the domain of cross-linguistic L2 literacy research. The current study sought to address a number of gaps left by existing research, by focusing on adult ESL users (rather than children), considering not only real word spelling ability but also pseudoword spelling ability and phonological awareness, and using the same materials and procedure with participants from a variety of L1 backgrounds (thus facilitating cross-linguistic comparisons). In many ways the results were consistent with previous research, demonstrating relatively high (real word) spelling accuracy yet somewhat weak phonological skills in morphosyllabic L1 speakers; more reliance on phonological skills in alphabetic L1 speakers; and significantly more errors involving vowels than consonants in abjad L1 speakers. However, there were also some unexpected patterns in the results, particularly the relatively low spelling accuracy and phonological awareness performance by the alphabetic L1 speakers. To some degree, these unexpected findings can be accounted for when considering another way to analyze the data: in terms of error rates, rather than strict accuracy. This highlights perhaps the most important individual finding from the study: the substantially different patterns of results, and conclusions, that may be reached when the data are scored differently. The field of L2 literacy research has much important work to do to document such variations and establish best practices for task choice, item selection, and particularly scoring procedures to improve reliability and validity.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Human Subjects Committee at Southern Illinois University Carbondale. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

KM contributed to study design, item selection, data collection, data analysis, and writing. EL contributed to data analysis and writing. KC contributed to study design, item selection, data collection, and writing. EH contributed to study design, item selection, data collection, and writing.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2020.01309/full#supplementary-material

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The Spelling Errors of French and English Children With Developmental Language Disorder at the End of Primary School

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Children with Developmental Language Disorder (DLD) often struggle learning to spell. However, it is still unclear where their spelling difficulties lie, and whether they reflect on-going difficulties with specific linguistic domains. It is also unclear whether the spelling profiles of these children vary in different orthographies. The present study compares the spelling profiles of monolingual children with DLD in France and England at the end of primary school. By contrasting these cohorts, we explored the linguistic constraints that affect spelling, beyond phono-graphemic transparency, in two opaque orthographies. Seventeen French and 17 English children with DLD were compared to typically developing children matched for age or spelling level. Participants wrote a 5 min sample of free writing and spelled 12 controlled dictated words. Spelling errors were analyzed to capture areas of difficulty in each language, in the phonological, morphological, orthographic and semantic domains. Overall, the nature of the errors produced by children with DLD is representative of their spelling level in both languages. However, areas of difficulty vary with the language and task, with more morphological errors in French than in English across both tasks and more orthographic errors in English than in French dictated words. The error types produced by children with DLD also differed in the two languages: segmentation and contraction errors were found in French, whilst morphological ending errors were found in English. It is hypothesized that these differences reflect the phonological salience of the units misspelled in both languages. The present study also provides a detailed breakdown of the spelling errors found in both languages for children with DLD and typical peers aged 5–11.

Keywords: spelling, cross-language, French, English, Developmental Language Disorder

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INTRODUCTION

Language and literacy development are intricately related. Children build from their knowledge of sounds and words to progressively recognize and represent them in writing. On the one hand, awareness of speech sounds and the ability to manipulate them have been evidenced as an important predictor of later reading and spelling in a range of writing systems (Caravolas et al., 2012, 2013; Moll et al., 2014). On the other hand, it is also recognized that knowledge of word meaning supports the development of proficient reading (Nation and Snowling, 2004; Ricketts et al., 2007) and writing (Dockrell and Connelly, 2015).

It is thus unsurprising that many children with language difficulties also experience literacy difficulties. There is a well-documented comorbidity between Developmental Language Disorder (DLD) and dyslexia, with comorbidity rates ranging from 17 to 71% (Adlof and Hogan, 2018). In relation to spelling, a recent meta-analysis highlighted the spelling difficulties of children with DLD as compared to typical peers (Joye et al., 2019). The average adjusted standardized difference in spelling scores across studies was $g = -1.42$ (95% CI [−1.60; −1.24]) when children with DLD were compared to same-age typical peers, but non-significant when they were compared to younger children matched on language, reading or spelling, suggesting a clear spelling delay in this population. Furthermore, the meta-analysis highlighted that the difference in scores was particularly important in those children identified as having reading or phonological difficulties in addition to their language disorder.

At school entry DLD is reported to affect approximately 7.5% of the population (Tomblin et al., 1997; Norbury et al., 2016). The terminology and diagnostic criteria for language disorders have been the subject of debate in recent years (Ebbels, 2014). Lately, DLD has emerged as a preferred term from a consensus of experts (Bishop et al., 2016, 2017). DLD describes children who continue to experience language difficulties beyond the age of five, in the absence of any known medical condition, such as acquired brain injury or intellectual disability. DLD does not, however, exclude children with lower non-verbal ability scores (between −1 and −2 SD from the mean). It also recognizes that children with DLD may present with other developmental difficulties, especially dyslexia.

How language difficulties should be identified in pre-school (Dockrell and Marshall, 2015) and at school age (Bishop et al. 2016) is still a matter of debate. The taxonomy of linguistic difficulties experienced by children with DLD is broad (Rapin and Allen, 1987), and typically changes over time (Botting and Conti-Ramsden, 1999; Law et al., 2008), making identification a lengthy and unreliable process. Recently, the identification of language difficulties has increasingly turned to "markers" or "red flags" to pinpoint differences from typical language development (Visser-Bochane et al., 2017). Tasks such as sentence repetition and non-word repetition have been shown to be reliable indicators of language difficulties in a variety of languages at school age, alongside traditional measures of word and sentence production and comprehension (Conti-Ramsden et al., 2001; Leclercq et al., 2014). Amongst the potential clinical markers of language disorder identified in English, phonological and grammatical errors are recurrent in the literature. Specifically, omission of morphological inflections for the past tense (-*ed*), progressive (-*ing*) and noun plural/verb third person (-*s*), are commonly reported in the spontaneous language of English children with DLD (Leonard, 2014). These difficulties are, however, inconsistent, with children with DLD sometimes producing the target correctly, and sometimes not. Critically, differences in the rate of these grammatical errors are observed not only when children with DLD are compared to same-age children, but also when they are compared to younger children matched for language level (Leonard et al., 1992; Oetting and Horohov, 1997), suggesting that specific linguistic processes may be affected in DLD. Word-ending omissions are generally observed in preschool children with DLD, and become less apparent at school age (Bishop, 1994; Rice et al., 1998; Marchman et al., 1999).

The growing literature assessing clinical markers of DLD in languages other than English has challenged the universality of these specific phonological and grammatical errors as indicators of DLD in the early years (see Leonard and Kueser, 2019, for a discussion). For example, in French, clitic pronoun omissions have been proposed as potential markers of DLD (Leonard, 2016). French children with DLD produce an unusually high rate of object clitic errors in the early years (aged 3–7, Hamann et al., 2003) and at school age (5–13, Jakubowicz et al., 1998) and continue experiencing difficulties processing sentences with clitic pronoun cues even in late primary school (7–12, Maillart and Schelstraete, 2003). Difficulties with clitic pronouns are not the only markers of DLD in French. Consistent with English, difficulties have also been reported with verb morphology and in particular with the past tense (passé composé), which involves the auxiliary "être" (be) or "avoir" (have), often omitted (Jakubowicz, 2006). However, the data suggest that these difficulties may be restricted to the early years (Thordardottir and Namazi, 2007).

When it comes to potential school-age markers of DLD, spelling error analysis has provided useful insight into the continuing linguistic difficulties of children with DLD (Windsor et al., 2000; Bishop and Clarkson, 2003; Silliman et al., 2006; Larkin et al., 2013; Critten et al., 2014). In English, errors with verb endings (in particular past tense –*ed*) and noun plural –*s* are found in the spelling of children with DLD when compared to same-age peers, but results are inconsistent when comparisons are made with younger literacy- or language- matched controls (Silliman et al., 2006; Larkin et al., 2013; Critten et al., 2014). Furthermore, the ability of children with DLD to represent the *root* of derived and inflected words was found to be in line with their spelling level (Deacon et al., 2014), suggesting a subtle and specific difficulty with some morphological endings, rather than a broader morphological deficit. Spelling error analysis has also pointed to recurrent difficulties producing phonologically plausible spellings when children are compared to same-age peers, but not to younger peers matched for reading, language or spelling levels (Mackie and Dockrell, 2004; Larkin et al., 2013; Mackie et al., 2013; Critten et al., 2014). In French, spelling error analysis of samples of children with DLD in primary school has highlighted particular difficulties with word segmentation, and a high rate of phonologically implausible errors at the end of primary school in comparison to age-matched peers (Broc et al., 2013). To our knowledge, no spelling error comparison is available in French for children with DLD and younger ability-matched peers.

The comparison with spelling-matched peers is relevant to understanding the specific linguistic difficulties that might underlie spelling difficulties in children with DLD. If children with DLD present with specific phonological or morphological spelling errors over and above what might be expected given their spelling level, this would suggest that learning is specifically impaired in these areas. If, on the contrary, they present with error types commensurate with their spelling level, this would suggest an overall delay in all linguistic processes involved in spelling, commensurate with their language skills. This methodology has been used to characterize the spelling profiles of dyslexic children, pointing to subtle differences in their spelling, over and above those expected given their spelling level (e.g., specific difficulties with the silent letter *e*, Bourassa and Treiman, 2003; and with consonant clusters in English, Bruck and Treiman, 1990; or with long words in Danish, Juul and Petersen, 2017). If such differences could be found in children with DLD, they might be a marker of language difficulties in spelling, and a potential target for future interventions.

Together, the literature reviewed above suggests that children with DLD may have a long-lasting difficulty representing the sounds of words in spelling across languages, alongside more language-specific errors in primary school. However, to our knowledge, comparison with younger peers is rarely, if ever, provided in languages other than English, limiting the ability to draw conclusions on the specific linguistic mechanisms that may be affected in children with DLD, over and above their language and literacy levels (Joye et al., 2019). Another limitation in interpreting the current literature pertains to the inconsistency of tasks used to assess spelling. Whilst some studies have assessed children using a range of controlled words (Silliman et al., 2006; Broc et al., 2013; Critten et al., 2014) and pseudo-words (Larkin et al., 2013), others have used free writing tasks to assess spelling (Windsor et al., 2000; Mackie and Dockrell, 2004; Broc et al., 2013; Mackie et al., 2013), arguably giving children the advantage of choosing the words that they produce in the texts and thus allowing them to use words they are more confident in spelling. Furthermore, word and pseudoword lists have not consistently included morphologically- and orthographically- complex items (see for example McCarthy et al., 2012; Larkin et al., 2013), limiting investigations of spelling constraints in this population to the phono-graphemic conversion level.

French and English are two interesting orthographies to contrast for constraints in spelling development. Both are considered to be highly inconsistent in the phoneme-to-grapheme direction: approximately 20.9% consistency for French and 27.7% for English [although the grapheme-to-phoneme consistency is higher in French (87.6%) than in English (66.3%) – see estimation for monosyllabic words by Ziegler et al., 1996, 1997]. Both orthographies are phonomorphemic (i.e., they represent both sound and meaning units in spelling), and are governed by a range of orthographic rules and regularities (Pacton and Deacon, 2008). However, they differ on a number of other aspects critical to learning to spell beyond the early years: transparency and productivity of derivational morphology (Duncan et al., 2009; Casalis et al., 2015), transparency and richness of morphological inflections (McLeod, 2007), syllabic complexity (Seymour et al., 2003) and complexity and consistency of orthographic rules (Sprenger-Charolles, 2003). The sections below detail how the phono-graphemic, morphological and orthographic characteristics of French and English affect literacy development in these two languages, drawing specific hypotheses for the current study.

At the phono-graphemic level, inconsistencies do affect the rate and pattern of literacy development in French and English. Seymour et al. (2003) showed that children learning to read English took two years to reach about 70% of accuracy in familiar word reading, while French children reached this level after 1 year of being taught to read, and about 99% accuracy after 2 years. This was despite letter-sound correspondences being well-acquired by the end of the first year of instruction. In contrast, non-word reading reached only 64% accuracy in English, even after 2 years of reading instruction, against 97% in French. It is hypothesized that the relatively simple syllabic structure of French facilitates decoding, whilst its orthographic inconsistency makes mastering real word reading a slightly longer process. In English, both syllabic complexity and orthographic inconsistency affect the rate of learning to read (real and non-words) negatively. One particular area of difficulty in reading English pertains to the inconsistency of the vowel system (e.g., *beak, break and head*). In comparison, French vowel sounds are relatively consistent in the reading direction (- eau-, - au-, and -o- are always read /o/, Peereman and Content, 1997). When it comes to spelling real and non-words, English and French children also present with slightly different profiles. Caravolas et al. (2003) compared the spelling scores of poor and good spellers in third grade, on a parallel list of words and non-words matched for length and syllabic structure. Both French and English good spellers reached about 90% accuracy for words. However, differences were evident for non-words, where English good spellers spelled about 60% of the targets accurately, compared to 80% in French. Furthermore, phonological accuracy of the spelling attempts was poorer in the English than in the French sample. English spellers (good or poor) struggled with representing the syllabic structure of the words as compared to French spellers, and omitted unstressed vowels in particular. By contrast, French poor spellers were slightly more likely to omit consonants than vowels in their spelling. It is hypothesized that the syllable-timed stress pattern of French (Delattre and Olsen, 1969) has little effect on vowel production and thus facilitates the perception and written representation of these units, whereas the stress-timed pattern of English makes these units particularly difficult to perceive and spell. On the basis of the literature reviewed above, we thus expected errors at the phono-graphemic level on unstressed vowels in English in the present study, and on consonants in French. We further expected these errors to be particularly evident in the DLD groups, as this group typically experiences difficulties with phonological processing.

At the orthographic level, rules and regularities can also have an impact on spelling accuracy. For example, French children learn early on that, in order to spell the sound /g/ before the letters *-i-* and *-e-*, they have to add a *-u-* (e.g., *girafe* /ʒiʁaf/ -*giraffe*- and *genou* /ʒənu/ -knee- but *guitare* /gitaʁ/ -guitar- or *guêpe* /gɛp/ -wasp-), or that a “cédille” is needed in front of *-a-* or *-o-* for the letter *-c-* to make the /s/ sound (e.g., *cap* /kap/-cape- and *col* /kɔl/- collar-, but *glaçage*/glasaʒ/-icing- or *garçon* /gaʁsɔ̃/ -boy-). They also learn for example that the letter *-s-* needs to be doubled in order not to become sonorant between two vowels (e.g., *asile* /azil/-asylum- but *assis* /asi/-seated-). In English, orthographic constraints in phono-graphemic conventions also exist. For example, English children learn early on that long vowels are often spelled using the *-e-* letter at the end of CVC words (e.g., *pin* /pɪn/ but *pine* /pʌɪn/). Furthermore, in both languages, children have to choose between many alternatives in spelling vowels (e.g., /ɛ/ can be spelled - *in-*, - *ain-*, - *ein-*, - *im-*, - *aim-*, *-eim-*, /ɑ/ can be spelled - *en-*, - *an-*, *-em-*, or *-am-* and /bo/- *o-*, *-ô-*, - *au-*, *-eau-* in French, whilst the spelling for /i:/ has got as many as 13 grapheme representations in English: *mE, nicelY, thEmE, machInE, sEE, sEA, cAEsar, concEIve, nIEce, kEY, quAY, pEOple, and subpOEna*) (see Sprenger-Charolles and Béchennec, 2004, for a comprehensive review of orthographic constraints in learning to read and spell French and English). Because of the complex nature of orthographic constraints in both languages, we expected young and DLD spellers in our study to have difficulties with these rules. Specifically, we expected long and complex vowel spelling and phoneme-grapheme correspondences dependent on orthographic rules to be difficult for these groups in both languages. At the morphological level, little is known about the differential role of derivational morphology in literacy development in French and English. To our knowledge, only two studies have assessed this aspect of morphology comparatively in these two languages. One examined the ability to derive words and pseudowords orally in grade 1–3 French and English children (Duncan et al., 2009). The other assessed word decoding in a set of words and pseudowords that were or were not derived, in a population of grade 4 French and English children (Casalis et al., 2015). Taken together, their results suggest that French children have an earlier and more proficient awareness of derivation processes in word formation than their English peers. They were more likely to successfully use this process to produce derived words and pseudowords orally and judge their acceptability in grades 1–3 (Duncan et al., 2009) or to decode them in grade 4 (Casalis et al., 2015). On the basis of these results, we expected our French sample to perform well in spelling derived words compared to their English peers, and we included specifically derived items in our word lists to assess this aspect of morphological spelling.

Finally, inflectional morphology differs greatly in French and English spelling. The range of morphological markers is much greater in French than in English. Nouns are inflected not only for number (final *-s*, exceptionally *-x*), but also for gender (feminine *-e*). Verbs are inflected for all tenses and persons in French (as opposed to just the third person, past tense and present progressive in English). As an example, the French present for verbs ending in *–er* (e.g., *chant**er**, to sing*) has no less than five different inflections (*-e, -es, -ons, -ez,* and *-ent*): *Je chant**e** (I sing), tu chant**es** (you sing), il chant**e** (he sing**s**), nous chant**ons** (we sing), vous chant**ez** (you (pl.) sing), ils chant**ent** (they sing)*. This is known to be a challenge to French spelling and there is a strong emphasis on grammatical spelling early on in French education (Morin et al., 2018). By contrast inflectional morphology in English is comparatively simple. There is no gender marking in the noun phrase, only the plural, marked by a regular *-s* ending, (which is heard as /z/, /s/ or /ɪz/ depending on the phonological context) and possessive marking (using the apostrophe *–'s* or *–s'* and realized phonologically like a plural). In a few irregular cases plural may provoke a phonological change in the stem as in *foot/feet*, *woman/women, scarf/scarves* or *stimulus/stimuli*. The past tense for verbs is marked by *-ed* (heard as /t/, /d/, or /ɪd/ depending on the context), except for a set of irregular verbs, which also see their stem altered (e.g., *buy/bought*, *stand/stood*). The present progressive is marked by *-ing* and the third person present by *-s*. Inflectional morphology in English is introduced early in the school curriculum, and largely mastered within the first year of schooling. For example, the plural *-s* is mastered as early as the first semester of grade 1 in English-speaking children (Treiman, 1993; Turnbull et al., 2011). Furthermore, and critically for the population of children with DLD, morphological inflections are typically heard in English (*-s*, *-ing*, and *-ed* are pronounced in oral language as well as represented in spelling), whereas there are many silent and homophone inflections in French (e.g., the plural *-s*, or feminine *-e* are often silent in French, and the verb endings *-er*, *-é*, *-ait*, *-ais* or *-aient* all sound the same, see the review by Pacton and Deacon (2008), on French and English morphology). In the present study, by comparing English children with DLD, who may be able to spell word endings either by ear or by application of their morphological knowledge, to a group of French children, who necessarily need to apply morphological knowledge in their spelling of word endings, the present study aims to shed further light on the mechanisms underlying these specific error types. If found in both populations of children with DLD, as compared to spelling-matched peers, morphological ending omissions might be indicative of a specific underlying morphological deficit. If found only in the English-speaking population of children with DLD, they might instead reflect underlying phonological difficulties. It is indeed still a matter of debate whether the word ending omissions produced by children with DLD are phonological or grammatical in nature. Final *-s* and *-ed* are relatively non-salient units to perceive in oral language, and it has been hypothesized that deficits in the phonological representation of children with DLD might impair their production of these discrete units (Marshall and van der Lely, 2007; Parisse and Maillart, 2007).

Given the limited research into spelling development across languages beyond the early years and the lack of characterization of spelling profiles in children with DLD at school-age, the present study's aims were twofold:

- To investigate French-English cross-language differences in spelling development beyond the first 2 years of literacy instruction.
- To provide a detailed profile of the specific spelling errors produced by children with DLD learning to spell in French or English at the end of primary school, as compared to both age- and spelling-matched typical peers.

MATERIALS AND METHODS

Participants

Participant recruitment and data collection procedures were approved by our institution's ethics committee and in line with current data management regulation. All children and their parents/guardians gave their informed consent before participation. One hundred and two participants were recruited from five schools in the South-East of England and seven schools in the South-East and North of France. The same recruitment process was used in both countries. Mainstream schools with a language unit were approached, as well as mainstream schools with a known caseload of children with DLD. Language units ("ULIS-école" in France) are specialist units within mainstream schools, where children with language disorders receive specialist instruction for some of the curriculum and are included in the mainstream classroom for the rest of their learning. Teachers, speech and language therapists and Special Educational Needs Coordinators (SENCOs, in the United Kingdom) were consulted verbally, and parents were consulted using a brief questionnaire (within the consent form), in order to identify children experiencing language and literacy difficulties within the language units and mainstream Year 3, 4, 5, and 6 classes (ages 8–11).

Children were further tested to ascertain their language difficulties using standardized measures. Three measures were taken: sentence repetition, word comprehension and sentence comprehension. Children's diagnosis of DLD was confirmed and they were included in the DLD sample if they scored −1.28 SD or below in at least two of these measures, or on a composite of all three measures. Children reaching scores −2 SD or below on a standardized test of Non-Verbal Performance (NVP) were excluded. Following this procedure, 17 children with language difficulties were identified within the French sample and 17 in the English sample.

A further 17 typically developing children matched on chronological age (CA), and 17 younger children (SA) matched on the raw spelling scores of the Wechsler Individual Achievement Test (WIAT), were identified in each country. These children had NVP, language and spelling scores within the norm for their age range, as reported by parents and teachers and measured on standardized tasks. **Table 1** provides a summary of the groups' characteristics.

As indicated in **Table 1**, children in France (FR) were marginally older than their English peers (EN). This is because French children start formal literacy instruction at age 6, whilst English children start at age 5. Years of instruction were preferred over developmental age for matching, as we considered spelling to be a skill highly dependent on explicit instruction in school. The French and the English TD samples were representative of the general population, as evidenced by their spelling, reading, NVP and language composite standard scores.

Measures

Control Measures

Standardized assessments of language, word reading, phonological awareness and NVP were administered as grouping and control measures. **Table 2** provides a description of the parallel tasks used to assess language, reading, phonological awareness and NVP in both languages.

Personal Narrative Text

A naturalistic sample of writing was obtained using a narrative task. The narrative Curriculum-Based Measure for Writing (CBM-W) from Dockrell et al. (2014) was used in both languages. The task was administered in small groups. Children chose to write to one of the following prompts: "One day, I had the best day ever..." ("Un jour, j'ai eu la meilleure des journées...") or "One day, I had the worst day ever..." ("Un jour, j'ai eu la pire des journées..."). Children were given a lined A4 sheet with the prompt, and told they were to write the best story possible within 5 min. They were given 30 s to think about their story before they started writing. At the end of the 5 min, children finished their last sentence and put their pens down. The proportion of words spelled correctly in this task has good construct validity (0.87) as an accuracy measure and a 0.30 consistency level with the WOLD-writing overall expression score (Dockrell et al., 2014).

TABLE 1 | Characteristics of the participants.

	FR			EN		
	CA	DLD	SA	CA	DLD	SA
N	17	17	17	17	17	17
N boys	6	13	8	7	10	8
N children with other known diagnoses (ADHD and/or dyslexia)	0	7	0	0	7	0
N children scoring below −1 SD on the word reading measure	0	15	5	0	11	1
N children scoring below −1 SD on the phonological awareness measure	0	5	2	0	7	3
N children who speak other languages at home	1	2	1	0	4	0
Age	10.15 (0.73)	10.14 (0.83)	7.85 (1.04)	9.82 (0.7)	9.94 (0.99)	6.89 (0.86)
Language Composite	−0.12 (0.56)	−2.3 (1.08)	0.09 (0.65)	−0.1 (0.73)	−1.86 (0.45)	−0.07 (0.49)
Non-verbal performance	0.41 (0.74)	−0.2 (0.89)	0.15 (1.05)	0.55 (0.71)	−0.47 (1)	0.27 (0.97)
Word Reading Accuracy	0.36 (0.41)	−2.79 (1.53)	−0.67 (0.93)	0.71 (0.9)	−1.25 (0.9)	0.59 (1.07)
Phonological awareness	0.75 (0.4)	−0.75 (1.25)	0.13 (0.84)	0.57 (0.36)	−0.57 (1.06)	0 (0.94)
WIAT spelling	−0.07 (0.66)	−1.83 (0.75)	0.21 (0.75)	0.69 (0.72)	−1.45 (0.48)	0.34 (1.1)
WIAT spelling raw score	31.18 (4.14)	17.35 (6.77)	19.76 (5.01)	36.24 (6.25)	22 (3.18)	21.29 (3.2)

Age is expressed in years, and all other scores are Z-scores, calculated from the mean and standard deviations of the test's results for the child's age group when available, or from the sample's mean and standard deviation stratified by country and age group.

TABLE 2 | Characteristics of the parallel French and English grouping and control measures.

Ability	French test	Task	Rel./Val.	English test	Task	Rel./Val.
Language – Sentence repetition	L2MA2 – Répétition de phrases	Child repeats 15 sentences of increasing complexity	NA/0.85**	CELF-4 – Recalling sentences	Child repeats 32 sentences of increasing length	0.91/0.84**
Language – Sentence comprehension	BALE – Oral language	Child chooses 1 out of 4 pictures that goes with the sentence given. 20 items. No discontinuation rule.	NA/NA	TROG-2	Child chooses 1 out of 4 pictures that goes with the sentence given. Up to 20 blocks of 4 items. Discontinued after 5 blocks failed.	0.87/0.54*$_a$
Language - Word Comprehension	BALE – Oral language	Child chooses 1 out of 6 pictures that goes with the word given. 15 items. No discontinuation rule.	NA/NA	BPVS-3	Child chooses 1 out of 4 pictures that goes with the word given. Up to 14 blocks of 12 items. Discontinued after 8 or more errors within a block	NA/NA
Non-verbal Performance – Matrices	Raven's Colored Progressive Matrices	Child chooses 1 out of 6 figures to fill in a pattern. 3 sets of 12 patterns to complete. No discontinuation rule.	0.80/0.91*$_b$	Raven's Colored Progressive Matrices	Child chooses 1 out 6 figures to fill in a pattern. Three sets of 12 patterns to complete. No discontinuation rule.	0.80/0.91*$_b$
Reading – Timed word reading	BALE – Regular and irregular word reading (low frequency)	Child reads 20 regular words and 20 irregular words. No discontinuation rule.	NA/NA	BAS-3 – Word reading list A	Child reads up to 90 words of increasing complexity (discontinued after 8 failures within a block of 10)	0.98/0.89*$_c$
Phonological Awareness – syllable, rime and phoneme extraction	Parallel bespoke task	Child extracts the common unit in 24 pairs of disyllabic words (8 syllable, 8 rime and 8 phoneme pairs).	NA/NA	Parallel bespoke task	Child extracts the common unit in 24 pairs of disyllabic words (8 syllable, 8 rime and 8 phoneme pairs).	NA/NA
Spelling – Word spelling	WIAT-CDN-FR – Spelling	Child spells up to 53 words of increasing complexity (discontinued after 6 misspellings)	0.91/NA	WIAT-UK-II – Spelling	Child spells up to 53 words of increasing complexity (discontinued after 6 misspellings)	0.94/78*$_d$

*CELF-4: Clinical Evaluations of Language Fundamentals, 4th edition UK (Semel et al., 2006), L2MA2: "Langage oral, Langage écrit, Memoire, Attention," 2nd edition (Chevrie-Muller et al., 2010), TROG-2 : Test of Reception of Grammar, 2nd edition (Bishop, 2003), BALE: "Batterie Analytique du Langage Ecrit" (Jacquier-Roux et al., 2010), BAS-3: British Ability Scale, 3rd edition (Elliott and Smith, 2012), Parallel bespoke French-English phonological awareness task adapted from Duncan et al. (2006), Raven's matrices (Raven et al., 1998a,b), WIAT-UK-II: Wechsler Individual Achievement Test – 2nd UK Edition (Wechsler, 2005b), WIAT-CDN-FR: Wechsler Individual Achievement Test, Canadian Edition (Wechsler, 2005a), Rel. Reliability, Val. Validity; *concurrent validity, **construct validity, $_a$ with 'concepts and following directions' from the CELF-3 $_b$ with WISC-R, $_c$ with list B of the same test, $_d$ with WRAT3, NA, not available.*

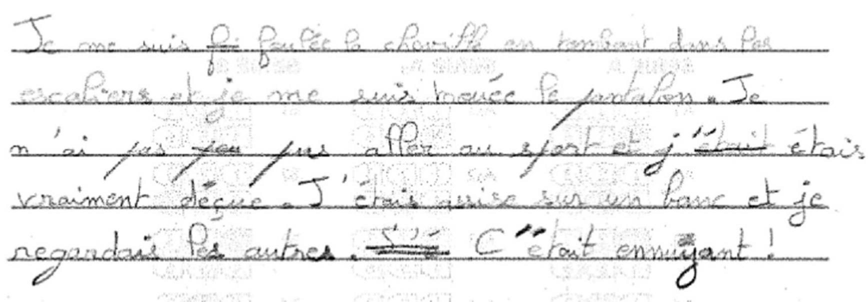

FIGURE 1 | Example of a text produced by a French child aged 10 years 11 months (year 5).

Figures 1, 2 provide an example of production from a TD French and an English participant respectively.

Twelve Dictated Spelling Words

The 12 dictated words were chosen for analysis from the French and English version of the WIAT-spelling test (Wechsler, 2005a,b). All children were administered the full test as a group, in order to obtain their standard score. Each word was given verbally to children, then used in its sentence context, and then given again in isolation for children to spell, as per the test manual's instructions. A subset of the words commonly misspelled by children in both languages was then selected

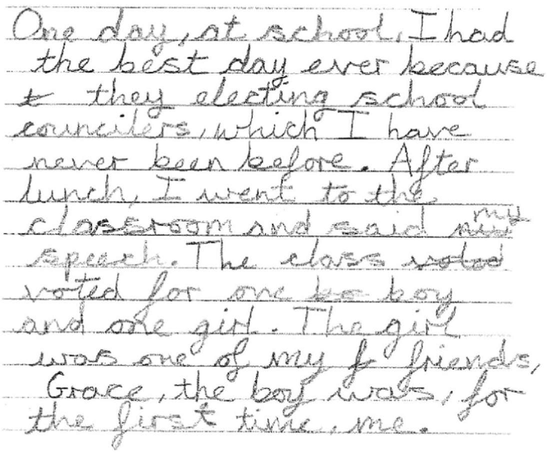
One day, at school, I had
the best day ever because
t they electing school
councilers, which I have
never been before. After
lunch, I went to the
classroom and said my
speech. The class voted
voted for one bo boy
and one girl. The girl
was one of my f friends,
Grace, the boy was, for
the first time, me.

FIGURE 2 | Example of a text produced by an English child aged 10 years 11 months (year 6).

for further analysis. Words were chosen to be representative of the phonological, orthographic, morphological and semantic conventions of written French and English. Words were also matched across languages on number of letters, phonemes, and as much as possible on frequency counts. Accuracy scores on the 12 words were highly correlated with raw scores on the full WIAT scale, both in French ($r = 0.94$) and in English ($r = 0.96$). Cronbach's Alpha was 0.85 on the French scale, and 0.89 on the English scale, indicating good reliability. **Table 3** provides a list of the 12 words chosen in each language.

Procedure

Both experimental tasks were administered in small groups of up to eight children, in one 30-min session. The non-verbal performance test was also administered during this first session, following the test manual's instructions for group administration Children were then seen individually to assess their language, phonological awareness and reading skills.

Productivity and Accuracy Measures for the Text and Dictated Words

For the texts, productivity was measured in number of words produced by each child, excluding proper nouns and illegible words. For both tasks, accuracy was measured by dividing the number of words correctly spelled by the number of words attempted.

Qualitative Analysis of Spelling Errors

After measuring accuracy in the texts and dictated words, a qualitative coding of the spelling errors was conducted by the first author and by two trained independent raters who were native speakers of each language. The framework for spelling error analysis was adapted from Apel and Masterson (2001). Spelling errors were classified as either phonological, orthographic, morphological or semantic in nature, as detailed in **Table 4**. Subcategories were attributed to specific error types within these broad categories, for a fine-grained characterization of spelling profiles in children with DLD, as shown in **Table 4**. Cohen's Kappa between raters was 0.82 (88% agreement) in English and 0.76 (81% agreement) in French. Rate of errors in each category is given in number of errors per word produced, in order to account for individual differences in productivity.[1]

RESULTS

Productivity and accuracy results are presented first, followed by the qualitative analysis of the spelling errors. These results are always presented for the language comparison first (French vs. English), and then for the subgroup comparisons (CA vs. DLD vs. SA) within each language. Finally, regression models to predict a subset of outcome spelling measures are presented.

Productivity and Accuracy Within and Across Languages

Robust ANOVAs and *post hoc* tests were run to assess language and subgroup effects on productivity and accuracy measures, in order to account for the presence of outliers and the heterogeneity of variance (Mair and Wilcox, 2020). A robust measure of effect size (ξ) was computed where relevant. ξ-values of 0.10, 0.30, and 0.50 correspond to small, medium, and large effect sizes respectively (Wilcox and Tian, 2011). **Table 5** presents the mean and standard deviation for the productivity and accuracy measures in the two tasks for our groups of interest.

Language Comparison

In the texts, English children produced more words ($F(1) = 6.70$, $p = 0.013$, ξ [95% CI] = 0.32 [0.07-0.52]) than French children. On average, English texts were 10 words longer than the French texts. There was no difference in productivity in the word dictation task, with all children attempting all 12 words dictated.

English children produced a higher rate of correct words in the texts ($F(1) = 50.15$, $p < 0.001$, ξ [95% CI] = 0.79) than French children. On average, English children produced a misspelling every six words of their texts, whilst the French children produced a misspelling every second word. Similarly, in dictation, word accuracy was higher in English than in French ($F(1) = 10.03$, $p = 0.003$, ξ [95% CI] = 0.08 [0–0.39]). On average, there was a misspelling in every word attempted in both the English and the French dictated words.

Subgroup Comparisons

In both languages, children with DLD and SA peers produced shorter ($F(2) = 39.00$, $p = 0.001$, ξ [95% CI] = 0.71 [0.46–0.86]) and less accurate ($F(2) = 53.21$, $p = 0.001$, ξ [95% CI] = 0.65 [0.39–0.89]) texts than their CA peers. On average, children with DLD and SA peers produced a misspelling every two/three words, whilst CA peers produced a misspelling every seven/eight words in their texts. In word dictation, word accuracy was better in the CA than in the DLD and SA groups ($F(2) = 169.92$, $p < 0.001$, ξ [95% CI] = 0.99 [0.76–0.99]), in both languages. On average, there was a

TABLE 3 | Characteristics of the words chosen from the parallel WIAT-spelling tasks.

FR	Freq	NbPhon	NbLet	EN	Freq	NbPhon	NbLet
main	684	2	4	big	2666	3	3
gros	757	3	4	hand	295	4	4
plomb	19	3	5	careless	3	5	8
sautait	7	4	7	strength	22	6	8
grimpa	1	5	6	riding	143	5	6
plafond	29	5	7	climbed	373	5	7
suis	855	3	4	guess	127	3	5
excitation	3	9	10	right	852	3	5
mer	521	3	3	knew	270	3	4
dois	117	3	4	patients	38	6	8
soupçon	3	5	7	ceiling	35	5	7
aujourd'hui	249	7	11	couldn't	NA	5	8
Mean (*SD*)	271.54 (335.15)	4.33 (2.02)	6 (2.52)	Mean (*SD*)	438.55 (778.25)	4.42 (1.16)	6.08 (1.83)

EN, English word targets; Freq, English: Frequency per million (=number of occurrences of target word/number of all word occurrences in database × 1,000,000), French: Estimated frequency of Usage per million (U = number of occurrences of target word/number of all word occurrences in database × dispersion of the frequencies across readers × 1,000,000); NbPhon, number of phonemes; NbLet, number of letters; FR, French word targets. The indices given above were all taken from the Children's word printed database for English (Masterson et al., 2010) and from the Manulex database for French (Lété et al., 2004).

misspelling in every word attempted in the DLD and SA samples, and one misspelling every three to four words in the CA samples.

Qualitative Analysis of Spelling Errors

Results from the qualitative error coding were analyzed using Wilcoxon rank-sum tests, to account for the overall positive skewness and heterogeneity of variance in the data. A Bonferroni correction for multiple comparisons was applied to reduce the chance of false positives. *P*-values below 0.005 were considered significant. **Figure 3** presents bean plots for the proportion of each error type, per language and group, in the texts and dictated words. The bean plots represent the median, data points and a bean-shape smoothed density curve (verticalized), showing the non-normal distribution of the data across all error types. Results from the Wilcoxon rank-sun tests are given in turn for the language comparisons in both tasks, and for the subgroup comparisons, within each language and for both tasks. Error types are then further broken down using the fine-grain coding scheme, for each type of error (phonological, orthographic, morphological, and semantic), in order to provide a detailed profile of the types of errors made within each language and group.

Phonological Errors

As shown in **Figures 3A,B**, the rate of phonological errors was not significantly different across languages in the texts (W = 1486.5, p = 0.16, r = 0.14) or dictated words (W = 1228, p = 0.61, r = 0.05).

In the French texts, children with DLD produced a higher rate of phonological errors than their CA peers (W = 245, $p < 0.001$, r = 0.64). This was the only significant difference (CAvsSA: W = 103, p = 0.08, r = 0.30; DLDvsSA: W = 199, p = 0.05, r = 0.33). The same result was found in the French dictated words, with more errors in the DLD than in the CA samples (DLDvsCA: W = 257.5, $p < 0.001$, r = 0.72; CAvsSA: W = 79, p = 0.006, r = 0.46; DLDvsSA: W = 202, p = 0.05, r = 0.34).

In the English texts, the rate of phonological errors did not significantly differentiate any of the subgroups (DLDvsCA: W = 191, p = 0.04, r = 0.35, CAvsSA: W = 122.5, p = 0.41, r = 0.14, DLDvsSA: W = 86.5, p = 0.01, r = 0.42). However, in the dictated words, English children with DLD (W = 243, $p < 0.001$, r = 0.62) and SA peers (W = 48, $p < 0.001$, r = 0.61) produced a higher rate of phonological errors than their CA peers, with no other group differences (DLDvsSA: W = 164, p = 0.51, r = 0.11).

In both languages and tasks, phonological errors consisted largely of consonant omissions (especially in consonant clusters, e.g., *ecept* for *except*) and vowel (e.g., *dack* for *duck*) and consonant substitutions (e.g., *den* for *then*). See **Appendices A, B** for the breakdown of error types within the phonological category.

Orthographic Errors

As shown in **Figures 3C,D**, the rate of orthographic errors was not significantly different across languages in the texts (W = 1547.5, p = 0.10, r = 0.16). However, in the dictated words, the difference in rates of orthographic errors between English and French children approached significance (W = 885.5, p = 0.0054, r = 0.28), with more orthographic errors in the English word samples.

In the French texts, children with DLD (W = 229, p = 0.004, r = 0.50) and SA peers (W = 48, $p < 0.001$, r = 0.57) produced a higher rate of orthographic errors than CA peers, but did not differ significantly from one another (DLDvsSA: W = 125, p = 0.51, r = 0.11). By contrast, in the dictated words, only SA peers produced a higher rate of orthographic errors than CA peers (W = 48, $p < 0.001$, r = 0.57), with no other group differences (DLDvsCA: W = 188.5, p = 0.13, r = 0.26; DLDvsSA: W = 108.5, p = 0.22, r = 0.21).

In the English texts, SA children produced a higher rate of orthographic errors than CA peers (W = 40.5, $p < 0.001$, r = 61), all other group comparisons being non-significant (DLDvsCA: W = 206.5, p = 0.03, r = 0.36; DLDvsSA: W = 108.5, p = 0.22,

TABLE 4 | Coding of spelling errors, adapted from Apel and Masterson (2001).

Overall category	Fine-grained coding	Definition	Example (FR)	Target (FR)	Example (EN)	Target (EN)
PHON – Errors where the child did	PHON-OM-vow	Omission of a stressed vowel	*frpé	frappé	*destintion	destination
not represent the phonological skeleton of the word	PHON-OM-cons	Omission of an obligatory consonant	*tabeau	tableau	*chool	school
	PHON-SUB-vow	Substitution of a stressed vowel	*lou	les	*dack	duck
	PHON-SUB-cons	Substitution of a consonant	*pardi	parti	*den	then
	PHON-ADD	Addition of a phoneme	*lavai	avait	*minunts	minutes
ORTH - Errors where the child did not call on relevant orthographic	ORTH-IRR-silent	Omission of an unpredictable silent letter	*plafon	plafond	*climed	climbed
knowledge in his/her production	ORTH-IRR-cons	Substitution of an ambiguous consonant spelling	*cand	quand	*squeesing	squeezing
	ORTH-IRR-vow	Substitution of an inconsistent long vowel grapheme	*ancre *copin	encre copain	*laiter *hed	later head
	ORTH-IRR-vow	Substitution or omission of an unstressed vowel grapheme	N/A	N/A	*apon *favrite	upon favourite
	ORTH-IRR-accent	Error on an accent	*embéter	embêter	N/A	N/A
	ORTH-IRR-MGR	Error of letter inversion	*avce	avec	*beacuse	because
	ORTH-REG	Error on a regular spelling pattern	*poto	poteau	*sista	sister
	ORTH-RUL	Error on a taught spelling rule or an illegal letter sequence	*grinpa	grimpa	*recieve *annd	receive and
	ORTH-PHON	Error with orthographically constrained graphemes-phoneme correspondences affecting phonology	*amourese *gour	amoureuse jour	*tims *techer	times teacher
	ORTH-MOR	Error with rule-constrained applications of inflections and derivations	*obligait	obligeait	*realy *blammed	really blamed
MOR – Errors where the child did	MOR-INF-gender	Error on gender inflection	rempli	remplie	N/A	N/A
not call on relevant morphological	MOR-INF-tense	Error on tense inflection	demander	demandé	*happend	happened
knowledge in his/her production	MOR-INF- Person	Error on person marking	avais	avait	*comse	comes
	MOR-INF-Number	Error on number marking	copain	copains	way's	ways
	MOR-INF-Poss	Error on possessive marking	N/A	N/A	teachers	teacher's
	MOR-DER-base	Error on the base of a complex word	*gran	grand	ment	meant
	MOR-DER-Pre	Error on the prefix of a complex word	*extrordinaire	extraordinaire	*extrordinary	extraordinary
	MOR-DER-Suff	Error on the suffix of a complex word	*maîtrèsse	maîtresse	assemble	assembly
	MOR-CON	Errors on word contractions	*quon	qu'on	*I'am	I'm
	MOR-PHON	Omission of a morphological marker affecting phonology	grand le	grande les	head (verb) goal	headed goals
SEM - Errors on the meaning of the word attempted	SEM-SEG	Segmentation errors	*les cole *on n'a	l'école on a	*some thing	something
	SEM-HOMO	Homophone errors (within the same grammatical category)	poing	point	peace	piece
	SEM-MOR	Use of a grammatical homophone	et à	est a	their your	there you're
	SEM-PHON	Wrong word choice: use of another word, affecting semantics and phonology	j'ai	j'aime	were	wear

$r = 0.21$). A slightly different trend was observed in the dictated words, where English children with DLD ($W = 273$, $p < 0.001$, $r = 0.76$) and SA peers ($W = 9$, $p < 0.001$, $r = 0.80$) both performed worse than their CA peers.

In the French texts and dictated words, orthographic errors were largely found on irregular vowel (e.g., *rancontre* for *rencontre*) and consonant spellings (e.g., *commense* for *commence*), regular orthographic patterns (e.g., *poto* for *poteau*) and silent letters (e.g., *pui* for *puis*). In the English texts, errors on unstressed (e.g., *choclate* for *chocolate*) and long vowels (e.g., *laiter* for *later*), regular orthographic patterns (e.g., *netle* for *nettle*) and contextual spelling dominated (e.g., *gat*

TABLE 5 | Mean and standard deviation for the spelling productivity and accuracy measures.

		FR			EN		
		CA	DLD	SA	CA	DLD	SA
Written texts	Words attempted	35 (5)	15 (3)	20 (3)	51 (4)	25 (6)	21 (5)
	Proportion of words correct	0.75 (0.03)	0.45 (0.07)	0.44 (0.09)	0.95 (0.02)	0.81 (0.02)	0.74 (0.03)
12 words	Words attempted	12 (0)	12 (0)	12 (0)	12 (0)	12(0)	12 (0)
	Proportion of words correct	0.62 (0.05)	0.22 (0.07)	0.24 (0.07)	0.85 (0.03)	0.30 (0.04)	0.29 (0.02)

for *gate*), especially in the younger and DLD groups. In the dictated words, English children also produced orthographic errors on silent letters (e.g., *climed* for *climbed*) and irregular vowel and consonant spellings (e.g., *sealing* for *ceiling*). See **Appendices C, D** for the breakdown of error types within the orthographic category.

Morphological Errors

As shown in **Figures 3E,F**, French children produced a higher rate of morphological errors than their English peers in their texts overall ($W = 2341.5$, $p < 0.001$, $r = 0.70$). The same result was observed in the dictated words ($W = 1884$, $p < 0.001$, $r = 0.39$).

In the French texts, the rate of morphological errors was not significantly different across any of the groups (DLDvsCA: $W = 189$, $p = 0.13$, $r = 0.26$; DLDvsSA: $W = 127$, $p = 0.56$, $r = 0.10$; SAvsCA: $W = 94.5$, $p = 0.09$, $r = 0.29$). However, in the dictated words, French children with DLD ($W = 232$, $p = 0.002$, $r = 0.52$) and SA peers ($W = 29$, $p < 0.001$, $r = 0.34$) produced a higher rate of morphological errors than their CA peers.

The pattern was similar in English, with no significant difference in the rate of morphological errors in the texts across groups (DLDvsCA: $W = 171$, $p = 0.30$, $r = 0.18$, DLDvsSA: $W = 121$, $p = 0.41$, $r = 14$, SAvsCA: $W = 99$, $p = 0.08$, $r = 0.30$), but differentiated results in the dictated words. In the dictated words, English children with DLD ($W = 259$, $p < 0.001$, $r = 0.70$) and SA peers ($W = 26.5$, $p < 0.001$, $r = 0.72$) also produced a higher rate of morphological errors than their CA peers.

In the French texts, children produced a large number of morphological errors on tense (e.g., *aller* for *allé*), number (e.g., *les table* for *les tables*) and person inflections (e.g., *j'était* for *j'étais*). In the English DLD and SA samples, the majority of morphological errors were omissions of inflections (e.g., *tell* for *tells*). The pattern was slightly different in the dictated words, where French children also produced many derivational base errors (e.g., *sotait* for *sautait*). In the English dictated words, in addition to inflection omissions, children with DLD and SA also produced errors with contractions (e.g., *could'nt* for *couldn't*), derivational suffixes (e.g., *strengcth* for *strength*) and tense marking (e.g., *climbd* for *climbed*). See **Appendices E, F** for the breakdown of error types within the morphological category.

Semantic Errors

As shown in **Figures 3G,H**, French children produced a higher rate of semantic errors than English children in their texts overall ($W = 2118.5$, $p < 0.001$, $r = 0.56$). The trend was reversed in the dictated words ($W = 629.5$, $p < 0.001$, $r = 0.51$), where English children produced more semantic errors than their French peers. Note, however, that this error type was marginal in both languages in the dictated words, with error rates flooring close to zero per word attempted.

In the French texts, children with DLD produced a higher rate of semantic errors than CA peers ($W = 236$, $p = 0.002$, $r = 0.54$) but there were no other group differences (DLDvsSA: $W = 168.5$, $p = 0.42$, $r = 0.14$; SAvsCA: $W = 82.5$, $p = 0.03$, $r = 0.36$). However, in the dictated words, no group difference appeared, with the error rate being close to zero across groups (DLDvsCA: $W = 145$, $p = 1$, $r = 0$; CAvsSA: $W = 128.5$, $p = 0.42$, $r = 0.14$; DLDvsSA: $W = 129$, $p = 0.44$, $r = 0.13$).

The rate of semantic errors was close to zero in the English texts and did not differentiate any of the groups (DLDvsCA: $W = 192$, $p = 0.07$, $r = 0.31$; DLDvsSA: $W = 181$, $p = 0.16$, $r = 0.24$; SAvsCA: $W = 140$, $p = 0.87$, $r = 0.03$). The same was observed in the dictated words (DLDvsCA: $W = 209.5$, $p = 0.02$, $r = 0.41$; CAvsSA: $W = 99$, $p = 0.08$, $r = 0.30$; DLDvsSA: $W = 179.5$, $p = 0.15$, $r = 25$).

In the French texts, children with DLD and SA produced a large proportion of segmentation errors (*je ma muse* for *je m'amusais*). In all groups, errors on grammatical homophones were also prominent (e.g., *à* for *a* or vice versa). These errors were almost absent in English texts. In the dictated words, however, English children, especially in the DLD and SA subgroups produced some errors with grammatical homophones (e.g., *new* for *knew*) and word choice (e.g., *guest* for *guess*). See **Appendices G, H** for the breakdown of error types within the semantic category.

Controlling for Sampling Differences Across Languages

In order to control for any sampling confounds that could explain the cross-language differences observed, we ran further regression analyses. These regressions examined the following predictors: age, NVP and phonological awareness as control variables in a first step and language (French vs. English) in a second step. They were run for outcome measures where significant cross-language differences were found, that is: the number of words produced in the texts (where English children were more productive than French peers), the proportion of words correct in both tasks (where English children were more accurate than French peers); the rate of morphological errors in texts and dictated words and the rate of semantic errors in the texts only (where French children produced more errors than their English peers); the

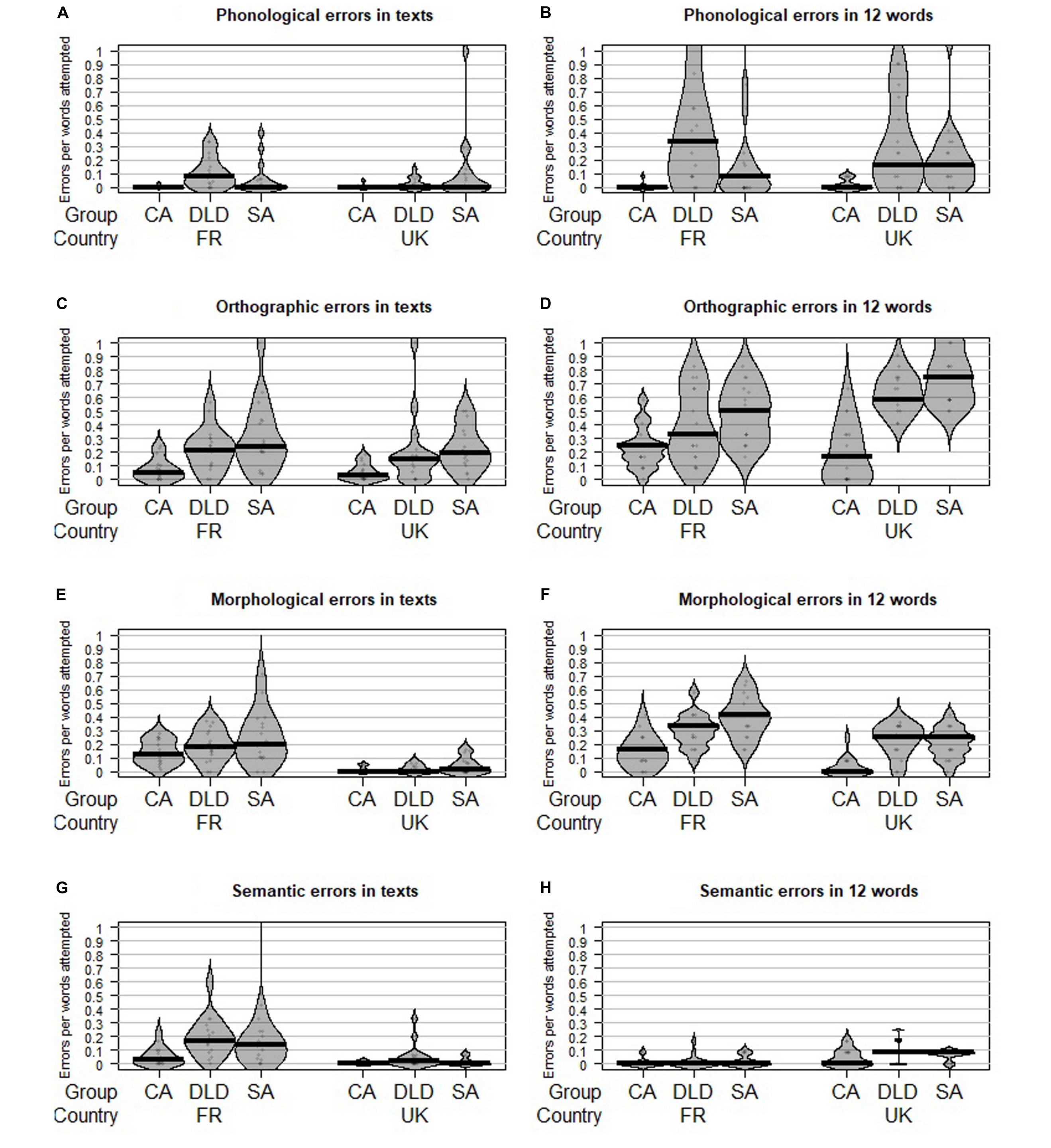

FIGURE 3 | Median and distribution of the proportion of each error type, per language and group.

rate of orthographic and semantic errors in the dictated words (where English children produced more errors than their French peers).

Number of words produced in the texts was the only continuous outcome with normally distributed residuals and a generalized linear model was applied using the lm() function in R (R Core Team, 2018). For all other measures, beta regressions for beta-distributed outcomes were applied, using the betareg() function in R (Cribari-Neto and Zeileis, 2010). Zero-order correlations between all variables of interest are presented in the first instance.

Zero-Order Correlations Between the Measures of Interest

Table 6 presents the correlation between the control and spelling measures, for the French and the English samples separately.

Non-verbal performance and phonological awareness correlated strongly with most of the spelling outcomes selected. In English, both measures correlated strongly with the accuracy measures on both tasks, and with the rate of morphological and orthographic spelling errors in the 12 dictated words in particular. In French, they were also strong correlates with the spelling accuracy and productivity measures (in addition to age). In French, phonological awareness was a strong correlate of semantic errors in texts but did not correlate with semantic errors in the dictated words nor with morphological errors in the texts.

Regression Models for Productivity and Accuracy Measures Where English Children Outperformed French Children

Stepwise regressions were run to assess the effect of language over and above age, NVP and phonological awareness, for the productivity and accuracy measures where English children performed better than French children: (1) number of words produced in the texts, (2) proportion of correct words in the texts, (3) proportion of correct words in the 12 dictated words. These regressions are presented in **Table 7**.

Number of words produced in the texts

The initial model with age, NVP and phonological awareness explained a significant 18.52% of variance in text productivity. The addition of the language predictor in a second step explained a significant further 12.52% of variance (new model R^2 = 30.75%).

Proportion of words correct in the texts

The initial model with age, NVP and phonological awareness explained 14.73% of variation in the proportion of correct words in the texts. The addition of language in a second step explained a significant further 33.02% (new model R^2 = 47.74%).

Proportion of words correct in the 12 dictated words

The initial model with age, NVP and phonological awareness explained 24.49% of variation in the proportion of correct words in the 12 dictated words. The addition of language in a second step explained a significant further 20.02% (new model R^2 = 44.51%).

The regressions confirmed language was a significant predictor of our productivity and accuracy measures of interest, over and above age, NVP and phonological awareness. All control measures being equivalent, English students were more likely than French students to produce longer and more accurate texts, and more correct words in the dictated words.

Regression Model for the Qualitative Outcome Measures Where English Children Outperformed French Children

Stepwise regressions were run to assess the effect of language over and above age, NVP and phonological awareness, for the qualitative outcome measures where English children performed

TABLE 6 | Correlation table for the control and spelling variables of interest.

French

	Age	NVP	PA	Text prod.	12 words acc.	Text acc.	Text MOR	12 words MOR	12 words ORTH	Text SEM	12 words SEM
Age		0.43	0.12	0.23	0.46*	0.37	−0.15	−0.61***	−0.33	−0.22	−0.12
NVP	0.63***		0.44*	0.39	0.34	0.42	−0.35	−0.48*	−0.20	−0.26	−0.19
PA	0.13	0.59***		0.46*	0.67***	0.54**	−0.09	−0.43	−0.41	−0.53**	−0.01
Text prod.	0.40	0.59***	0.46*		0.58***	0.68***	−0.11	−0.44*	−0.23	−0.53**	−0.21
12 words acc.	0.42	0.70***	0.54**	0.63***		0.73***	−0.20	−0.76***	−0.67***	−0.64***	−0.27
Text acc.	0.54**	0.65***	0.59***	0.59***	0.78***		−0.40	−0.63***	−0.47*	−0.79***	−0.08
Text MOR	−0.22	−0.18	−0.37	−0.08	−0.32	−0.47*		0.39	0.22	0.15	0.17
12 words MOR	−0.34	−0.63***	−0.52**	−0.66***	−0.79***	−0.66***	0.21		0.54**	0.59***	0.22
12 words ORTH	−0.58***	−0.72***	−0.48*	−0.63***	−0.85***	−0.75***	0.39	0.72***		0.43	0.23
Text SEM	0.09	−0.24	−0.26	0.04	−0.29	−0.27	0.15	0.33	0.19		0.03
12 words SEM	−0.10	−0.29	−0.52**	−0.31	−0.51**	−0.36	−0.01	0.36	0.29	0.05	

English

*Significance levels of Spearman correlations are indicated as follows: *p < 0.05, **p < 0.01, ***p < 0.001, p-values were corrected for multiple tests using Holm–Bonferroni procedure [rcorr.adjust() function in the RcmdrMisc package (Fox, 2018)]; NVP, Non-Verbal Performance, as measures by the Raven's matrices; PA, Phonological Awareness; Text prod., raw number of words attempted in the texts; 12 words acc., Proportion of words correctly spelled in the 12 words analyzed from the WIAT spelling test; Text acc., Proportion of words correctly spelled in the texts produced using the writing Curriculum-Based Measure; Text MOR, proportion of morphological errors per word within the CBM texts; 12 words MOR, proportion of morphological errors per word within the WIAT 12 words; 12 words ORTH, Proportion of orthographic errors per word within the WIAT 12 words; Text SEM, proportion of semantic errors per words within the CBM texts; 12 words SEM, proportion of semantic errors per words within the WIAT 12 words.*

TABLE 7 | Regression models for productivity and accuracy outcomes where English children outperformed French children.

Outcome: number of words produced in the texts

	Model step 1					**Model step 2**				
	R^2	*B*	*SE*	$t/F_{R}{}^2$	*p*	R^2	*B*	*SE*	$t/F_{R}{}^2$	*p*
Constant		−30.2	12.4	−2.4	0.017*		−49.8	12.3	−4.05	0.001***
Age		2.10	1.48	1.42	0.159		3.12	1.38	2.25	0.026*
NVP		1.02	0.53	2.04	0.044*		0.91	0.049	1.84	0.069
PA		0.52	0.37	1.41	0.161		0.94	0.35	2.69	0.008**
Lang (EN)							14.98	3.48	4.31	< 0.001***
Model	0.182			8.433	< 0.001***	0.308			12.1	< 0.001***
R^2 change						0.125			18.54	< 0.001***

Outcome: proportion of words correct in the texts

	Model step 1						**Model step 2**					
	R^2	*B*	*SE*	χ^2	*df*	*p*	R^2	*B*	*SE*	χ^2	*df*	*p*
Constant		−2.33	0.74	−3.13	1	0.0017**		−4.75	0.72	−6.6	1	< 0.001***
Age		0.09	0.09	1.02	1	0.31		0.22	0.08	2.83	1	0.005**
NVP		0.06	0.03	2.03	1	0.043*		0.05	0.03	1.68	1	0.09
PA		0.01	0.02	0.63	1	0.527		0.07	0.02	3.44	1	0.0005***
Lang (EN)								1.59	0.21	7.67	1	< 0.001***
Model	0.147			21.53	5		0.478			45.74	6	
R^2 change							0.330			58.85		< 0.001***

Outcome: proportion of words correct in the 12 dictated words

	Model step 1						**Model step 2**					
Constant		−4.93	0.75	−6.60	1	< 0.001***		−6.97	0.75	−9.25	1	< 0.001***
Age		0.24	0.08	2.79	1	0.005**		0.34	0.08	4.304	1	< 0.001***
NVP		0.04	0.03	1.41	1	0.16		0.03	0.03	1.11	1	0.266
PA		0.07	0.02	3.14	1	0.0017**		0.11	0.02	5.41	1	< 0.001***
Lang (EN)								1.28	0.20	6.39	1	< 0.001***
Model	0.245			20.57	5		0.445			39.5	6	
R^2 change							0.200			40.84		< 0.001***

better than French children: (1) morphological errors in the texts, (2) morphological errors in the 12 dictated words, (3) semantic errors in the texts. These regressions are presented in **Table 8**.

Proportion of morphological errors in the texts

The initial model with age, NVP and phonological awareness explained 1.58% of variation in the rate of morphological errors in the texts. The addition of language in a second step explained a significant further 46.18% (new model R^2 = 47.76%).

Proportion of morphological errors in the 12 dictated words

The initial model with age, NVP and phonological awareness explained 22.23% of variation in the rate of morphological errors in the 12 dictated words. The addition of language in a second step explained a significant further 25.37% (new model R^2 = 47.6%).

Proportion of semantic errors in the texts

The initial model with age, NVP and phonological awareness explained 6.27% of variation in the rate of semantic errors in the 12 dictated words. The addition of language in a second step explained a further 30.67% (new model R^2 = 36.94%).

The regressions confirmed language was a significant predictor of our qualitative measures of interest, over and above age, NVP and phonological awareness. English children were less likely than French children to produce morphological and semantic errors in the texts, and morphological errors in the dictated words, regardless of age, NVP and phonological awareness levels.

Regression Model for the Qualitative Outcome Measures Where French Children Outperformed English Children

Stepwise regressions were run to assess the effect of language over and above age, NVP and phonological awareness, for the qualitative outcome measures where French children performed better than English children: (1) orthographic errors in the 12 dictated words, (2) semantic errors in the 12 dictated words.

TABLE 8 | Regression models for qualitative outcome measures where English children outperformed French children.

Outcome: proportion of morphological errors in the texts												
	Model step 1						**Model step 2**					
	R^2	*B*	*SE*	χ^2	*df*	*p*	R^2	*B*	*SE*	χ^2	*df*	*p*
Constant		−2.1	0.67	−3.17	1	0.001**		−0.50	0.63	−0.79	1	0.43
Age		0.03	0.08	0.36	1	0.72		−0.06	0.07	−0.88	1	0.38
NVP		−0.02	0.03	−0.78	1	0.43		−0.02	0.02	−0.80	1	0.42
PA		0.03	0.02	1.26	1	0.21		0.01	0.02	0.43	1	0.66
Lang (EN)								−1.44	0.19	−7.55	1	< 0.001***
Model	0.016			128.4	5		0.478			153.5	6	
R^2 change							0.320			56.9		< 0.001***
Outcome: proportion of morphological errors in the 12 dictated												
	Model step 1						**Model step 2**					
Constant		2.07	0.59	3.49	1	< 0.001***		3.75	0.57	6.56	1	< 0.001***
Age		−0.09	0.07	−1.22	1	0.22		−0.21	0.06	−3.42	1	< 0.001***
NVP		−0.08	0.03	−3.23	1	0.001**		−0.06	0.02	−2.75	1	0.006**
PA		−0.01	0.02	−0.81	1	0.42		−0.05	0.02	−3.10	1	0.002**
Lang (EN)								−1.21	0.17	−7.19	1	< 0.001***
Model	0.222			74.01	5		0.476			94.93	6	
R^2 change							0.254			51.69		< 0.001***
Outcome: proportion of semantic errors in the texts												
	Model step 1						**Model step 2**					
Constant		−1.43	0.70	−2.04	1	0.04*		0.24	0.72	0.34	1	0.74
Age		0.11	0.08	1.32	1	0.18		0.02	0.08	0.29	1	0.77
NVP		−0.06	0.03	−1.98	1	0.048*		−0.05	0.03	−1.85	1	0.06
PA		0.01	0.02	0.23	1	0.82		−0.03	0.02	−1.41	1	0.16
Lang (EN)								−1.05	0.21	−5.01	1	< 0.001***
Model	0.0627			148.5	5		0.369			159	6	
R^2 change										25.11	1	< 0.001***

The regression models for these outcome measures are presented in **Table 9**.

Proportion of orthographic errors in the 12 dictated words

The initial model with age, NVP and phonological awareness explained 36.15% of variation in the rate of orthographic errors in the 12 dictated words. The addition of language in a second step reduced the model's prediction coefficient (Pseudo R^2 = 36.08%).

Proportion of semantic errors in the 12 dictated words

The initial model with age, NVP and phonological awareness explained 21.2% of variation in the rate of semantic errors in the 12 dictated words. The addition of language in a second step explained a significant further 25.37% (new model R^2 = 47.6%).

The regressions confirmed the importance of language in explaining the proportion of semantic errors, over and above age, NVP and phonological awareness. With equivalent age, NVP scores and phonological awareness scores, French students were less likely than English students to produce semantic errors in the dictated words. However, language was not a significant contributor to the model explaining the proportion of orthographic errors in the 12 words.

DISCUSSION

The present study aimed to characterize the spelling difficulties of children with DLD at the end of primary school, in two languages of similar orthographic opacity, but contrasted for their linguistic constraints: French and English. The results point to cross-language differences in text productivity and error rates, with all French groups producing shorter and less accurate texts than their English peers overall. They also point to qualitative differences in the locus of these errors, with more orthographic errors in the English dictation samples and more morphological errors in the French texts and dictation samples. Nevertheless, across languages and error types, children with DLD performed in line with their SA but not CA peers, suggesting a delay in their spelling profiles commensurate with language and literacy levels. Fine-grained analysis of errors further shows language-specific constraints in the spelling of each group of children.

TABLE 9 | Regression models for qualitative outcome measures where French children outperformed English children.

Outcome: proportion of orthographic errors in the 12 dictated words												
	Model step 1						**Model step 2**					
	R^2	*B*	*SE*	χ^2	*df*	*p*	R^2	*B*	*SE*	χ^2	*df*	*p*
Constant		5.51	0.72	7.62	1	< 0.001***		5.43	0.77	7.06	1	< 0.001***
Age		−0.31	0.08	−3.78	1	< 0.001***		−0.31	0.08	−3.67	1	< 0.001***
NVP		−0.07	0.03	−2.40	1	0.017*		−0.07	0.03	−2.45	1	0.014*
PA		−0.05	0.02	−2.65	1	0.008**		−0.05	0.02	−2.43	1	0.015*
Lang (EN)								0.07	0.20	0.35	1	0.72
Model	0.362			30.19	5		0.361			30.25	6	
R^2 change							−0.07			0.13		0.72
Outcome: proportion of semantic errors in the 12 dictated words												
	Model step 1						**Model step 2**					
Constant		−1.11	0.58	−1.92	1	0.055		−2.06	0.60	−3.44	1	< 0.001***
Age		−0.09	0.07	−1.34	1	0.18		−0.05	0.07	−0.82	1	0.41
NVP		0.01	0.03	0.24	1	0.81		0.005	0.02	0.21	1	0.84
PA		−0.07	0.02	−4.14	1	< 0.001***		−0.06	0.02	−3.66	1	< 0.001***
Lang (EN)								0.76	0.18	4.18	1	< 0.001***
Model	0.212			225.4	5		0.370			234.2	6	
R^2 change							0.158			17.51	1	< 0.001***

Word- and Sentence- Level Processes Involved in Spelling Across French and English

By using a linguistic framework for the assessment of spelling errors, we were able to highlight differences in the constraints affecting spelling in French and English. It was predicted that orthographic constraints were more likely to affect spelling performance in English, whilst morphological constraints were more likely to affect spelling performance in French. We indeed found poorer morphological spelling scores in French as compared to English, in both tasks, but we could not quite highlight any difference in the rate of orthographic errors between the two languages, in any of the tasks, although the proportion of orthographic errors in dictation was slightly higher in English than French altogether. This result highlights the importance of considering spelling as a multi-component skill rather than as a single construct, with lexical and sublexical constraints on the one hand, and grammatical constraints on the other (Morin et al., 2018). It also emphasizes the need for several tasks to tap into these distinct mechanisms. The assessment of spelling is often limited to word-level tasks, emphasizing the influence of word properties, such as syllabic complexity, frequency and transparency, on spelling performance (Wimmer and Landerl, 1997; Marinelli et al., 2015). In our study, the orthographic constraints of English appeared only in the word dictation task, where children could not choose the words they spelled, whilst French morphological constraints were most evident in text production, where children had to consider the grammatical context of many words in order to spell inflections accurately. Finally, the many segmentation errors found in the French younger and DLD samples were evidenced in text production only. To our knowledge, the present study provides the first direct comparison of word- as well as sentence-level constraints on spelling in English compared to another language. It was striking that our French sample overall produced shorter and less accurate texts than their English peers, despite English being consistently described as an outlier in terms of spelling difficulty (Share, 2008). We argue that future studies of spelling development are needed, that contrast orthographies not only for orthographic consistency but also morphological richness, both derivational and inflectional (see for example Desrochers et al., 2018, contrasting English, French, and Greek on these aspects).

Developmental Patterns of Spelling in Children With DLD

The present work was motivated by a meta-analytic review of the literature on the spelling performance of children with DLD across European orthographies (Joye et al., 2019). That review did not highlight any difference in the quantity of errors produced by children with DLD compared to younger typically developing children matched for language or literacy skills, but did highlight a clear lag in spelling scores compared to same-age children. By comparing the spelling errors of these three groups of children qualitatively, we aimed to assess whether the locus of these spelling difficulties might differ in children with DLD when a more detailed analysis of their spelling errors was included.

Our group comparisons did not highlight significant differences in the spelling profiles of children with DLD and younger typically developing children matched for spelling level. Children with DLD produced errors similar to those of their younger peers, and in similar proportions, that is: segmentation errors in French texts, errors with contextual patterns and inconsistent vowel spellings in English, and a range of phonological errors in both languages. Errors with inflection omissions and contractions were also found in the English SA and DLD samples, whilst in French, morpheme substitutions were most common, and found overwhelmingly across all three groups.

It should be noted that all comparisons were run with a stringent significance threshold of 0.005, due to the multiple comparisons being conducted in the study (i.e., Holm–Bonferroni correction for multiple comparisons). Visual examination of the data (**Figure 1**) does suggest that French children with DLD might produce a slightly higher rate of phonological errors than their SA peers. It also suggests the distribution for this error type is spread toward the higher end in the English-DLD sample as compared to their SA peers. On the other hand, orthographic and morphological errors seem to be slightly higher in the younger group in both languages (than both CA and DLD groups). Considered together, these visual trends suggest a developmental pattern whereby children with DLD are delayed in their orthographic and morphological spelling, but might remain more impaired than should be expected in the phonological domain. However, these trends are not corroborated by the numerical comparisons.

The current results also provide developmental benchmarks for the assessment of spelling in a population of children with DLD in French and English middle school. Future studies may want to characterize further the spelling profiles of French and English children in early primary and secondary school. This has been done to an extent for adolescents in previous studies (Dockrell et al., 2009; Broc et al., 2013, 2014), but those studies have not included a younger group of SA TD matched peers, making it difficult to assess whether patterns of spelling development are typical in the population of children with DLD over time. Further data are needed to test whether morphological ending errors appear in French samples later on in adolescence, and to what extent they deviate from younger peers matched for spelling level. Future studies may also explore whether morphological ending and contraction errors (in English) and segmentation errors (in French), as well as phonological errors (in both languages), persist in adolescence, over and above what might be expected given overall spelling development. Longitudinal designs may also be appropriate for this type of characterization (Nauclér, 2004).

Linguistic Constraints in the Spelling Development of Children With DLD

The phonological and morphological difficulties of children with DLD have often been investigated in their early oral language (Leonard, 2014). One aim of the current study was to assess whether some of these oral language difficulties remain in written language, and to assess whether they could be found in languages other than English and thus test any claim for universality in atypical language development. A few studies have found suffix omissions to be a particular feature of the spelling of children with DLD (Windsor et al., 2000; Mackie and Dockrell, 2004; Silliman et al., 2006; Larkin et al., 2013; Mackie et al., 2013; Critten et al., 2014). Those studies were conducted in English only, and pointed to specific difficulties with spelling *-ing*, plural and 3rd person *-s* and past tense *-ed*, as also observed in the oral language of English children with DLD (Windsor et al., 2000). In our analysis, these errors were classified as "omissions of a morphological marker affecting phonology," within the morphological category. Observation of the descriptive data as shown in **Appendices E, F** suggests that these errors are also found overwhelmingly in our English DLD sample. However, they are not found in the French DLD and SA samples. Instead, a large number of segmentation errors were found in the French DLD and SA samples, either in the semantic category ("Segmentation errors," e.g., *les cole for l'école) or in the morphological contraction category ("Errors on word contractions," e.g., *quon for qu'on).

Several interpretations can be drawn from these data. Firstly, our data suggest that, if specific to the population of *English* children with DLD, inflection omission errors are not necessarily found in other languages, at least not in French middle school, arguing against any claim for universality of these particular error types. Secondly, our data question whether the drivers of these specific errors in English are morphological in nature. It has been argued that phonological salience is an important factor to consider when assessing morphological omission errors in the oral language of children with DLD (Parisse and Maillart, 2007). It is possible that English children with DLD continue to produce omissions of non-salient morphological markers for an extended period of time, just as they continue producing other errors with difficult phonological combinations (such as consonant cluster reductions, substitutions of closely related consonants and vowels) in both French and English. Finally, our written data complements accounts of French DLD-specific errors in oral language (Jakubowicz et al., 1998; Hamann et al., 2003; Thordardottir and Namazi, 2007). In oral language, French clitic pronouns have been found to be particularly difficult for children with DLD. We found here that those speech segments which can be found in multiple lexical and grammatical contexts, and present with some degree of phonetic similarity (la, le, les, me, m', te, t', etc.) continue to be difficult to represent in written language for French children with DLD in late primary school, with a high rate of morphological errors in the contraction category (see **Appendices E, F** for a breakdown of error types). These errors, along the many segmentation errors found in the French DLD and SA sample (e.g., récré a tion), highlight the immature lexical representations of this population, and suggest difficulties integrating grammatical information from non-phonologically salient units. This is in line with evidence from typical development suggesting phonological and non-phonological aspects of language are intricately related in the early years (Hipfner-Boucher et al., 2014), and evidence from children with DLD highlighting their sensitivity to phonological aspects of grammatical segments (Tomas et al., 2015). It is likely that difficulties with both segmental and supra-segmental aspects of language in this population drive further difficulties with later lexical and orthographic representations (Share and Shalev, 2004). Our data do not settle this matter, but do suggest that linguistic constraints apply to written as well as oral language, and that assessing spelling qualitatively does indeed provide a good "window into residual language deficits" (Bishop and Clarkson, 2003), and possibly the representation of phonetically subtle but grammatically discrete linguistic units Of course, spelling is not just about phonology and morphology, and involves a range of orthographic constraints that children need to learn and apply in their production. Our linguistic framework for spelling error analysis also incorporates these constraints and shows how much they indeed influence the spelling performance of children with DLD, in support of previous studies (Soriano-Ferrer and Contreras-González, 2012). We argue that a broad linguistic framework incorporating oral as well and written word forms is likely to be appropriate to assess and support the spelling development of children with DLD (Apel and Masterson, 2001).

Underlying Processes in French and English Spelling Development: Commonalities and Differences

Possible constraints in understanding the spelling profiles of our sample were explored with a set of control measures (age, non-verbal performance and phonological awareness).

Overall, the regression analyses supported the role of language found in the quantitative and qualitative errors analyses conducted in sections "Productivity and accuracy within and across languages" and "Qualitative analysis of spelling errors." Even after accounting for age, NVP and phonological awareness, language was still a significant predictor of text productivity and spelling accuracy in the text and dictated words. English children were more likely to obtain higher scores on these measures, but also more likely than French children to produce semantic errors in the dictated words. By contrast, French children were more likely to produce a higher proportion of morphological and semantic errors in their texts and morphological errors in the dictated words. There was one exception to these confirmatory results: language did not predict the proportion of orthographic errors in the 12 dictated words, over and above age, NVP and phonological awareness. In this model, age was a particularly good predictor of the decrease in the proportion of orthographic errors, suggesting in both languages, continued exposure with written content improves the retention of orthographic patterns, in line with self-teaching accounts (Conrad, 2008; Shahar-Yames and Share, 2008).

The correlations presented in section "Zero-order correlations between the measures of interest" also provided some insight into the processes involved in different components of spelling in the two languages. Age, NVP and phonological awareness correlated with most of the spelling outcomes considered, in both languages. However, in French, the proportion of semantic errors in the dictated words and morphological errors in the texts was not associated with age or phonological awareness. We interpret this as an indication that these errors are related to spelling skills that were still not mastered in the French older control group (homophones and morphological inflections). In contrast, large correlations were found between phonological awareness and semantic errors in the texts, and morphological/orthographic errors in the 12 dictated words, indicating phonological awareness plays an important role in representing semantic, orthographic and morphological units in French word spelling. In English, all three control measures correlated with the spelling productivity and accuracy variables and most qualitative measures. However, semantic errors in general and morphological errors in the texts did not correlate very strongly with the predictors. This likely reflects the low rate of such errors in the English sample altogether.

Phonological skills have been related to French and English spelling in previous studies (Moll et al., 2014), and to an extent, our models confirmed previous findings: (1) English spelling is particularly reliant on phono-graphemic skills, and possibly for an extended period of time than other orthographies, due to its opacity; (2) French spelling is also reliant on phonological skills early on, but may also call on a wider range of processes later on (see Moll et al., 2014; Desrochers et al., 2018). However, in the existing literature, spelling had been considered as a single construct. By differentiating between different component spelling skills in the present study, we also found differentiated patterns of relationships. This was rather an incidental finding as the focus of the present study was really on spelling errors. Future studies may want to further investigate the nature of the differences observed in the present study, including predictors of different components of text spelling such as morphological awareness (e.g., in Desrochers et al., 2018) but also reading and transcription skills involved at different stages of the development of text production (Llaurado and Dockrell, 2020). We also suggest that reading might be a better indicator of phonological skills in late primary school than an explicit measure of phonological awareness. Not all children with DLD in our sample presented with low phonological awareness scores, but a large proportion of them presented with low reading scores (as shown in **Table 1**).

Limitations

Although the present study attempted to draw on a range of linguistic components in the list of words that children were given to spell, it was impossible to match our French and English list of words on all sublexical aspects critical to spelling (morphological, orthographic and phonological complexity as well as frequency, number of orthographic and phonological neighbors, syllabic complexity and word length). Arguably, 12 words is also too small a list to be fully representative of the constraints of each language. Spelling error analysis is a time-consuming process requiring several raters and several rounds of coding, for adequate training and reliability checks. Unfortunately, because of constraints with time and raters' availability, we had to restrict the analysis to a limited number of words, which we attempted to match across languages. Such attempts are of course imperfect. Future studies may, however, rely on recent developments in the cross-language assessment of language and literacy. One promising tool for future analyses is the Multilanguage Assessment Battery of Early Literacy, recently made available online for a range of languages (MABEL, Caravolas et al., 2020) and which authors may want to consider when developing cross-language studies of spelling errors.

Similarly, giving children a free writing task does not allow to capture all the spelling processes that may be at play in spelling for writing. Children may or may not use some of the spelling processes we were aiming to assess. Arguably as well, 5 min is a rather short amount of time for children to generate ideas and produce a text, and it is likely that children's familiarity with this type of tasks may have affected their productivity and spelling performance on this task. Observations during data collection and discussions with teachers in both French contexts suggest that French children are typically given more time and scaffolding in writing tasks and may have been surprised by such a short and free writing task. Such accounts were not given in the English contexts.

Beyond task differences, cross-language comparisons between French and English are complicated by the fact children do not start formal literacy instruction at the same age. Although as a group, the age of the French and English samples did not differ significantly, English children had typically been in formal education for a year longer than their French peers. One cannot rule out the possibility that this difference affected our cross-language comparisons. Socio-economic and instructional factors could also be controlled in future. It is possible that the explicit teaching (or the lack of) of particular aspects of spelling could affect children's response and the quality of their errors in our spelling tasks.

CONCLUSION

The present study assessed the locus of spelling difficulties in two samples of middle school children with DLD in France and in the United Kingdom. Results suggest a pattern of overall delay in spelling development in children with DLD in both languages, with a range of phonological, orthographic, morphological and semantic errors similar to those of younger peers. They also confirm that the difficulties observed in the early oral language of children with DLD persevere in late primary school in written language, that is difficulties with morphological endings in English and difficulties with pronoun contractions and word segmentation in French. We argue that these specific difficulties in each language might be related to the phonological salience of these grammatical forms. In the general population too, error types were specific to each language assessed, with clear orthographic constraints in English, and morphological constraints in French. Further studies may want to assess children's spelling at other developmental timepoints and in a broader range of languages contrasted for phono-orthographic transparency and morphological complexity.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

This study involved human participants and was approved by the ethics committee of UCL Institute of Education. Written informed consent to participate in this study was provided by the participants and by their legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

NJ planned, collected the data, and analyzed and wrote for the present study. JD and CM advised and provided feedback at all of these research stages. All the authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

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Grammatical Spelling and Written Syntactic Awareness in Children With and Without Dyslexia

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Children with dyslexia face persistent difficulties in acquiring not only reading skills but also spelling skills. Among difficulties in spelling, problems in grammatical spelling have been studied very rarely. The goal of the study is to better understand grammatical spelling difficulties in children with dyslexia by assessing written syntactic awareness skills, a linguistic factor that has not been investigated in the context of spelling until now. It is worth noting that while morphological awareness has been well studied in children with dyslexia, only very few studies have focused on syntactic awareness, which is, however, necessary to produce number or gender agreement. Twenty children with dyslexia were matched to typically developing children on both chronological age and on grammatical spelling level. All the children were asked to perform a subject verb agreement grammatical spelling test and a written syntactic awareness test on the same sentences, as well as control measures. Results demonstrated that the children with dyslexia performed equally compared to grammatical spelling matched children in grammatical spelling, whilst they performed less well compared to children of the same age. For syntactic awareness, they were less accurate at identifying the subject of the complex sentences than spelling age matched children, even though both groups were matched in grammatical spelling. These results demonstrate that children with dyslexia face a specific deficit in written syntactic awareness. It highlights how better understanding of the spelling difficulty will better guide treatment.

Keywords: dyslexia, grammatical spelling, written syntactic awareness, subject verb agreement, spelling acquisition

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INTRODUCTION

Children with dyslexia who represent between 10 and 15% of school age children (Vellutino et al., 2004) are known to have not only reading but also spelling deficits (Maughan et al., 2009). Spelling deficits include phonetic spelling (phoneme to grapheme correspondences, Angelelli et al., 2004) lexical spelling (spelling of the words, with inconsistent mappings in opaque languages such as French; Alegria and Mousty, 1996) and grammatical spelling difficulties (inflexional suffixes on words, verbs, or adjectives, Egan and Pring, 2004). To date, few studies have evaluated the spelling difficulties of children with dyslexia and even fewer have had the objective of specifically evaluating their grammatical spelling difficulty. However, even for students with dyslexia who have access to higher education, inflectional spelling errors are still observed in text productions and in dictation tasks (Tops et al., 2013). For these reasons, it is important to understand more fully the persistent difficulties encountered by children with dyslexia. In the few studies up to now, some authors have investigated the relationship between grammatical spelling and difficulties in morphological awareness. However, to the best of our knowledge, not one has tried to evaluate a closely related but different skill, written syntactic awareness, which is nevertheless involved in the underlying processes of grammatical spelling.

Inflectional Spelling in Typically Developing Children

The production of written language, in particular the spelling of words, is described within the framework of computational models. According to Houghton and Zorzi (2003) there are two routes of word spelling: on the one hand, the lexical route, which consists in retrieving the orthographic representations of words stored in the output orthographic lexicon, and on the other hand, the phonological route, which consists in a sub-lexical process of phoneme-grapheme conversion. Spelling new words requires the use of the phonological route, whereas spelling known words or irregular words (i.e., words that contain an infrequent sound-spelling association) requires the use of the lexical route. These processes concern the mechanisms of isolated word production, without integrating the processes involved in the production of sentences or texts.

At the level of the sentence, children have to deal with grammatical spelling rules that are relatively complex depending on the language. While children write isolated words by transcribing what they hear or by retrieving the spelling of words from memory, the production of grammatical spelling is a complex process. Indeed, in some cases, the agreement marks are inaudible, which creates phonemically inconsistent spellings. It requires therefore children to remember to apply the rules. For example, in the French sentence *Les filles regardent le match des garçons* (the girls are watching the boys' game), the plural agreement on the nouns *filles* (girls) and *garçons* (boys) and the verb *regardent* (are watching) are inaudible. Words in singular (*fille* – girl, *garçon* – boy, regarde – *is watching*) and words in plural (*filles* – girls, *garçons* – boys, *regardent* – are watching) are homophones, which does not allow the plural forms to be written with sound-letter rules. So, children need to know the agreement rules but also they need to know when to apply them. In English, the agreement of regular past verbs presents a similar difficulty for children created by phonemically inconsistent spellings. Indeed, the "ed" endings are pronounced differently depending on the verb, while they are all spelled "ed" (e.g., "kissed" pronounced /kist/ and "killed" as /kild/; Nunes et al., 2006). In order to spell these verbs correctly, children cannot apply the sound-letter rules, they need to learn the grammatical rule of ending for regular past verbs. In Danish, present participle inflection –*ende* is pronounced without *d*, which creates homophones with plural nouns ending with –*ene* (Juul, 2005). For instance, the present participle *legende* (playing) is a homophone of the plural noun *legene* (the games), which requires the mastery of word class differences between verb and noun to choose the correct spelling.

One of the predominant hypotheses concerning the cognitive processes of grammatical spelling acquisition is that of an algorithmic application of the agreement rule, *when I see a subject in plural, I add an –nt mark to the verb* (Fayol et al., 1999; Largy, 2001). This hypothesis of algorithmic application of the rule is interpreted in the theoretical framework *Adaptative Control of Thought* of Anderson (1996) according to which children need to go through three stages in the development and automatization of a cognitive skill: (i) the declarative stage, in which children learn the rules and are able to mention the different steps of their application; (ii) the knowledge compilation stage, in which children start using the different steps (actions); (iii) the procedural stage, in which the rules become progressively automatized thanks to multiple productions requiring the application of the rules. The learning is an attention-demanding process, which will take several months to be mastered and become fast and effortless (Logan, 1988). In French, children usually begin to learn subject verb agreement rules around third grade and are able to manage them around fifth grade (Fayol et al., 1999).

As we have seen, spelling does not only depend on the application of sound-letter conversions, but it requires the ability to apply the grammatical rules. This application of the agreement rules relies in some cases on the mastery of abstract concepts such as the syntactic classes of words. In French, in order to make a verb agreed, children must be able to identify the verb and its subject. In Danish, in order to make a present participle agreed, children must differentiate the present participles from plural nouns. Recognizing the syntactic class to which a word belongs refers to syntactic awareness. Although it is involved in the grammatical agreement process, written syntactic awareness has almost never been studied. Conversely, a related skill, oral morphological awareness has been widely studied in relation to grammatical spelling.

Morphological Awareness in Typically Developing Children

In an attempt to understand developmental progression in grammatical spelling, several authors have focused on the relationship between grammatical spelling and oral morphological awareness (Nunes et al., 1997a). The relation between awareness of oral language and literacy has been already widely studied at the level of phonological awareness (Bus and van Ijzendoorn, 1999). The studies that will follow focus on the relation between grammatical spelling and awareness of the morphological structure of spoken words.

Morphological awareness is the ability to reflect on and to manipulate morphemes, which are the smallest language units that carry meaning (Nagy et al., 2014). Morphemes within the words can be inflectional affixes (e.g., *assess-ed*) or derivational affixes (e.g., *teach-er*). A wide variety of tasks are used to assess morphological knowledge. The word analogy task has been frequently used in the context of grammatical spelling (Nunes et al., 1997b). The task is entirely oral. It consists of asking the child to transform a word which is analogous to a word that had just been transformed by the experimenter (e.g., *teacher-taught*; *writer* say –*wrote*–). In another morphological awareness task, oral production of verbs is induced by sentence analogy (e.g., *The dog is scratching the chair. The dog scratched the chair. The dog is chasing the cat. –The dog chased the cat–,* Nunes et al., 1997b,c, 2006). In other tasks, the instructions are to inflect a pseudoword (e.g., *Say samp. Today the girl samps. What did she do yesterday? Yesterday, she s– samped–*, Walker and Hauerwas, 2006). According to Carlisle (1995) the tasks based on pseudowords are probably more explicit, since children need to manipulate the words and they cannot retrieve the derived word from their lexicon, a process that has been observed in written language (Totereau et al., 1998; Cousin et al., 2002). Through several correlational (Walker and Hauerwas, 2006) and longitudinal studies (Nunes et al., 1997b,c) morphological awareness in spoken language has been shown to be a strong predictor of grammatical spelling performance. Intervention studies have even shown a causal relationship between oral morphological awareness and grammatical spelling (Bryant et al., 1997; Nunes et al., 2003). Morphological awareness interventions were also observed to be particularly beneficial to children with literacy difficulties (Goodwin and Ahn, 2010).

The influence of oral awareness at the morphological level on grammatical spelling skills appears to be demonstrated. However, Egan and Tainturier (2011) showed that orthographic lexical representation was a stronger predictor of past tense spelling than morphological awareness. Therefore, spelling mastery at the lexical level appears to be more related to grammatical spelling than a skill of oral awareness. Egan and Tainturier (2011) understand this less pronounced relationship between spelling and morphological awareness to be because morphological awareness tasks are orally presented and answered by children orally. Morphological awareness tasks also require underlying cognitive processes such as manipulation skills, which are not the same as the processes involved in a written production task.

Consistent with this idea, Juul (2005) suggested assessing the knowledge of grammatical categories through an odd word out written task, in which three of four written words belonged to the same grammatical class (noun, verb or adjective). Danish children had to find the odd one out, for example, find the noun *frakke* (coat) among the three verbs *slippe* (let go), *hente* (fetch), *voelge* (choose). The author found that the knowledge of word classes was correlated to inflectional spelling. This study is interesting because it shows that another kind of knowledge, based on written word class distinctions, appears to be related grammatical spelling.

Syntactic Awareness in Typically Developing Children

Another aspect of language awareness that has been linked until now to reading abilities rather than to spelling abilities, is syntactic awareness. Tasks were administered in either oral or written modality. Syntactic awareness is the ability to reflect on and manipulate the grammatical well-formedness and syntactic structure of sentences (Bowey, 1986; Cain, 2007; Tong et al., 2014). In Bowey's first study, syntactic awareness was assessed by an oral error correction task in which the child was informed that the sentence contained a mistake and was asked to say the sentence the right way. However, the intentional manipulation of the syntax was questionable because, according to Gaux and Gombert (1999) it is likely that the child could perform the task based on the semantic violations and an automatic correction of them. In order to create a task that requires a more deliberate manipulation of syntax, Gaux and Gombert (1999) proposed an oral replication task. The task consisted of asking the child to reproduce, in a correct sentence, an agrammaticality presented in an incorrect model sentence (e.g., reproduce a gender agreement error between the article (and adjective) and the noun: *Le (M) dernier (M) voleuse (F) emporte les bijoux*, The last thief is taking away the jewels, in a correct sentence: *Le (M) nouveau (M) coiffeur (M) coupe les cheveux – Le (M) nouveau (M) coiffeuse (F) coupe les cheveux* –, The new hairdresser is cutting hair). In the same task, the authors tested the replication of an incorrect sentence on the basis of an inversion of the word order, for example the inversion of the name and the article. Finally, which is of great interest to the present experiment, they evaluated the identification of a syntactic class of a word within the sentence in the written modality, for example the identification of the subject, verb or adjective, with the same principle of replication. A subject was identified in a model sentence and the child had to underline the word that had the same syntactic function in another sentence. Gaux and Gombert (1999) observed that poor comprehenders exhibited a deficit in the majority of the syntactic awareness tasks.

In sum, the claims of a link between syntactic awareness and written language have so far focused on reading and particularly on reading comprehension. To the best of our knowledge, only one study has considered the relationship between written syntactic awareness and grammatical spelling, by proposing a task of identifying the subject of the sentence. Identifying the subject and checking if it is singular or plural is, however, the first action to be performed in order to execute the algorithmic application of the verbal agreement, according to Anderson (1996). In this first study (Van Reybroeck, 2012) ninety-seven children from grade 4 to grade 6 completed a syntactic awareness task. The authors showed that the task of identifying the subject predicted grammatical spelling performance, after considering variability due to age and to orthographic lexical representation. No study has so far investigated written syntactic awareness in dyslexic children, which could, however, provide new evidence to better understand their difficulties.

Grammatical Spelling and Morphological Awareness in Children With Dyslexia

Only a few studies have investigated grammatical spelling difficulties amongst children with dyslexia. Their results relate on the one hand to grammatical spelling *per se*, or to the links between this skill and morphological awareness. As far as grammatical spelling is concerned, the authors observed converging results in the direction of a specific difficulty in grammatical spelling. Egan and Pring (2004) demonstrated that children with dyslexia produced more errors on regular past tense verbs in comparison to reading and spelling level matched children. In another study, Hauerwas and Walker (2003) also found with a spelling level matched group of children that difficulties were more pronounced in a sentence context than in a list context, the former being less attention-demanding. In comparing dyslexic children with spelling age matched children, these results support the idea of a specific deficit and a deviant profile rather than a delay in acquisition. Converging evidence comes from the study by Diamanti et al. (2014) conducted in Greek, in which children with dyslexia revealed a delayed more than a deviant performance pattern in spelling derivational and inflectional suffixes, except for verb inflections, where those children performed worse than spelling-level-matched children. For the latter case, they demonstrated a deviant profile. It is important to note that even for students with dyslexia who have access to higher education, grammatical spelling errors are still observed in text production and in dictation tasks (Tops et al., 2013).

In the previous studies (Hauerwas and Walker, 2003; Egan and Pring, 2004; Diamanti et al., 2014) by choosing a spelling level matched group of children as a control group, the authors were able to highlight a deficient pattern in grammatical spelling. They showed that a poorer performance of the dyslexic compared to the matched group was the result of a lower level than expected on the basis of their spelling level. In this way, one should consider that the deficit may not be underpinned by their poorer phonological and orthographic lexical levels. Therefore, why do children with dyslexia have a specific deficit in grammatical spelling? Another explanation can be found by evaluating associated language factors, as studied at the developmental level, which has led some authors to address the question of a possible deficit in oral morphological awareness in children with dyslexia. The evidence for specific difficulties in oral morphological awareness among dyslexic children has been mixed until now. Note that since the aim of the present study was to better understand the development of spelling, the following studies involve children with dyslexia and not children with developmental language disorder, who frequently present syntactic deficits among their deficits in language skills (Bishop and Snowling, 2004).

In one of the first studies, Bryant et al. (1998) found that children who became poor readers initially had a good performance in morphological awareness in word and sentence analogy tasks, but then lost this advantage some time later without being in deficit. Consistent with that view, Egan and Pring (2004) showed that children with dyslexia do not show deficits in morphological awareness in a sentence analogy task, compared with spelling level matched children. Their deficit was limited to reading and spelling. Inconsistent with that view, Hauerwas and Walker (2003) found that children with spelling deficits performed worse than spelling level matched children on an oral morphological awareness task. Thus, these last results suggested a specific deficit in morphological awareness. With regard to the relationship between grammatical spelling and awareness of language, Egan and Tainturier (2011) confirmed that morphological awareness was not a significant predictor of grammatical spelling in children with dyslexia, whereas it was a determinant for typically developing children. Hauerwas and Walker (2003) showed the opposite results since they observed significant relation between grammatical spelling and oral morphological awareness in children with spelling deficits and not in spelling-level matched children.

In sum, it is not clear at present whether children with dyslexia show a specific deficit in oral morphological awareness that could be related to their difficulty in grammatical spelling. It is therefore important to further explore this issue by assessing other factors of language awareness that have not yet been investigated regarding grammatical spelling, such as written syntactic awareness.

The Present Study

The aim of the study was to better understand the specific difficulties in grammatical spelling encountered by children with dyslexia in evaluating their awareness of language. While several studies have focused on oral morphological awareness, in this study, written syntactic awareness has been evaluated, a linguistic factor that had not been investigated until now with regard to grammatical spelling difficulties. The questions addressed were, first, to know whether children with dyslexia (DYS children) show a deficit pattern in written syntactic awareness using both grammatical spelling level matched children (SL children) and chronological age matched children groups (CA children). The novel aspects of the study were the evaluation of a new linguistic factor, written syntactic awareness, and the use of a specific matching group on grammatical spelling instead of spelling level. Indeed, since lexical spelling and grammatical spelling are based on different underlying cognitive processes, a grammatical spelling match should allow a better understanding of the differences in profiles between children. The second research question was to evaluate the contribution of written syntactic awareness to the variance in grammatical spelling and to look at whether the contribution of syntactic awareness is more or less marked in DYS children than in control children. We made the following predictions: (a) if difficulties in awareness of language may be the consequence of spelling difficulties as argued by Bryant et al. (1998), DYS children should have an equivalent performance in syntactic awareness to SL children; (b) if the difficulties in syntactic awareness are specific and not the consequence of difficulties in spelling, DYS children should perform less well than matched children in grammatical spelling; (c) in the case of a specific deficit in syntactic awareness in DYS children, this skill should contribute to a greater extent to the variance in grammatical spelling in this specific group of children.

MATERIALS AND METHODS

Participants

Sixty-nine French-speaking children from several primary schools took part in the experiment. They were from rural schools in Belgium and were of average socio-economic status. Out of those children, twenty constituted the DYS group (seven girls, 13 boys, M_{age} = 131.35 months, age range: 113–152 months) and came either from a type eight class of a specialized school in Belgium (specific school and class for students with specific learning disabilities) or from a mainstream school. They had been previously diagnosed with dyslexia by a multidisciplinary team of professionals or by a speech therapist, without having a developmental language disorder. At the time of the study, nineteen of them obtained deficit scores (scores below the 3rd percentile) in the standardized spelling test Corbeau (L2MA, Chevrie-Muller et al., 1997) which is a dictation task in which children's performance is marked in three areas: phonetic (phoneme to grapheme correspondences), lexical (spelling of the words) and grammatical spelling (agreement rules). One of the twenty children obtained a score close to the deficit threshold: below 4th percentile for a 10-year norm (the oldest norm available), while the child was 12 years old. In reading, children from the DYS group obtained a score below the 4th percentile on the word reading test Lecture en Une Minute (Khomsi, 1998). They also obtained scores below the 16th percentile on the reading comprehension subtest L3 from the Orlec battery (Lobrot, 1967). None of the children were bilingual, according to the criterion of speaking another language for more than 7 h a week (criterion adopted by Marchman et al., 1999).

The DYS children were matched to typically developing children, CA children from Grade 6 (N = 24), on the one hand, and on the other hand, to SL children from Grade 4 (N = 21). The DYS children were first matched with SL children, typically developing children matched on grammatical spelling level and gender when it was possible (SL children, N = 16, nine girls, seven boys, M_{age} = 119.82 months, age range: 101–130 months). The same dyslexic children were also matched to CA children, typically developing children matched on chronological age, and gender when it was possible (CA children, N = 16, eight girls, eight boys, M_{age} = 136.37 months, age range: 115–148 months). Initially a group of 69 children took part in the experiment but only 52 children were included in the analysis either to allow for a correct match between the groups or because children scored below two standard deviations in the spelling test despite being in the control group. The final groups of typically developing children were composed of 16 children each.

Therefore, the present sample was composed of 52 children. **Table 1** provides the characteristics of the participants by group. One-way analyses of variances (ANOVAs) demonstrated an effect of age (p < 0.001) and confirmed that the DYS children were correctly matched on chronological age with the CA children. The DYS children were also correctly matched on grammatical spelling with the SL children. All the children's parents gave their active consent for participation in the experiment and the children gave their verbal consent. The study was approved by the Ethics Committee of the Psychological Sciences Research Institute.

Measures

In the experiment, children were administered control measures, used to match DYS children to CA and SL children and to evaluate their written language level, as well as experimental measures, used to answer our research questions.

Control Measures

Spelling

The standardized spelling test entitled *Le Corbeau* (Chevrie-Muller et al., 1997) consisted of a short text to be written under dictation. The children's performance was marked on three scores: phonetic (phoneme to grapheme correspondences; maximum score 15), lexical (spelling of the words; max. score 22) and grammatical spelling (agreement rules; max. score 13). The assessment of grammatical spelling was composed of different rules including only two items out of 13 that were verb agreements, the focus of this study. The other items were five past participle agreements, two homophones, one adjective agreement, two noun agreements and one determiner. The maximum accuracy score was 50.

TABLE 1 | Characteristic of the participants by group: means and standard deviations by group and one-way ANOVA.

		DYS		CA		SL		Group effects		*Post hoc* comparisons[a]
Measures		***M***	***SD***	***M***	***SD***	***M***	***SD***	***F***	***p***	
Gender	Girls	15		8		9				
	Boys	5		8		7				
Age in months		131.35	11.27	136.37	12.33	119.82	7.88	10.11	<0.001	SL < CA = DYS
Nonverbal IQ[b]		83.06	2.30							
Phonetic spelling	Raw score	8.40	3.50	14.87	0.50	13.19	1.68	36.27	<0.001	DYS < SL = CA
	Standardized score	−5.27	4.63	0.28	0.42	−0.97	1.43	17.29	<0.001	DYS < SL = CA
Lexical spelling	Raw score	7.15	4.49	17.62	3.05	13.31	3.07	36.93	<0.001	DYS < SL < CA
	Standardized score	−3.53	1.34	−0.16	1.15	−1.02	0.91	41.67	<0.001	DYS < SL = CA
Grammatical spelling	Raw score	3.30	1.66	9.50	1.67	4.25	1.61	69.49	<0.001	DYS = SL < CA
	Standardized score	−2.24	1.36	0.15	0.55	−1.64	0.66	27.96	<0.001	DYS = SL < CA
Spelling total	Raw score	18.85	8.63	42.00	4.60	30.75	5.12	55.19	<0.001	DYS < SL < CA
	Standardized score	−3.72	1.92	0.00	0.89	−1.40	0.84	33.98	<0.001	DYS < SL = CA
Reading comprehension	Raw score	14.20	7.32	29.75	4.55	23.31	4.57	32.88	<0.001	DYS < SL < CA
	Standardized score	−1.65	1.16	0.63	0.90	0.66	0.67	35.39	<0.001	DYS < SL = CA

DYS, Dyslexic children; CA, Chronological age matched children; SL, Grammatical spelling level matched children. [a]*Post hoc comparisons are Bonferroni, all p* < *0.05.* [b]*WISC-IV scaled score (Wechsler, 2005; M = 100, SD = 15).*

Reading comprehension

Reading comprehension skill was evaluated by the standardized subtest L3 from the Orlec battery (Lobrot, 1967). It consisted of a multiple-choice test involving the completion of 36 sentences by selecting the missing word out of five possible options, in a time limit of 5 min. The options included distractors such as homophones (e.g., *mère* [mother] instead of *mer* [sea]), phonological distractors (e.g., *palais* [palace] instead of *balai* [broom]), or semantic distractors (e.g., *pattes* [paws] instead of *oreilles* [ears]). The scores used consisted of the number of words correctly chosen to complete the sentences (max. score 36).

Experimental Measures

Syntactic awareness

In order to evaluate syntactic awareness, 24 sentences were created. Four types of sentences were created to manipulate the level of syntactic complexity: (a) simple syntactic structure, in which the subject of the sentence directly precedes the verb, e.g., *Les sportifs passent beaucoup de temps dans la salle de musculation* (Athletes spend a lot of time in the weights room); (b) complex noun 1 of noun 2 structure, in which the subject precedes the verb but is distanced by a complex noun phrase, e.g., *Les feuilles de l'arbre tombent dès le mois de septembre* (The leaves of the tree fall from September); (c) complex complement structure, in which the subject precedes the verb but is distanced by a complement of the subject, e.g., *Les débats à propos de la pollution attirent l'attention de tout le monde* (Debates about pollution attract everyone's attention); (d) interrogative structure, in which the sentence structure is reversed since the subject follows the verb, e.g., *Dans quelle église chantent les choristes pour le concert de Noël?* (In which church do the choir sing for the Christmas concert?). To ensure that the conditions were as similar as possible apart from syntactic complexity, two variables were controlled for verbs: the level of acquisition of lexical spelling from *Echelle d'acquisition en Orthographe Lexicale* (Acquisition scale in lexical spelling, Pothier and Pothier, 2003); and the frequency of the words *Manulex* (Lété et al., 2004). Two Kruskal-Wallis tests revealed no difference between the four types of sentences for the level of acquisition of lexical spelling of the verbs, $\chi^2(3, N = 24) = 0.08$, $p = 0.99$) and for the frequency of the verbs, $\chi^2(3, N = 24) = 1.31$, $p = 0.73$. The sentences and their characteristics are presented in **Appendix 1**. The children were asked to take their sheet from the grammatical spelling task, and with a green pen circle the word or words that were the subject of the sentence, underline the verb and draw an arrow from the subject to the verb (method inspired by the test used by Aubret and Blanchard, 1991). The children had to perform this task for the sentences they had previously completed for the grammatical spelling task. The internal reliability (Cronbach's α) in the current sample is 0.95. It is interesting to note that a written, rather than an oral, subject identification task was chosen because when sentences were long, the sentences remained visible, allowing the child to reread them, whereas the same sentences in oral language could be difficult to memorize while performing the subject identification task. The written modality also seemed to be closer to the task that the child is led to do in writing, the purpose of the study being to better understand potential difficulties in grammatical spelling.

Grammatical spelling

In order to assess grammatical spelling, the same 24 sentences were presented in a dictation task before the syntactic awareness task. The children had to first listen to the sentences orally, then to write down the two missing words in the blank spaces in the sentences while the sentences were repeated. In order to avoid the children automatically putting plural agreement marks on every verb, verbs with singular agreement were introduced, as well as distractors. So, the task included for example for the simple structure condition, 6 verbs, of which 4 were expected to show plural agreement and 2 singular. Distractors were determinant, preposition or adverb (distractors and verbs in italics in **Appendix 1**). The internal reliability (Cronbach's α) in the current sample is 0.94.

Procedure

All testing took place either at the specialized school or at the mainstream school. For children in the mainstream school, the tasks were conducted collectively in their classrooms in one 40 min session. Some children with dyslexia were assessed in small groups, others were assessed individually, depending on the organization of the class. Children were not informed about the focus on grammatical spelling. To avoid a potential learning effect between the syntactic awareness task and the grammatical spelling task, the children first performed the grammatical spelling task, then the control tasks and finally the syntactic awareness task. Indeed, the identification of the subject within the sentence requested by the syntactic awareness task was likely to help children to better perform the production of the verb agreement in the grammatical spelling task. This is the reason why this test of syntactic awareness was administered in second place. In both parts, grammatical spelling and syntactic awareness, to ensure that the children understood the instructions, an example was given, followed by a training item with individual corrective feedback. To ensure a blind process, the score sheets were anonymized prior to scoring.

Statistical Analysis

Descriptive statistics for the different variables are displayed in **Table 2** and a scatter plot shows in **Figure 1** the dispersion of scores for the three groups. The graph shows that the dispersion of scores is particularly important in children with dyslexia for the syntactic awareness task. Statistical analyses were run using SPSS 25. Preliminary analyses were conducted to examine whether the data met the normality assumption of parametric procedures. The analyses revealed no distributional problems (all measures $Sk < |2|$ and $Ku < |7|$). A Generalized Linear Mixed Model (GLMM) was run instead of a classical analysis of variance in order to include information by item. GLMM was chosen because it allows us to consider the variability of the items and the variability of the participants. Indeed, an analysis of variance does not take into account both the variability introduced by participants and the variability introduced by items in the same analysis, which could possibly lead to high Type 1

TABLE 2 | Means and standard deviations for dependent variables by group.

	DYS		CA		SL		Group effect		*Post hoc* comparisons[a]
Measures	***M***	***SE***	***M***	***SE***	***M***	***SE***	***F***	***p***	
Grammatical spelling									
Simple structure	0.36	0.05	0.78	0.04	0.39	0.06	23.93	<0.001	DYS = SL < CA
Complex noun 1 of noun 2 structure	0.36	0.05	0.62	0.06	0.39	0.06	6.98	<0.01	DYS = SL < CA
Complex complement structure	0.35	0.05	0.65	0.06	0.33	0.06	11.40	<0.001	DYS = SL < CA
Interrogative structure	0.35	0.05	0.61	0.06	0.37	0.05	5.79	<0.01	DYS = SL < CA
Syntactic awareness									
Simple structure	0.83	0.05	1.00	0.00	0.83	0.05	10.81	<0.001	DYS = SL < CA
Complex noun 1 of noun 2 structure	0.62	0.08	0.99	0.01	0.80	0.06	17.01	<0.001	DYS < SL < CA
Complex complement structure	0.22	0.06	0.77	0.07	0.49	0.09	18.41	<0.001	DYS < SL < CA
Interrogative structure	0.12	0.04	0.81	0.06	0.35	0.08	48.14	<0.001	DYS < SL < CA

DYS, Dyslexic children; CA, chronological age matched children; SL, grammatical spelling level matched children. [a]Post hoc comparisons are sequential Bonferroni, all p < 0.05.

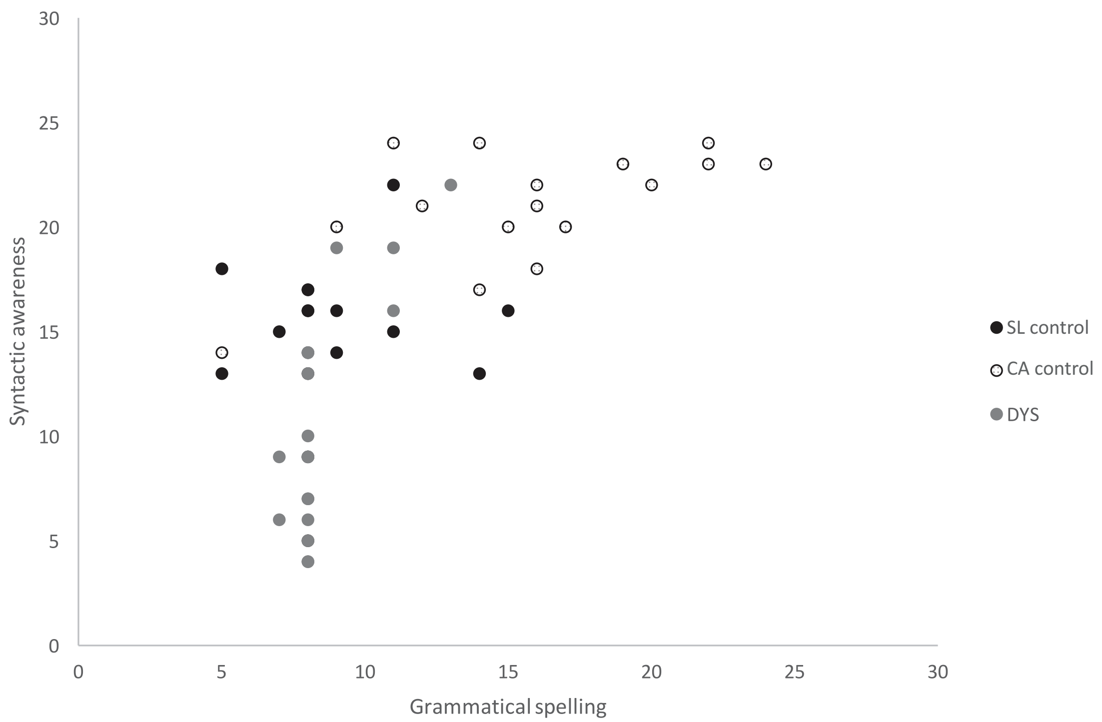

FIGURE 1 | Grammatical spelling and syntactic awareness outcomes by group.

error rates (Baayen et al., 2008). GLMM analyses were run on the grammatical spelling and on the syntactic awareness accuracy with Group (three levels: DYS, CA and SL children) and Sentence structure (four levels: simple, complex noun 1 of noun 2, complex complement, interrogative) entered as fixed factors. Furthermore, one random factor was included in the model for participants, allowing us to consider the interdependence between our observations due to repeated measures. The model also included the interaction between Group × Sentence structure. When a main effect was significant, the *post hoc* sequential Bonferroni given by the GLMM is reported. When the interaction was significant, simple effects were analyzed with repeated measures ANOVAs, for which the assumption of sphericity was checked with Mauchly's test. We applied Greenhouse-Geisser corrections for data violating the sphericity assumption. The alpha level was set at 0.05 for all the analyses.

RESULTS

Grammatical Spelling

Grammatical spelling accuracy was submitted to a 3 × 4 GLMM with Group [DYS, CA, SL] × Sentence structure [simple, complex noun 1 of noun 2, complex complement, interrogative] entered as fixed effects. The effect of group was significant, $F(2, 1227) = 21.94$; $p < 0.001$. Sequential Bonferroni *post hoc* showed that the DYS children ($M = 0.36$, $SE = 0.03$) and the SL children ($M = 0.37$, $SE = 0.04$) conjugated fewer verbs correctly than CA children ($M = 0.67$, $SE = 0.03$, each comparison was significant at $p < 0.01$). The effect of sentence structure ($p = 0.27$) and the interaction Group × Sentence structure ($p = 0.41$) were not significant.

Syntactic Awareness

Syntactic awareness accuracy was submitted to a 3 × 4 GLMM with Group [DYS, CA, SL] × Sentence structure [simple, complex noun 1 of noun 2, complex complement, interrogative] entered as fixed effects. The effect of group was not significant ($p = 0.09$) while the effect of sentence structure was significant, $F(3, 1235) = 15.77$; $p < 0.001$, as well as the interaction between group and sentence structure, $F(6, 1235) = 2.57$; $p = 0.018$. Simple effect analyses showed that the effect of group was significant for the four sentence structures separately: simple, $F(2, 1235) = 10.81$; $p < 0.001$; complex noun 1 of noun 2, $F(2, 1235) = 17.01$; $p < 0.001$; complex complement, $F(2, 1235) = 18.41$; $p < 0.001$; interrogative, $F(2, 1235) = 48.14$; $p < 0.001$. Sequential Bonferroni *post hoc* showed that, for simple structure, DYS children ($M = 0.83$, $SE = 0.05$) identified fewer subjects than CA children ($M = 1.00$, $SE = 0.00$), but the same number as SL children ($M = 0.83$, $SE = 0.05$). For the other three complex structures, DYS children identified fewer subjects than CA but also fewer than SL children. DYS children ($M = 0.12$, $SE = 0.04$) identified the subject of the sentence much less well in interrogative sentences compared to CA children ($M = 0.81$, $SE = 0.06$, $p < 0.001$, $d = 13.88$) and to SL children ($M = 0.35$, $SE = 0.08$, $p = 0.01$, $d = 3.67$; each comparison was significant at $p < 0.01$). For complex noun 1 of noun 2 structure, DYS children ($M = 0.62$, $SE = 0.08$) identified the subject of the sentence less well compared to CA children ($M = 0.99$, $SE = 0.00$) and SL children ($M = 0.80$, $SE = 0.06$). For complex complement structure, DYS children ($M = 0.22$, $SE = 0.06$) also identified fewer subjects than CA children ($M = 0.77$, $SE = 0.07$) and SL children ($M = 0.49$, $SE = 0.09$).

Factors Associated With Grammatical Spelling

In order to better understand the grammatical spelling profiles of the children, correlations between grammatical spelling, syntactic awareness and the control measures were analyzed. As can been seen in **Table 3**, the measures were not correlated in the same way in the three groups. In the DYS group, experimental grammatical spelling is most highly correlated with syntactic awareness, $r = 0.75$, $p < 0.001$, while in the CA group, the same correlation is moderate, $r = 0.60$, $p = 0.01$, and in the SL group, it is not significant, $p = 0.68$.

To evaluate the contribution to the variance in grammatical spelling, hierarchical multiple regression analyses were

TABLE 3 | Correlations coefficients between measures by group.

Measures		1	2	3	4	5	6
SL children							
1	Phonetic spelling	_					
2	Lexical spelling	0.40	_				
3	Grammatical spelling	0.47	0.47	_			
4	Spelling total	0.72**	0.88**	0.75**	_		
5	Reading comprehension	0.55*	0.64**	0.79**	0.82**	_	
6	Experimental grammatical spelling	0.25	0.47	0.48	0.52*	0.57*	_
7	Experimental syntactic awareness	0.05	−0.37	−0.13	−0.24	0.07	0.11
CA children							
1	Phonetic spelling	_					
2	Lexical spelling	0.32	_				
3	Grammatical spelling	0.08	0.76**	_			
4	Spelling total	0.35	0.97**	0.87**	_		
5	Reading comprehension	−0.19	0.50*	0.69**	0.56*	_	
6	Experimental grammatical spelling	0.20	0.83**	0.77**	0.85**	0.37	_
7	Experimental syntactic awareness	−0.05	0.51*	0.57*	0.54*	0.31	0.60*
DYS children							
1	Phonetic spelling	_					
2	Lexical spelling	0.68**	_				
3	Grammatical spelling	0.59**	0.76**	_			
4	Spelling total	0.87**	0.94**	0.83**	_		
5	Reading comprehension	0.62**	0.81**	0.65**	0.80**	_	
6	Experimental grammatical spelling	0.35	0.71**	0.65**	0.64**	0.67**	_
7	Experimental syntactic awareness	0.38	0.65**	0.71**	0.63**	0.65**	0.75**

*$p < 0.05$; **$p < 0.01$.

conducted for each group separately. Phonetic spelling, lexical spelling and syntactic awareness were entered to evaluate their relative importance in predicting grammatical spelling. For all regression models, the collinearity diagnostics showed that all the variance inflation indices (VIF) were below 1.44, indicating that multicollinearity was weak and not a barrier to performing the regression analyses.

As can been seen in **Table 4**, the regression model accounted for a significant proportion of variance in grammatical spelling in the DYS group, $R^2 = 0.67$, $p < 0.001$, and in the CA group, $R^2 = 0.73$, $p < 0.001$, while the model was not significant in the SL group, $p = 0.19$. For DYS children, lexical spelling and syntactic awareness both explained a significant and unique amount of variance in grammatical spelling (lexical spelling: $\beta = 0.54$, $p = 0.03$, syntactic awareness: $\beta = 0.47$, $p = 0.02$). Conversely, only lexical spelling explained a significant amount of variance in grammatical spelling for CA children (lexical spelling: $\beta = 0.71$, $p < 0.01$, syntactic awareness: $\beta = 0.24$, $p = 0.21$).

DISCUSSION

The aim of the study was to shed light on a factor of language awareness which differs from phonological or morphological awareness, and which has never yet been investigated in relation to grammatical spelling in children with dyslexia. However, syntactic awareness does seem to be one of the underlying cognitive processes related to the application of a grammatical rule. The question was to know: (1) whether children with dyslexia had a specific difficulty in syntactic awareness or not and if so, (2) to what extent that syntactic awareness contributed to variance in grammatical spelling in DYS children compared to in control children. We anticipated that, if DYS children had a specific difficulty in syntactic awareness, they would perform less well than SL children in syntactic awareness. In this case, the contribution of syntactic awareness to grammatical spelling variance should also be greater in this group.

Children with dyslexia and control children were asked to perform a grammatical spelling task and a syntactic awareness task that involved identifying the subject of the sentence and relating it to the verb of the sentence.

Grammatical Spelling

First of all, the results showed that children with dyslexia have a poorer level of grammatical spelling compared to CA children, which is in accordance with previous studies that present converging results in this direction (Hauerwas and Walker, 2003; Egan and Pring, 2004; Diamanti et al., 2014). This study adds experimental evidence in favor of a grammatical spelling deficit in children learning French, an opaque writing system. Previous studies have been conducted with English-speaking dyslexic children, who also have to learn an opaque writing system (Hauerwas and Walker, 2003; Egan and Pring, 2004) and in Greek, which is a transparent writing system, in Diamanti et al. (2014). In our study, children had difficulty agreeing verbs that contain inaudible agreement marks such as *nt* that constituted phonemically inconsistent spellings. In English, children also had difficulty spelling past tense verbs that contain endings that cannot be written phonetically. In Greek, Diamanti et al. (2014) study showed that, among the difficulties in grammatical spelling, children had more difficulty with verb inflection, also characterized by inconsistencies. Therefore, our study provides an additional argument for a specific difficulty related to verb inflections in children with dyslexia.

The only difference between these studies and ours, apart from the language of the participants, is that we matched dyslexic children with control children on grammatical spelling, while the other authors matched children on reading or spelling levels. By matching children in spelling and demonstrating that dyslexic children are worse, it is possible to argue in favor of a specific grammatical spelling problem (Egan and Tainturier, 2011; Law et al., 2015). In our case, we wanted to match children on grammatical spelling to observe the specificity of their profile in syntactic awareness.

Syntactic Awareness

Our results provided a first experimental evidence in favor of a specific syntactic awareness difficulty in children with dyslexia. Children with dyslexia showed heterogeneity in their scores on

TABLE 4 | Hierarchical multiple regression analyses of grammatical spelling in each group.

		DYS				CA				SL			
	Predictors	**Δ R^2**	***B***	***SE***	**β**	**Δ R^2**	***B***	***SE***	**β**	**Δ R^2**	***B***	***SE***	**β**
Step 1	Constant	0.12	7.27	0.84		0.04	−14.00	39.29		0.06	3.47	5.58	
	1. Phonetic spelling		0.15	0.09	0.35		2.00	2.64	0.19		0.41	0.42	0.25
Step 2	Constant	0.42**	7.31	0.62		0.65**	1.58	23.51		0.17	2.03	5.32	
	1. Phonetic spelling		−0.10	0.09	−0.25		−0.71	1.65	−0.07		0.12	0.43	0.07
	2. Lexical spelling		0.29	0.07	0.88**		1.40	0.27	0.85***		0.39	0.24	0.44
Step 3	Constant	0.13***	6.52	0.63		0.04**	−11.70	24.98		0.09	−1.59	5.95	
	1. Phonetic spelling		−0.08	0.08	−0.19		−0.15	1.66	−0.01		−0.01	0.43	−0.00
	2. Lexical spelling		0.18	0.08	0.54*		1.17	0.31	0.71**		0.53	0.25	0.59
	3. Syntactic awareness		0.13	0.05	0.47*		0.43	0.33	0.24		0.24	0.19	0.33

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

the syntactic awareness task. However, results indicated that they identified fewer subjects of the sentences than both CA and SL children for the three types of complex structure sentences: interrogative, noun 1 of noun 2 and complement. They identified fewer subjects than CA children only for the simple structure sentences. Since the SL children were matched on grammatical spelling level and the dyslexic children faced greater difficulties in finding the subjects of the sentences than them, it is hard to explain how the deficit in syntactic awareness could be caused by a poor level in grammatical spelling. These results lead us to believe that children with dyslexia have a specific difficulty in syntactic awareness and a deviant profile for this language awareness factor.

In order to link these findings to the literature, a broader investigation of studies of morphological awareness is needed, since no studies have examined syntactic awareness in dyslexic children in relation to spelling. This, and the difference in modality between morphological awareness, administered orally, and syntactic awareness, administered in writing, must be taken into account. In this context, our results are in line with those of Hauerwas and Walker (2003) study which showed that children with dyslexia had specific difficulties in morphological awareness in a sentence context, but not in isolated words. In the present study, sentences were also used, which makes it understandable that the results go in the same direction.

On the other hand, the results of our study contradict those of Egan's study, which showed that dyslexic children do not have a difficulty in the task of oral morphological awareness, whereas difficulties were observed in reading and writing tasks. However, the difference in modality could explain this observation. Indeed, the cognitive processes in an oral task of manipulation of morphemes (Nagy et al., 2014) compared to those of a written identification task are quite different, not only in modality, but also the tasks as such. This could explain why the written syntactic awareness could be altered and not the oral morphological awareness.

Factors Associated With Grammatical Spelling

Our second research question was to examine to what extent syntactic awareness contributes more to grammatical spelling in children with dyslexia than in control children. The results are also consistent with a specific difficulty of syntactic awareness in children with dyslexia. Indeed, multiples regressions showed that syntactic awareness contributes to variance in grammatical spelling beyond the contribution of lexical spelling, and only in children with dyslexia. In chronological age matched children, lexical spelling is the only factor contributing to grammatical spelling and neither phonetic spelling nor syntactic awareness contribute to it.

Regarding the contribution of syntactic awareness to grammatical spelling, these results are not at first glance in accordance to those of Egan and Tainturier (2011) who found that it is more orthographic lexical memory that makes a contribution to grammatical spelling than morphological awareness. However, the results are not so contradictory because we also observed, like Egan and Tainturier (2011) an impact of the orthographic lexical spelling. In addition, our task of grammatical awareness was in the written and not oral modality, which could cause differences. The proximity between the syntactic awareness task and the grammatical spelling task may allow us to understand this observed link for this specific task and not for the morphological awareness task.

The syntactic awareness task included four types of sentences: a simple type and three complex types in which the subject does not directly follow the verb. Children with dyslexia were less able to identify subjects, even in simple structure sentences. Given that syntactic awareness is a necessary step in achieving grammatical agreement according to Anderson's model, it can be understood why these children have difficulty with grammatical spelling. While they have to identify nouns that are subjects, or verbs in sentences, they are not clear about these abstracts notions and are not able to implement the different actions required by the rule. It has been shown that cognitive overload related to the management of graphic gesture or lexical spelling can prevent the achievement of grammatical spelling (Van Reybroeck and Hupet, 2009). In the case of children with dyslexia, we know that both graphic gesture (Gosse and Van Reybroeck, 2020) and lexical spelling (Alegria and Mousty, 1996) can be problematic. However, our results lead us to think this: it may not only be cognitive overload that prevents them from producing agreement; it may also be related to their basic mastery of the application of the agreement rules. Moreover, in French, the rule examined in this study is a simple one that requires a basic level of syntactic awareness. After that, the children learn, for example, the rules of agreement of past participles which are more complex (Negro et al., 2014). We can assume that the difficulties of children with dyslexia will be exacerbated for the more complicated rules. One can therefore understand why the difficulties remain persistent even in dyslexic children who are at university (Tops et al., 2013). In this sense, the early identification and assessment of children with difficulties in syntactic awareness is an interesting avenue to investigate.

Regarding the contribution of lexical spelling on grammatical spelling, our results showed that the spelling skills in lexical orthographic representations contribute to the spelling of verb inflections more than syntactic awareness and more than phonetic spelling in both children with dyslexia and chronological age matched children. The contribution of lexical spelling to verb inflections is in line with Egan and Tainturier (2011) study in which the authors showed that the children who have difficulty with grammatical spelling also have a low level of lexical spelling. The influence of lexical spelling level on grammatical spelling was also observed in an experimental study among typically developing children in French. Indeed, Van Reybroeck and Hupet (2009) showed that when words are complex to write at the lexical level, because they are long words or words with inconsistencies, children more often omit the agreement marks in nouns or verbs. The interpretation is that the production of the agreement depends on the cognitive cost of simultaneous processing demands such as the lexical spelling complexity of the words.

Multiple regressions also showed the lack of contribution of phonetic spelling to grammatical spelling. The phonetic spelling represents the assessment of the phonological route according to Houghton and Zorzi (2003) and the sub-lexical process of phoneme-grapheme conversions. The children with dyslexia in our study had a deficient score in phonetic spelling, which means that they made mistakes in basic phoneme-grapheme conversions. Despite this, their level in phonetic spelling did not seem to be related to their level in grammatical spelling. This difference can be understood by the fact that the grammatical spelling does not correspond to the same cognitive processes. Grammatical spelling is a spelling of inconsistencies related to grammatical rules and not to the use of the phonological route. Concerning the mastery of the phonological route, it should also be noted that there is great inter-individual variability in scores in children with dyslexia. It is therefore possible that the level of phonetic spelling influences grammatical spelling for some children and not for others.

Limitations

This study has several limitations that should guide future research. First, our groups of dyslexic children and control groups were small, which could limit the extent to which the results can be generalized. In particular, the heterogeneity of the profiles of children with dyslexia should lead us to be cautious in generalizing the results to the whole population. It would therefore be interesting to be able to replicate this study with a larger sample. Second, our design study does not allow us to understand the nature of the interactions between syntactic awareness and grammatical spelling. However, it would be interesting to better understand the interactions such as the influence of a low subject identification ability on the learning of verbal agreement or the influence of a limited ability in grammatical spelling on the development of morphosyntactic awareness, given the supposed bidirectional causal relationship between the two skills (Nunes et al., 2006). Third, with regard to the procedure, we have to recognize a limitation because the two tests of grammatical spelling and syntactic awareness, involving the same sentences, were administered on the same day. It is possible that the children read the sentences for the syntactic awareness task more easily, for example, and did not reread them completely. At the same time, their performance on this second task was good for some of the sentences, suggesting that they read the sentences correctly.

Educational Implications

This study opens up new perspectives on the understanding of grammatical spelling difficulties in children with dyslexia. It highlights the need to evaluate this skill, and work, if required, not only on spelling production but also, prior to that, on understanding and managing the abstract concepts of the nature and function of words that are the basis of the algorithmic application of grammatical rules. In order to be able to apply the algorithm rules, children must be able to actually identify the subject of the sentence before carrying out rule application exercises or activities to automate the processes of written production. A sequence of progressive exercises in which children have to first manage syntactic awareness alone, without adding the cognitive cost of production, is an interesting approach that has been proven to be effective in primary and secondary control children (see intervention studies, Van Reybroeck et al., 2014, 2017). It would be interesting to examine whether children with dyslexia could benefit from this type of treatment based on syntactic awareness.

CONCLUSION

The present study has provided, for the first time, experimental evidence in favor of a specific deficit in syntactic awareness in children with dyslexia. Indeed, these dyslexic children were less able to identify the subjects of the sentences, which is required in order to produce verbal agreement. The findings also emphasized the contribution of syntactic awareness to variance in grammatical spelling in children with dyslexia only. These results have important practical implications for teachers and speech therapists in focusing on a new factor of language awareness, syntactic awareness, that may be impaired in children with dyslexia and should be evaluated and trained.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of the Psychological Sciences Research Institute. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

MV contributed to the conception and design of the study, organized the database, performed the statistical analysis, wrote the first draft of the manuscript, and approved the submitted version.

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APPENDIX

TABLE A1 | List of sentences used in the syntactic awareness task.

Sentences	Verb success rate of spelling in 4th Grade[a]	Verb frequency[b]
Simple structure		
Les canards *nagent* tranquillement dans la mare du *parc*	89	60.25
The ducks swim quietly in the pond of the park		
Les sportifs *passent beaucoup* de temps dans la salle de musculation	71	70.37
Athletes spend a lot of time in the weights room		
Les motards *escortent* le cortège présidentiel *depuis* deux heures	75	45.86
Motorcyclists have been escorting the presidential motorcade for 2 h		
Les explorateurs *annoncent* leur *dernière* découverte au journal télévisé	78	61.46
The explorers announce their latest discovery on the news		
Alexandre *cache* ses secrets dans le tiroir de sa *table* de nuit	84	64.15
Alexandre hides his secrets in the drawer of his bedside table		
Le magicien *imagine* un nouveau spectacle *pour* l'année prochaine	91	64.23
The magician imagines a new show for next year		
Complex noun 1 of noun 2 structure		
Les perles du collier *brillent* sous *les* projecteurs de la scène	91	60.04
The pearls of the necklace shine under the spotlights of the stage		
Les feuilles de l'arbre *tombent* dès le mois de *septembre*	100	67.57
The leaves of the tree fall from September		
Les aiguilles de l'horloge *tournent* à *nouveau* depuis leur réparation	100	65.26
The clock hands rotate again since their repair		
Les costumes du chanteur *étonnent* un *grand* nombre de spectateurs	58	59.46
The singer's costumes surprise a large number of spectators		
Le camion des pompiers *retourne* à la caserne *après* l'incendie	75	63.71
The fire truck returns to the fire station after the fire		
L'air *des* montagnes *apporte* beaucoup d'oxygène au corps humain	65	63.05
Mountain air brings a lot of oxygen to the human body		
Complex complement structure		
Les débats à propos de la pollution *attirent* l'attention de tout le *monde*	71	59.35
Debates about pollution attract everyone's attention		
Les inscriptions faites *sur* la porte *dégradent* le bois	79	36.77
The inscriptions on the door degrade the wood		
Ces fleurs rares découvertes il y a un an *poussent* au sommet d'*une* montagne	95	65.27
These rare flowers discovered a year ago grow on the top of a mountain		
Les infirmières dévouées à leur patrie *soignent* ce soldat rapidement et *avec* soin	78	59.01
The nurses dedicated to their country care for this soldier quickly and carefully		
La vie *dans* cette région dévastée par les combats *semble* difficile	71	64.72
Life in this region devastated by the fighting seems difficult		
Le marin affaibli *par* les nombreuses tempêtes *regarde* au loin	90	69.76
The sailor weakened by the many storms looks far away		
Interrogative structure		
Dans quelle ville *habitent* tes nouveaux amis rencontrés *en* vacances?	76	63.27
In which city do your new friends you met on holiday live?		
Dans quelle église *chantent* les choristes pour le concert de Noël?	88	63.73
In which church do the choir sing for the Christmas concert?		

(Continued)

TABLE A1 | Continued

Sentences	Verb success rate of spelling in 4th Grade[a]	Verb frequency[b]
Combien *coûtent* ces deux pantalons achetés *au* center commercial? How much do these two pairs of pants bought at the mall cost?	52	56.48
Dans quelle direction *bougent* les drapeaux décorant la *statue* de la liberté? In which direction do the flags decorating the Statue of Liberty move?	96	61.26
Dans quel carton *pleure* mon petit chat *chaque* nuit? In which box does my little cat cry every night?	95	62.78
A quelle heure *débute ton* championnat de tennis de table? What time does your table tennis championship start?	67	53.08

[a] The success rate of spelling in 4th Grade comes from Echelle d'acquisition en Orthographe Lexicale (Acquisition scale in lexical spelling, Pothier and Pothier, 2003). [b] The verb frequency comes from MANULEX (Lété et al., 2004).

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Distinguishing Syntactic Markers From Morphological Markers. A Cross-Linguistic Comparison

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This brief review summarizes findings about syntactic markers, i.e., graphemic elements that indicate syntactic relations, such as inflection morphemes. Current spelling models subsume inflection with derivation and stem alternations under "morphological spellings." They hence consider inflection only in relation to the orthographic word. This paper argues that syntactic markers are a specific category as they are part of the orthographic word but also systematically tied to the presence of syntactic features above the word level. Syntactic spelling refers thus not only to the correct spelling of a syntactic marker but to its correct application within a given syntactical context. In syntactic reading, (proof)readers must notice the marker and interpret it correctly to understand the sentence. Syntactic spelling and reading have hence been found to be highly demanding in many languages. Syntactic information is not decisive for sentence understanding in many cases, since the information can be deduced from the context. In order to focus the definition of syntactic markers, this paper restricts them to those graphemic elements that convey syntactical but no lexical features and are further unrelated to phonology. The paper concludes that syntactic markers and spelling should be distinguished from morphological spelling. Examples are given for English, French, Dutch, and German.

Keywords: syntactic marker, syntactic spelling, syntactic reading, English, French, Dutch, German

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DEFINITION OF "SYNTACTIC MARKERS"

Syntactic markers are serial graphemic elements that indicate syntactic features. These features create coherence within phrases and between words or word groups on the clause level. Syntactic features are, therefore, not word-related but link larger entities of a sentence. In many languages, syntactic features are identical with inflection affixes. An example of this is conjugation: In English, the 3rd person singular is marked syntactically, distinguishing (I/you/we. . .) *sing* and (s/he) *sings*. In French, conjugation more strongly differentiates between the markers of person. However, only the 1st and 2nd person plural are phonologically transparent. All other persons differ in spelling but not phonologically (cf. for the verb *to sing* the 1st and 2nd person plural compared to all other grammatical persons: [ʃɑ̃te], [ʃɑ̃tɔ̃], [ʃɑ̃t]).

Another example is the nominal plural <s> in English: Pronounced [s], as in *cats* [kɛts], the marker is phonologically transparent. Confusion might arise, however, between the ending of the (one-morpheme) word *fox* [fɔks] and the (two-morpheme) word *socks* [sɔks].

Moreover, plural <s> can be articulated as [s] or [z], depending on the previously articulated phonemes (Kemp and Bryant, 2003).

Neither all syntactic features, nor all markers, indicate inflection. Some mark a particular word class. The <wh> spelling in *whether*, for instance, highlights the interrogative pronoun in the paradigm of *what, when*, etc., and is therefore a syntactic marker. The homophone *weather*, in contrast, does not include any syntactic features. Similarly, in German, nouns and syntactic nouns are all spelled with an initial capital letter that highlights this word class in contrast to verbs and adjectives.

While many syntactic markers consist of a grapheme and represent a morpheme, such as plural <s> in English, they might consist of a grapheme that is not related to a separable morpheme, such as <wh> in interrogative pronouns. In some cases, it is even difficult to define the grapheme status of a syntactic marker, such as in the capital spelling of nouns in German (Kohrt, 1985). A difficult graphematic status is also found with the apostrophe, distinguishing between the possessive <'> or <'s> (case) and the plural <s> (numerous), as in *cat's* – *cats*' – *cats* [kɛts] (Bunčić, 2004).

Punctuation is not included in the definition of syntactic markers and hence not part of this paper. Simply put, punctuation refers to the global sentence structure, whereas syntactic markers refer to local contexts below sentence level, such as noun phrases.

Syntactic spelling refers not only to the correct spelling of a syntactic marker but to its correct application within a given syntactical context. This has been observed as highly demanding in several languages such as English (Kemp et al., 2017), French (Fayol et al., 2006), Dutch (Sandra et al., 1999; Bosman, 2005; Sandra and Van Abbenyen, 2009), German (Betzel, 2015), and Greek (Protopapas et al., 2013). Only phonologically inaccessible syntactic markers seem to be particularly difficult to spell.

This paper proposes, therefore, to define "syntactic markers" as graphematic elements whose occurrence is systematically tied to the presence of syntactic features. As the spelling of syntactic markers is particularly demanding when these markers are not phonologically deducible, the following considerations focus on these syntactic markers. Examples will be provided across English, French, Dutch, and German.

SYNTACTIC MARKERS ACROSS ORTHOGRAPHIES

In English and French, as well as many other languages, syntactic markers are inflection suffixes that indicate agreement or government on the level of phrase or clause. However, syntactic features differ between languages and in some cases, such as German, syntactic markers refer neither to inflection, nor to any other specific morpheme. The following examples of syntactic markers indicate syntactic relations and share the common feature that they cannot be inferred from the phonological structure.

A syntactic marker famously prone to spelling errors in **English** is the past tense marker on regular verbs <ed> such as *kissed* (Nunes et al., 1997b). The marker clearly indicates a verb form in contrast to nouns or adjectives. The phonological word form varies, according to the phonological context, between [t] or [d]. Confusion in spelling might be possible between the ending of a (one-morpheme) noun such as *bird* [bərd] or *belt* [bɛlt] and the (two-morpheme) verb *called* [kɒld] or *dressed* [drɛsd]. While the past tense of each regular verb is spelled <ed>, irregular verb forms are phonologically more transparent by deleting the silent <e>, such as *found* [faʊnd] and *felt* [fɛlt].

In oral **French**, the singular and plural sound identical, except of the article: *Le grand chat noir mange* [lə gʁɑ̃ ʃa mɑ̃ʒ] vs. *Les grands chats noirs mangent* [le gʁɑ̃ ʃa mɑ̃ʒ] ("The big cat/s black eat/s"). The plural marker has two forms: <s> for adjectives and nouns, and <nt> for verbs (3rd person plural). The singular form is not marked orthographically. Importantly, plural is conveyed by all the elements within a noun phrase and within subject-verb agreement (Dubois, 1965). Other syntactic markers that are extremely difficult to distinguish in spelling are the forms <er, ez, é, ée, és, ées, ai, ait, ais>. Each marker conveys precise information about person and/or number of nouns and adjectives, or various conjugations of verbs and participles. All markers are pronounced equally as [e] (Brissaud and Chevrot, 2011).

While homophony is the default in French inflection, it concerns only a small part of verbal inflection in **Dutch**. Present and past tense have a regular inflection pattern with stem + suffix. In present tense, the 1st person singular keeps the stem form, the 2nd and 3rd person singular add the suffix <t>. In most cases, both verb forms are phonologically transparent. They become homophonous, when the stem ends on <d>, i.e., *vinden* ("to find"), *vind* (1S), *vindt* (3S), both pronounced as [vɪnt]. In past tense, suffixes are for singular <de> (or <te>), for plural <den> (or <ten>). While in most cases the spellings are phonologically transparent and distinguish the stem in the first and the suffix in the second syllable (*belde* ([bɛl.də], "called"), stems ending on <d> (or <t>) mask this syllable structure as both <d> (or <t>), from the lexical stem and the suffix, are represented (cf. *meldde* [mɛl.də], "to inform"). Homophone dominance, on the lexical and sublexical level, increase congruity errors on the lower-frequency form (Sandra and Van Abbenyen, 2009).

Whereas in English, French and Dutch, inflection suffixes are syntactic markers, **German** syntactic markers do not necessarily point to inflection, nor do they always refer to a morpheme. One syntactic marker signifies the word class "noun" or, more precisely, the head of a noun phrase (NP) by an initial capital letter. Indeed, almost every word can become a noun without any morphological modification, although this is mainly applied to adjectives and verbs. An example for a verb vs. a nominalized verb is *Ich hörte sein Singen* ("I heard his singing") vs. *Ich hörte ihn singen* ("I heard him singing").

While the lexical-semantic characteristics of a noun are not clear-cut but lie on a continuum between a prototype and its periphery, the syntactic context of the noun phrase remains stable: In this perspective, capital spelling applies to the head of a NP. Whether a word is head of the NP is shown by whether the adjectives, with which the NP can be extended, are inflected. An adjective such as *schön* ("nice") can be used in this uninflected form at several positions in the sentence, e.g., *Ich hörte ihn schön singen* ("I heard him singing nicely"). However, it must be inflected within the noun phrase, as in *Ich hörte sein schönes Singen* ("I heard his nice singing") (Funke, 2020). While the noun closes the NP-unit, the capital letter highlights this demarcation visually (Maas, 1992).

These non-exhaustive examples in French, Dutch and German illustrate the definition of syntactic markers. The general scheme of French agreement reveals the relational aspect of these markers, as they have to be placed, redundantly, on each word of the syntactic unit (phrase or clause). The low occurrence of the Dutch examples reveals "homophone dominance" effects (Sandra and Van Abbenyen, 2009, p. 243; cf. Largy et al., 1996). The German examples show that a syntactic marker might not be classifiable as morpheme or grapheme (Kohrt, 1985), nevertheless, the capitalization of the noun is the visual index of a syntactic unit.

SYNTACTIC SPELLING

All existing spelling models have focused on the orthographic word. This is consistent, as all orthographic regularities are word-based. Early spelling models described spelling acquisition as a linear process in which learners first discover relations between graphemes and phonemes, and subsequently acquire orthographic and morphological structures represented in the respective writing system (cf. Frith, 1985). More recent approaches to spelling such as the triple word-form theory (Garcia et al., 2010; Bahr et al., 2012), have shown that learners do not acquire the linguistic levels coded within a writing system linearly. Instead, spelling development is a long-term process during which learners must learn to coordinate the different layers of the writing system (Sprenger-Charolles et al., 2003; Bahr et al., 2012). Existing spelling models distinguish between phonologic, orthographic, and morphological spellings.

So-called "morphological spellings" (Pacton and Deacon, 2008; Bahr et al., 2012) refer to morphologically complex words with stem (e.g., *sing*) and one or more affixes, and enclose derivational (e.g., *singer*) and inflectional (e.g., *sings*) morphology. It is suggested that inflection might be easier as derivation as young children typically focus on inflection (Carlisle, 1996; Kirby et al., 2011) and as the rules for inflection suffixes are, in general, very easy (such as 3rd person singular <s> in English). Therefore, authors rather point to inflection errors of young learners when those show over-generalizations of regular spelling such as ∗*snowmans* instead of *snowmen*.

Surprisingly, syntactic spelling refers to the regular forms and is based on a rather simple abstract, general rule. Although young spellers already identify, and may correctly produce, syntactic markers (Totereau et al., 1997; Turnbull et al., 2011), many studies have shown that learners' difficulties with syntactic markers may persist throughout school (Bryant et al., 2000; Totereau et al., 2013; Betzel, 2015). Even literate adults may produce syntactic spelling errors, observed in experiments (Largy et al., 1996) and in naturalistic writing situations (Surkyn et al., 2019). Indeed, the correct detection or production of a syntactic marker is not a result of the lexical identification of a word, but of structural relations within a group of words (Bock and Ferreira, 2014). The relational characteristics of syntactic markers – and the difficulties in processing them – become apparent in studies that analyze syntactic processing in spelling and reading.

Known sources of syntactic, or, more precisely, congruity errors are the effect of frequency and analogy, especially on the spelling of homophonous word forms, and the effect of words in the proximity of the target word. Resulting from experiments in French and Dutch, working-memory seems to be an important triggering factor for the emergence of congruity errors in homophones (Fayol et al., 1994; Largy et al., 1996; Sandra and Van Abbenyen, 2009). Sandra and Van Abbenyen (2009) additionally, suggests the importance of the process of lexical access in the long-term memory, assuming that storage of a given inflected verb form as well as the occurrence frequency. This is in line with the observation that younger learners seem to store some inflected words in the orthographic lexicon, as they experience them more frequently than others (Largy et al., 2007; Geoffre and Brissaud, 2012).

More specifically, the experiments in French have shown that subject-verb agreement errors occur when the agreement between subject and verb is covert. Prototypical examples are sentences with a subject containing two noun phrases mismatched in number (${}_{\text{clause}}[{}_{\text{NP-Sg}}$[The girl] ${}_{\text{PP}}$[of ${}_{\text{NP-Pl}}$[the neighbors]] sings]). While the first NP is the subject-NP, the second NP is a modifier of the subject-NP. If a second task needs attention, even literate adults do not always refer to the syntactic relation while spelling but tend to automatically produce syntactic markers between the NP adjacent to the verb (${}_{\text{clause}}[{}_{\text{NP-Sg}}$[The girl] ${}_{\text{PP}}$[of ${}_{\text{NP-Pl}}$[the neighbors]] ∗sing]). Fayol and colleagues have interpreted these attraction-errors (Bock and Miller, 1991) as a by-product of the automatization in syntactic spelling (Fayol et al., 1994). For learners, maintaining in memory the sentence to be written might be enough to disrupt the control for agreement (Fayol et al., 1999).

Other experiments were concerned with congruity errors in spelling verbal inflection with homophone nouns and verbs with different frequencies. Homophones were elicited in syntactic ambiguous (Largy et al., 1996) and unambigous contexts (Sandra and Van Abbenyen, 2009). In both experiments, congruity errors increase in adults and young learners when the noun is more frequent compared to the verb. The same effect was shown on sublexical level with concurrent word final spelling (Sandra and Van Abbenyen, 2009). The homophone dominance effect occurs on time pressure or under the condition of a secondary task. Observations on the development of the numerous alternative forms of the homophonic word ending [e] confirm the causally involved long-term memory and working memory. Development entails first the acquisition of the markers itself and its overgeneralization, then an increase of correct agreement, and from mid-secondary school on a decrease in agreement errors (Brissaud and Chevrot, 2011). The authors attest further that experienced writers also may recur to the most frequent word form under time pressure or in demanding writing contexts.

Syntactic Reading

Experiments on the detection of linguistic in/congruency while reading strengthen the results on spelling. On the basis of reaction time in a negative priming study, the observed effects reveal the executive costs of activating the strategy that a French NP requires <s> inflection after a plural determiner (Lanoë et al., 2016). The authors suggest the relevance to inhibit a highly automatized but in a given context misleading strategy that is added to the needed activation of the correct inflection marker. Note that in a sentence such as *Je mange les bonbons* vs. *Je mange les ∗bonbon* ("I eat the sweets"), all tested age groups, 6 graders, 9 graders, and adults required more time to determine the correct plural inflection of a noun when the sentence was preceded by a sentence with the pronoun *les* (3rd person plural), homophonous to the plural article *les* (i.e., *Je les mange* "I eat them").

Studies on adolescents' proofreading of Dutch verb homophones, similarly, evoke inhibition of an overlearned spelling pattern (Verhaert, 2016; Verhaert et al., 2016). They observed that error rates on homophone congruency amounted with the frequency of the verb, suggesting, as for spelling, an effect of homophone dominance. Due to the similar results of homophone dominance in spelling and proofreading and referring to the persistence of errors in syntactic spelling, the authors indicate a double trap for spellers, first during spelling, then during re-reading (Verhaert et al., 2016).

The here presented studies focus on the detection of orthographic markers in a given syntactic context while reading. However, most syntactic features that readers encounter in texts are embedded in semantics and context. In the incorrect example ∗*the friends house*, the missing apostrophe does not hinder comprehension, as the construction can only be understood as a possessive. This would be different if the word after *friends* could be a nominal or verbal form, as in *the friends drink* vs. *the friend's drink*. In first-pass reading, a reader will parse the syntactic structure embedded in the semantic context without necessarily identifying it. Syntactic reading takes place in cases of doubt or whenever the information cannot be extracted from the semantic context. In these cases, readers use the probabilistic cues to grammatical category at the beginning and end of a word (Arciuli and Monaghan, 2009). On this basis, readers take a lexical decision in sentence production and judgment (Kemp et al., 2009). An example of a syntactic reading task are parallel-constructed sentences where a syntactic marker is decisive for understanding. The study of Funke and Sieger (2012) asked pupils with perfect mastering of capital spelling of nouns to read sentences and then choose the correct ending of the sentence depending on whether a key word was a noun (i.e., capitalized) or a verb. A contextualizing sentence preceded each sentence. An example of the task is (Funke and Sieger, 2012, p. 1774):

> *Derek says, "Nowadays, so many people are divorced after only a few years of marriage. Most* <u>*love*</u>
>
> *. . .. . . someone else after a while."*
>
> *. . .. . . ends sadly.'*

The critical word in this example is *love*, used as a verb (solution a) or as a noun (solution b). In German, this difference is displayed in orthography as the noun would be capitalized. Although the participants were highly skilled spellers, only 30.7% of them reached the criterion of at least 15 (of 20) correct solutions in this task. More specific analyses revealed that pupils nevertheless seem to have considered capitalization while reading.

The presented research on syntactic spelling as well as syntactic reading indicates that syntactic spelling and proofreading might be similar processes (Verhaert et al., 2016). Both become conscious, hence non-automatic and slow when spellers or (proof)readers inhibit competing word forms associated with the linguistic context (Bock and Levelt, 1994). These processes differ greatly from the supposed automatic and fast visual word recognition process.

Training of Syntactic Spelling in Typical Educational Environment

Syntactic markers belong to the domain of orthography, as they are word-bound, but indicate relational information on phrase and clause level. Training of these markers seems complex as the processing of syntactic markers does not seem to be a precondition for the accomplishment of first-pass reading and writing tasks. However, on the one hand, performant readers do use syntactic markers for reading (Kemp et al., 2009; Funke and Sieger, 2012). On the other hand, syntactic spelling is difficult for all writers and proofreaders.

Regarding teaching, some studies indicate that children seem to discover syntactic constraints on spellings, at least to some extent, without being explicitly taught (Nunes et al., 1997a; Funke et al., 2013). However, the input material and the studying task is crucial for a potential discovery of the syntactic structure by the learner (Funke et al., 2013). Few intervention studies have trained a narrowly defined syntactic marker. The following intervention studies have drawn explicit attention to syntactic markers and have reported training effects on spelling.

Training effects are reported for English past-tense spelling (Nunes et al., 1997a) and the apostrophe (Bryant et al., 1997), for French plural markers (Thévenin et al., 1999; Bîlici et al., 2018) and for German (Bîlici et al., 2020). A training that focused on noun phrases in a sentence found effects on capital spelling of nouns, even if controlled with a group that focused on the lexical category noun (Brucher et al., 2020).

DISCUSSION: MODELING THE PROCESSING OF SYNTACTIC MARKERS

This review provided new perspectives on a category of orthographic markers that relate to syntax. Syntactic markers are the interface between orthography and syntax. Clearly, the syntactic marker is part of the orthographic word and might be stored, as part of the inflected word form or as suffix, in the orthographic lexicon. However, it refers to structural information on phrase and clause level.

Interestingly, all presented syntactic markers are based on very simple rules such as "if nominal plural add <s>" or "if noun use capital letter." These rules are part of the curriculum since the beginning of primary school. The learning process of syntactic markers seems confusing at first sight: While young spellers already identify and may correctly produce syntactic markers, even highly literate adults commit spelling errors in certain spelling tasks. This may be due to the fact that syntactic markers are, in most cases, redundant with phonology, semantics or context. In these cases, it is irrelevant whether a reader or writer notices and correctly interprets or produces the syntactic form-function relationship. In ambiguous syntactical contexts, however, syntactic spelling and reading is highly demanding and leads to rare but systematic errors, even in adults.

Several of the here quoted authors have proposed a model, that describes the processing of syntactic markers. The authors agree that learning of syntactic markers relies on the acquisition of the declarative spelling rules and activation of the correct inflection. They also agree that errors in experienced writers may be a by-product of the automatization of these rules.

Sandra and Van Abbenyen (2009) assume a full-form representation of inflected word forms in Dutch as well as two memory systems that might be causally involved in errors of syntactic markers: a given verb form and its occurrence frequency in the long-term memory as well as the conscious rule application of verb homophones in the working memory. Limitations of the working memory under conditions of time pressure or a secondary task lead to the homophone dominance effect. While in Dutch the application of syntactic rules for verb inflection applies only in a minority of cases, it seems also warranted for French where homophone inflection is the rule, not the exception (Largy et al., 1996). On the basis of priming studies on the detection of French plural markers, Lanoë and colleagues (2016) emphasize the ability to inhibit the overlearned strategy in order to select the syntactic marker associated with the linguistic context among homophone concurrent forms. All descriptions emphasize that the particular difficulty lies in choosing the right word-form amongst several competing word forms. This is even more difficult if the syntactic context is covert, such as NP1+NP2+V-sentences (Bock and Miller, 1991).

On the basis of the reviewed research, this paper emphasizes that syntactic markers and processing should be clearly distinguished from morphological spelling. Furthermore, it proposes limiting the category of "syntactic markers" to elements that convey structural-relational but no lexical features and that are either unrelated to phonology or cannot be recoded clearly. This heuristic limitation serves to distinguish the difficulties in processing syntactic markers systematically, as they are both syntactic and not supported phonologically. This is crucial to improve our understanding of the causes of spelling difficulties related to syntactic markers as well as the relation between orthographic form and syntactic function across languages.

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CW was the sole author and was responsible for all sections of the manuscript.

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Learning to Spell in Arabic: The Impact of Script-Specific Visual-Orthographic Features

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Learning to spell is a challenging process, especially for young learners, in part because it relies on multiple aspects of linguistic knowledge, primarily phonological and morphological. However, alongside these universals, there are significant writing system specifics, namely, language-specific and script-specific factors that may also challenge young readers and writers (Daniels and Share, 2018). The current study focuses on the impact of four distinctive visual-orthographic features of the Arabic abjad on spelling, namely, (i) the similarity of many basic letter-forms, (ii) allography (the positional variants of the letter forms), (iii) ligaturing (the joining of letters), and (iv) non-linearity (extra-linear diacritic-like signs used to mark consonantal, short vowel and morpho-syntactic distinctions). We examined the distribution of visual-orthographic spelling errors across three grade levels as well as the developmental changes in these errors. We predicted that these errors would account for a significant proportion of children's spelling errors. Ninety-six Arabic-speaking pupils from three elementary grades (1st, 2nd, 4th grades) were presented with a sequence of six pictures and asked to write a story or several sentences about the events depicted. All spelling errors were analyzed and categorized according to two types of categories: six visual-orthographic categories and six additional categories that relate to the more traditional error types (e.g., phonological). The results showed that the visual-orthographic category was the second most common error category across the three grade levels, accounting for over one quarter of all spelling errors. Ligaturing and letter shape formation errors emerged as the two most prevalent types of errors in this category. These findings clearly demonstrate that visual-orthographic features of the Arabic abjad pose significant challenges in learning to spell.

Keywords: spelling, Arabic, development, orthography, writing systems

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INTRODUCTION

To be literate today, an individual must not only be able to read but to write. Fluent written expression depends on a host of higher-order skills, but also on basic skills such as correct letter formation and the rapid and relatively effortless production of accurate word spellings. Learning to spell, however, is a complex and challenging process, especially for young learners because spelling typically relies on multiple aspects of linguistic knowledge, phonological, morphological and orthographic (Ehri, 1997; Perfetti et al., 1997; Bryant and Nunes, 2004; Nunes and Bryant, 2004; Treiman and Kessler, 2005; Verhoeven and Carlisle, 2006; Senechal and Kearnan, 2007; Ravid, 2012; Treiman, 2017; Perret and Olive, 2019).

Despite the impressive body of research findings on spelling development, the vast majority of this work has been undertaken in English, or in a few cases, other Western European (Roman) alphabets. Most children around the globe, however, learn to read and write in non-alphabetic writing systems such as Semitic abjads (e.g., Arabic and Hebrew), Brahmi-derived Indic abugidas, or morpho-syllabic Chinese. Relatively few studies have examined spelling development in these non-alphabetic scripts. The present study focuses on early spelling development in a non-European, non-alphabetic script – Arabic, a Semitic abjad.

Our approach to the study of spelling development is guided by the view that, alongside reading and spelling universals such as the representation of sound (phonology) and meaning (morphology), there are also significant writing system specifics, namely, language-specific and script-specific dimensions of writing system complexity that may also challenge young readers and writers (Perfetti and Harris, 2013; Daniels and Share, 2018). Ironically, the two most influential theoretical frameworks for describing cross-script diversity – Orthographic Depth (Katz and Frost, 1992) and Psycholinguistic Grain Size Theory (Ziegler and Goswami, 2005) give little consideration to non-European writing systems, both promoting a one-dimensional view of script variation, namely, spelling-sound (in)consistency. Daniels and Share (2018) have argued that theories of learning to read and write need to take into account the full range of writing system diversity. They propose that consideration of the full picture of the world's writing systems reveals multiple dimensions of complexity and call for future research to investigate the impact of these dimensions on reading and spelling. The present investigation responds to this call by exploring the impact of Arabic's unique visual-orthographic features on the early development of spelling. Our choice of Arabic is motivated by a number of factors.

First, Arabic is the sixth most spoken language in the world with close to 300 million speakers (Eberhard et al., 2019). It is the official language of 22 countries, and also the religious and liturgical language of more than 1.5 billion Muslims worldwide (Bokova, 2012). Second, the Arabic language has a unique orthography, containing a number of specific visual-orthographic features (common letter shapes, allography, ligaturing/cursivity, and non-linearity) all of which are pervasive in Arabic but rare or absent in most alphabetic scripts[1]. Shedding light on these special features is essential for a complete science of literacy learning. Third, a small but growing number of studies have begun to investigate the effect of these specific visual-orthographic features of the Arabic writing system on reading (e.g., Asaad and Eviatar, 2013; Dai et al., 2013; Ibrahim et al., 2013), but none has yet examined this issue in spelling.

Arabic Orthography

Arabic is a Semitic language written in an *abjad* or consonantal writing system (Daniels, 1992, 2018; Saiegh-Haddad, 2018). Arabic script is fundamentally cursive and is written from right to left (Azzam, 1993; Saiegh-Haddad and Henkin-Roitfarb, 2014). Arabic orthography consists of two sets of graphic signs: horizontally arrayed letters and vertically arrayed extra-linear diacritic-like signs. Twenty-eight of the 29 letters denote consonants, and 2 letters (*/ya:ʔ/* ي and */wa:w/* و) also represent the long vowels */i:/* and */u:/*, respectively. One more letter, */ʔalif/* (ا) represents the long vowel */a:/* (Bar-On et al., 2018).

The four main visual-orthographic features of Arabic are (i) the similarity of the basic letter-forms, (ii) allography (the positional variants of the letter forms) (iii) ligaturing (the joining of letters), and (iv) non-linearity (the use of extra-linear diacritic-like signs to mark consonantal, short vowel and morpho-syntactic distinctions).

(i) The similarity of many basic letter forms: One of the characteristic features of Arabic orthography is the similarity of many basic letter-forms. This feature stems from the fact that Arabic contains many more consonants than the Nabatean script from which it was derived (Daniels, 2018). A majority of letters have an identical or near-identical structure and are distinguished only by the existence, placement, and the number of dots (Eviatar and Ibrahim, 2014). These dots are non-optional and are considered an integral part of a letter, as in the case of the dot in the English lowercase letters < i > and < j >. Seven pairs of letters (ط ظ / ع غ / ف ق / د ذ / ر ز / س ش / ص ض) and two triplets (ج ح خ) and (ت ث ب) share the identical letter shape (*rasm*) (the complete inventory of Arabic letters is shown in Appendix A).

(ii) Allography: Another pervasive characteristic of Arabic orthography is allography, namely, the variability of letter forms. This variability depends on two factors. First, its position in the word – initial, medial, final. Second, whether or not it connects to the letter that precedes it. Together, letter position and ligaturing create the allographic variants: 23 letters are considered to have four letter-forms, and six letters have two forms (see (iii) Ligaturing/Cursivity). For example, the letter ب */ba:ʔ/ /b/* is written بـ when in initial position as well as in medial position when not ligatured to the previous letter, in medial position and ligatured to the previous letter ـبـ, and in word-final position ـب, and ب (ligatured and unligatured respectively). Note that both word-final forms have the characteristic word-final flourish or "tail" (see Appendix A). This highlights the fact that not all allographic variants are the product of ligaturing (as discussed in (iii) Ligaturing/Cursivity). In addition to the word-final flourish, there are internal form changes in the final vs. non-final */ka:f/* ك ـك, the open loops of the word-final */mi:m/* ـم, and minor changes in the location of the dotting in several letters (e.g., ث ـث */θa:ʔ/*). Two studies have now demonstrated that positional variants of letters affect word reading in Arabic (Taouka and Coltheart, 2004; Asaad and Eviatar, 2014). Both studies reported that incorrect positional variants (such as a word-final letter appearing in the middle of a word) slow reading times and reduce reading accuracy.

[1]Ligaturing is the norm in Syriac, N'ko, Manchu, and Mongolian, whereas consonants in Brahmi-derived Indic scripts are often combined either horizontally or vertically via ligaturing. Non-linear diacritics are found, in varying degrees, in almost all European alphabets (e.g., Spanish, Czech, Polish) as well as non-European alphabets (e.g., Vietnamese, Thaana). Allography (e.g., upper-case and lower-case letters) is also common in many alphabets, at least in word-initial position. The phenomenon of common letter shapes (e.g., p, q, b, d) is well-known in English.

(iii) Ligaturing/Cursivity: Cursivity is perhaps the most conspicuous feature of Arabic (Saiegh-Haddad and Henkin-Roitfarb, 2014; Yakup et al., 2015). The majority of the letters in a word connect to the adjacent letters creating a word that forms a single unbroken graphic unit. Thus, three types of words are possible: a fully connected word بيت */bayt/ "home,"* a partly connected word مولود */mawlu:d/* "born" and an entirely unconnected word ورود */wuru:d/* "roses." All 29 letters can connect to the previous letter (on the right side). For example, the letter named */ħa:ʔ/* (letter sound */ħ/*) can be connected on the right or the left حـ ـح or on both sides ـحـ. Similarly, the letter */sˤa:d/* (letter sound */sˤ/*) can also be right-connected or left-connected صـ ـص as well as doubly connected ـصـ and so on. In word formation, these two letters ص and ح are joined as صح */sˤaħ/* "correct." Six letters, however, have only two variant forms which can connect only from the right but not the left side (e.g., و ـو /w/ /u/ */wa:w/,* ر ـر /r/ */ra:ʔ/,* ز ـز /z/ */za:y/*, د ـد /d/ */da:l/*, ذ ـذ /ð/ */ða:l/*, and ا ـا /a/ */ʔalif/*). For example, the letter ر /r/ is unconnected in رز */ruz/* "rice," but (right-) connected in مرّ */murr/* "sour" (Saiegh-Haddad and Henkin-Roitfarb, 2014). Although some letter variants in Arabic involve systematic alterations (principally additions) depending on position (e.g., ض ضـ ـضـ ـض */dˤ/ /dˤa:d/* and ح حـ ـحـ ـح */ħ/ /ħa:ʔ/*), some changes are substantial to the point of appearing quite unrelated (e.g., ه هـ ـهـ ـه */h/ /ha:ʔ/*).

(iv) Tashkeel and Non-linearity: An additional feature of Arabic orthography is the extensive use of extra-lineal diacritic-like signs. These marks are placed mostly above but also below letters unlike the letters of most alphabets which are arrayed along a single horizontal axis. Daniels and Share (2018) refer to this dimension as non-linearity. In addition to the consonant dots discussed above in (i), Arabic orthography includes two classes of extra-lineal signs, named tashkeel: phonemic and morpho-syntactic (Saiegh-Haddad, 2018). The phonemic tashkeel consist of five major marks, three of which consistently map the three short vowels; */ʔal-fatħatu/* ◌َ represents ***/a/***, */ʔa-dˤammatu/* ◌ُ represents */u/*, and */ʔal-kasratu/* ◌ِ represents */i/*, one that denotes vowel nullification (*/ʔassuku:nu/* ◌ْ), and one that denotes consonant gemination (*/ʔʃʃaddatu/* ◌ّ) (N.B. the broken circle represents any consonant letter). The phonemic tashkeel can appear on almost any letter within the word, and they map contrastive phonemic information. In contrast, the three short vowels (*/ʔal-fatħatu/* ◌َ, */ʔa-dˤammatu/* ◌ُ, and */ʔal-kasratu/* ◌ِ) can also appear word-finally, in which case they map morpho-syntactic properties such as noun case and verb mood (Saiegh-Haddad, 2018). Finally, there are another three extra-lineal signs, called nunation */tanwi:n/*, which also have a morpho-syntactic function (i.e., the case endings of indefinite nouns) and only appear word-finally. They consist of the three vowel signs doubled to indicate that the vowel sound is followed by the consonant */n/*: double *fatħa* (◌ً) /an/, double *dˤamma* (◌ٌ) /un/, and double *kasra* (◌ٍ) /in/ (Saiegh-Haddad, 2018). The tashkeel also includes the following less frequent signs: */madda/*~, */hamzatu-l-wasˤli/* ٱ which only appears on the alif, and the "dagger" alif or superscript alif */ʔal-ʔalifu-l- xanjariyyatu/* ◌ٰ (see, for details, Saiegh-Haddad and Henkin-Roitfarb, 2014). The presence of tashkeel in Arabic text is called mashkul script, and makes the orthography phonologically transparent. The mashkul script is primarily used for early reading instruction at the onset of formal schooling, from first to fourth grades, and in children's books. It is also used for the Quraa'n and in poetry (Bar-On et al., 2018). However, the second version of Arabic script, the default for Arabic speakers, is the non-mashkul script */ɣayr-mashku:l/*, which relies on letters alone with no tashkeel other than the non-optional consonant dotting. The non-mashkul Arabic script is often considered deep because words can potentially be assigned many phonological forms, corresponding to both lexical and non-lexical readings (Bar-On et al., 2018; Saiegh-Haddad, 2018).

Studies of Spelling Development in Arabic

Understandably, studies of literacy learning in Arabic (and Hebrew) have mainly focused on the role of phonology. Indeed, several investigations have shown that phonological awareness plays a crucial role in spelling development in Arabic (Abu-Rabia and Taha, 2006; Batnini and Uno, 2015; Saiegh-Haddad and Taha, 2017). In a series of studies of spelling development, Abu Rabia and colleagues found that the most common type of spelling error committed by native Arabic-speaking children (and especially dyslexics) is phonological (Abu-Rabia and Taha, 2004, 2006; Abu-Rabia and Sammour, 2013). For example, Abu-Rabia and Sammour (2013) reported that most of the spelling errors occurred as a result of confusing emphatic consonants and their non-emphatic counterparts (e.g., ت /t/- ط /tˤ/, د /d/- ض/dˤ/, س/s/- ص/sˤ/, and ذ/ð/- ظ /ðˤ/). In addition to studies emphasizing phonology, several recent studies have emphasized the role of morphology in the early stages of Arabic spelling (e.g., Taha and Saiegh-Haddad, 2016; Saiegh-Haddad and Taha, 2017; see also Ravid, 2012). In this context, it is important to note that Semitic languages such as Arabic have a dense morphological structure as most content words (all verbs as well as most nouns and adjectives) are made up of two independent and unpronounceable bound morphemes: a root and a word pattern. The root is a consonantal skeleton that provides the word's core meaning, and the word pattern is a fixed prosodic template that specifies the word's categorical meaning and some of the phonological characteristics of the surface form (vocalic, syllabic, and prosodic form) (McCarthy, 1981; Saiegh-Haddad and Henkin-Roitfarb, 2014; Boudelaa and Marslen-Wilson, 2015; Shalhoub-Awwad and Leikin, 2016). The root-and-pattern structure of Arabic is also a salient feature of the orthographic structure of written Arabic (Saiegh-Haddad and Taha, 2017). Research has shown that elementary school children in second, fourth and sixth grades use derivational morphological structure to spell real and pseudowords (Taha and Saiegh-Haddad, 2017). Furthermore, morphological awareness has been found to predict unique variance in spelling development, beyond phonological awareness and general cognitive skills among normal and reading-disabled children (Saiegh-Haddad and Taha, 2017). It has also been shown that both morphological and phonological interventions have a significant impact on spelling in Arabic, among normal and reading-disabled children, especially in the initial grades (Taha and Saiegh-Haddad, 2016).

To date, only a single study has focused on the challenges that beginning spellers incur due to the unique visual-orthographic features of the Arabic writing system. Dai et al. (2013) examined the influence of letter ligaturing on printed word learning ("orthographic learning") in third-grade Arabic readers. Test stimuli consisted of forty pseudowords, all with the *fatħa* short vowel sign. Half of the pseudowords consisted of non-connecting letters (e.g., رَوزَة) whereas the other 20 pseudowords were composed of the remaining letters of the Arabic orthography which were all presented in their connecting form (e.g., خَمضَك). The children were asked to read aloud and to spell all test stimuli (20 connected and 20 unconnected items). The results showed that connectedness not only slowed down reading speed but also reduced accuracy for spelling.

As mentioned above, the greater part of the current literature on spelling development in Arabic has focused on the contributions of universal factors such as phonology and morphology, rather than the script-specific visual-orthographic dimensions of the Arabic writing system. The main purpose of the current study is to examine the effect of the four distinctive script-specific visual-orthographic features of the Arabic writing system reviewed above (similarity of basic letter-forms, allography, ligaturing, and non-linearity) on spelling among children in Grades 1, 2, and 4. We hypothesized that visual-orthographic factors of Arabic orthography would account for a non-trivial proportion of spelling difficulties.

MATERIALS AND METHODS

Participants

Ninety-six pupils from three grades participated in this study: 32 first graders, 32 second graders, and 32 fourth graders[2] (16 boys and 16 girls from each grade). Children were recruited from four Arabic-speaking elementary schools in the north of Israel. These schools were selected to represent a wide range of socio-economic backgrounds and included two schools from a middle SES neighborhood, a third high-SES school, and fourth low-SES school. All participants were native speakers of the local dialect of Palestinian Arabic spoken in the north of Israel. Complete classrooms were tested in a group-testing situation with no child excluded.

Materials

The Picture Story Writing Task (adapted from Mayer, 1969) was administered to all participants. In this task, each child was presented with a sequence of six color pictures (see Appendix B) and asked to write a story or several sentences about the events depicted in the pictures. These six pictures were taken from the wordless picture book, *Frog, where are you?* (Mayer, 1969). The booklet, consisting of 25 pictures, depicts the adventures of a child and his puppy, out to search for a frog that has gone missing. This writing task has been used extensively in cross-linguistic work among a wide range of age groups (Berman and Slobin, 1994). It contains no words and provides a fairly rich context for spoken and written language production (Reilly et al., 2004).

It should be noted that the abbreviated six-picture version that we administered omits some of the attempts to search for the lost frog but keeps the main plot of the story events intact. Similar to other research on story writing (e.g., Berninger et al., 1997; Graham et al., 2000), the choice of this particular task was solely designed as a trigger to elicit writing, tailored especially for first and second graders who are used to perform reading and writing tasks involving pictures. The written productions were used to generate a naturalistic corpus of spelling errors.

Procedure

The task was administered toward the end of the school year to entire first, second, and fourth-grade classrooms in the four schools. In each of the four schools, two classes in each grade level were randomly selected. Instructions were given in the pupils' mother tongue to the entire class. Each student in the class received the set of pictures, an empty ruled page, and the following instructions: "*Look at the pictures in the correct order (each picture was numbered from 1 to 6) and write a story or some sentences telling the story of what is happening in the pictures.*" The task was administered in a single 45-min lesson.

Error Analysis

Our error analysis took into account the fact that children's written productions across this range of ages vary considerably in terms of lexical, morphological and orthographic content and complexity. Because error types may also vary as a consequence of these differences, we confined our error analysis to a subset of 45 key words common to all productions across the three grade levels (first, second, and fourth grade). A subset of 45 words were selected after examining the pupils' productions and then selecting those words that appeared most frequently across all three grade levels. This corpus included 37 content words – 19 nouns (e.g., ضُفدَع /*dˤufdaʕ*/ 'frog'), 18 verbs (e.g., بَحَثَ /*baħaθa*/ "looked for"), and 8 function words (e.g., في /*fi:*/ "in").

The total number of words in each pupil's written production was counted, along with the number of words from the corpus of 45 words. If a child wrote a word more than once, each production was counted separately because this created an opportunity for an error. Spelling errors were then recorded and classified according to two types of categories: six categories relevant to the visual-orthographic focus of the present study and six additional categories that relate to the more traditional error types (e.g., phonological). The first four visual-orthographic categories were based on four of the 10 dimensions of orthographic complexity discussed by Daniels and Share (2018), namely, *letter-form confusion* (errors caused by confusion between letters with the same or very similar structure which are differentiated only by the existence, placement, and number of dots), *allography* (errors caused by selecting the inappropriate positional variant of a letter form (word-initial, medial or final), *ligaturing* (an inappropriate connection or omission of an obligatory connection between adjacent letters), and *non-linearity* (errors in the location and/or order of the

[2]Third graders were not recruited for this study due to the limited resources at our disposal, both in terms of budget allotted and time constraints (particularly the need to gather the data for each grade level during the same time period at the end of the school year). Due to these constraints, recruiting fourth graders was prioritized (and not third graders), as the transition from mashkul script to non-mashkul script occurs in the fourth grade (see Bar-On et al., 2018).

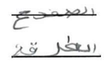
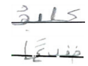
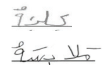
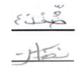
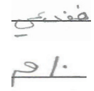
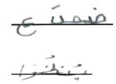
extra-lineal signs (tashkeel and letter dotting) in the vertical axis). Most fourth graders (who typically are used to non-mashkul script) did not write with Arabic's optional tashkeel, therefore, we decided to ignore this dimension for all pupils. This decision stemmed from the fact that when administering the writing task, no direct instruction was given to the pupils to write with tashkeel, since our purpose was to obtain a naturalistic corpus of errors. A fifth category — *letter shape formation,* emerged in the course of data coding. This category comprised errors in which the child either added or omitted an integral feature of letter form. The sixth category included *other* (unclassifiable) visual orthographic errors such as illegible productions (see **Table 1**). The six additional (*non*-visual-orthographic) error categories were *phonological* (errors caused by inappropriate application of sound-symbol correspondence rules that change the phonemic makeup of a word resulting in an incorrect pronunciation, e.g., الدّفدع */ʔaddufdaʕ/* instead of الضّفدع */ʔadˤdˤufdaʕ/* "the frog"), *spelling conventions* (caused by incomplete mastery of spelling conventions, e.g., اختفا */ʔixtafa/* instead of اختفى */ʔixtafa/* "disappeared," which is phonologically permissible but is the wrong form of the letter */ʔalif/* (i.e., ا instead of ى)), *morpho-orthographic* (errors caused due to lack of reliance on suitable word-pattern or clitics, e.g., يصططيع ***/yasˤtˤatˤi:ʕ/*** instead of يستطيع */**yastat**ˤi:ʕ/* "can," this error occurred due to a lack of reliance on the appropriate verbal word-pattern letters), *morpho-syntactic* (errors caused by inappropriate application of vocalic word endings which denote the syntactic categories of case and mood, e.g., كانٌ */ka:nan/* instead of كانَ */ka:na/*), *diglossic* (errors that transcribe the spoken or colloquial form instead of the standard Arabic form, e.g., نايم */na:yem/* instead of نائم */na:ʔim/*), and a category of *other* error types (unclassifiable), e.g., errors caused by adding two graphic signs to a letter which represent two short vowels.

RESULTS

Table 2 presents the total number of words written by the children across the three grades, the number of words in the selected corpus of 45 key words, the proportion of corpus words out of the total number of words produced, the total number of spelling errors in this corpus, and the error rate per word. **Table 2** shows that, with increasing grade levels, children, as expected, wrote more words, and spelled these words more accurately. Significant differences across grades were found in the proportion of corpus words out of the total number of words produced [$F(2, 93) = 18.07$, $p < 0.001$, $\eta_p^2 = 0.28$]. Bonferroni *post-hoc* contrasts revealed a significantly larger proportion of corpus words in Grade 1 compared to Grade 2 ($p < 0.001$), and to Grade 4 ($p < 0.001$), but no significant difference between grades 2 and grade 4 (n.s.) (see **Table 2**). As for the spelling errors within the 45 corpus words, children committed around two errors per three words in both Grades 1 and 2, and even after 4 years of formal schooling, children were still far from achieving spelling mastery, making on average one error in every second word. This confirms that spelling is indeed a challenging task in Arabic.

The first aim of this study was to determine the overall proportion of visual-orthographic spelling errors. We predicted that this category of errors would account for a non-trivial proportion of children's errors. This category combined the four dimensions of ligaturing, letter shape confusion, allography and non-linearity, as well as the newly added category of letter shape formation. The data presented in **Table 3** show that the visual-orthographic category was the second most common error category across the three grade levels, accounting for over one quarter (27.2%) of all spelling errors. This finding clearly shows that visual-orthographic errors, as anticipated, constitute a significant proportion of young children's naturally occurring spelling errors. Turning to the more traditional categories of *non*-visual-orthographic errors, the most common errors were violations of *spelling conventions*, comprising between one third and one half of all errors. The *phonological* category

TABLE 1 | Examples of spelling errors from the six visual-orthographic categories.

Visual-orthographic categories	Incorrect spelling	Correct spelling
Letter-form confusion		الضِّفدع */ʔadˤdˤufdaʕ/ 'the frog'* الغرفة */ʔalɣurfa/ 'the room'*
Allography		كلبهُ */kalbuhu/ 'his dog'* ضفدعًا */dˤufdaʕan/ 'frog'*
Ligaturing		كلبهُ */kalbuhu/ 'his dog'* ملابسَهُ */mala:bisahu/ 'his clothes'*
Non-linearity		الضِّفدع */ʔadˤdˤufdaʕ/ 'the frog'* نَظَرَ */naðˤara/ 'he looked'*
Letter shape formation		ضِفدعي */dˤufdaʕi:/* 'my dog' نام */na:ma/ 'he slept'*
Other (unclassifiable errors)		ضِفدَع */dˤufdaʕ/* 'frog' ينظُران */yanðˤura:n/ 'they are looking'*

Some of the incorrect spellings contain errors from the six additional (non-visual-orthographic) categories.

TABLE 2 | Means and standard deviations (in parentheses) of the total number of words produced per child, the mean number of words in the selected corpus of 45 key words, the proportion of corpus words out of the total number of words produced, the mean number of spelling errors in the 45-word corpus, and the error rate per word across three grades.

	Grade 1	Grade 2	Grade 4
Total words produced	43.1 (9.67)	64.6 (20.55)	82.9 (32.43)
Mean number of corpus words	29.1 (6.34)	34.9 (9.73)	46.1 (14.98)
Proportion of corpus words out of the total number of words produced (in percentages)	68.6 (11.47)	55.0 (7.36)	57.5 (9.65)
Total spelling errors (in the 45-word corpus)	20.7 (10.39)	22.2 (10.78)	22.7 (14.64)
Error rate per word	0.71 (0.32)	0.68 (0.37)	0.48 (0.25)

TABLE 3 | Means (in percentages) and standard deviations (in parentheses) of error rates for the combined visual-orthographic category and the six additional categories at three grade levels.

Error category	Grade 1 %	Grade 2 %	Grade 4 %	Total %	P	Effect Size (η_p^2)
Visual-orthographic (combined)						
	18.2 (13.91)	27.5 (16.62)	35.8 (21.23)	27.2	<0.01**	0.148
Non-visual-orthographic						
Phonological	18.4 (14.15)	23.9 (17.50)	27.7 (23.01)	23.3	0.137	0.042
Spelling conventions	52.3 (19.04)	41.9 (17.00)	32.6 (19.74)	42.3	<0.001***	0.161
Morpho-orthographic	5.8 (6.63)	3.6 (4.89)	1.9 (3.97)	3.8	<0.05*	0.085
Morpho-syntactic	2 (4)	1.1 (2.80)	1 (2.22)	1.4	0.328	0.024
Diglossic	2.8 (4.83)	1.2 (2.21)	0.8 (3.45)	1.6	0.082	0.052
Other	0.5 (1.66)	0.8 (2.55)	0.2 (0.98)	0.5	0.406	0.019
Total	100	100	100	100		

$^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

TABLE 4 | Means (in percentages) and standard deviations (in parentheses) of error rates for the separate visual-orthographic categories across three grade levels.

Error types	Grade 1 %	Grade 2 %	Grade 4 %	Total %	P	Effect size (η_p^2)
Letter-form confusion	6.5 (20.05)	13.3 (25.11)	12.2 (23.79)	10.7	0.456	0.017
Allography	13.5 (25.14)	5.1 (15.43)	6.6 (15.12)	8.4	0.179	0.036
Ligaturing	22.1 (26.81)	46.5 (41.23)	38.2 (37.46)	35.6	<0.05*	0.077
Non-linearity	1.6 (8.84)	0.9 (3.63)	0 (0)	0.8	0.525	0.014
Letter shape formation	34.6 (38.48)	30.6 (37.48)	35.9 (35.26)	33.7	0.836	0.004
Other	6.1 (20.14)	0.4 (1.78)	0.8 (2.36)	2.4	0.103	0.048

Eight children from the sample did not make any visual orthographic errors: 5 first graders; 1 second grader; and 2 fourth graders. Therefore, as can be seen in the table, the sum of the error rates of all of the visual-orthographic categories for each grade does not total 100%. $^*p < 0.05$.

was the third most prevalent category accounting for around one quarter of all spelling errors. It is important to note, however, that the category of phonological errors, which has received the most attention in the Anglophone literature was eclipsed by the (combined) visual-orthographic category that was the particular focus of the present investigation. Each of the three remaining non-visual-orthographic categories – *morpho-orthographic*, *morpho-syntactic,* and *diglossic,* each accounted for only a few percent of the total corpus of errors (see **Table 3**). One-way between-subjects ANOVA were conducted to examine developmental changes across grades in the proportion of errors in the combined visual-orthographic category and the six additional categories. Significant differences across grades were evident in the proportion of visual-orthographic spelling errors [$F(2, 93) = 8.06$, $p = 0.001$]. Bonferroni *post-hoc* contrasts revealed significantly greater visual-orthographic error rates in Grade 4 compared to Grade 1 ($p < 0.001$), but no significant difference between grades 1 and grade 2 ($p = 0.108$), or between grades 2 and 4 ($p = 0.188$) (see **Table 3**). Regarding the six additional categories, there was a significant decline in the proportion of spelling convention errors [$F(2, 93) = 8.93$, $p < 0.001$] but the proportion of phonological errors remained steady across the grades. This latter finding indicates that phonology continues to trouble young spellers throughout most of their elementary years. There was also a significant but small decrease (amounting to a few percentage points) in morpho-orthographic errors. No other developmental differences were evident in the other non-visual-orthographic categories.

The second aim of the current study was to examine the distribution of the visual-orthographic spelling error categories as well as the developmental changes that occur in these errors across the three grade levels. **Table 4** displays the error rates for the separate visual-orthographic categories that were the main focus of the present study. The results showed that both ligaturing errors and letter shape formation were the two most prevalent types of errors, each accounting for around one third of all visual-orthographic errors across grades. Confusion of identical or near-identical letter forms (10.7%) and allographic substitutions (8.4%) also contributed a non-trivial number of visual-orthographic errors. The *non-linearity* category, for reasons already discussed in the method section, comprised less than 1% of all visual-orthographic errors (see **Table 4**).

One-way ANOVAs were again used to examine developmental changes in each of the six visual-orthographic categories across the three grade levels. The only category with significant developmental change was *ligaturing* [$F(2, 93) = 3.89$, $p = 0.024$]. Bonferroni *post-hoc* contrasts indicated that, counter-intuitively, the proportion of *ligaturing* errors *increased* significantly from Grade 1 to Grade 2 ($p < 0.05$) then remained steady from Grade 2 to Grade 4 ($p > 0.05$) (see **Table 4**).

DISCUSSION

This study investigated the impact of Arabic's unique visual-orthographic features on the early development of spelling. Participants were asked to compose a story based on six pictures taken from the wordless picture book, *Frog, where are you?* (Mayer, 1969). Spelling errors in a subset of 45 keywords common to almost all productions across three grade levels were recorded and classified into two types of categories: six categories relevant to the visual-orthographic focus of the present study and six additional categories that relate to the more traditional error types (e.g., phonological).

The findings revealed a high rate of errors across all grades. These findings are in line with an ample body of research that has been undertaken in English, and other (Western) European alphabets on spelling development showing that spelling is a complex and challenging process (Ehri, 1995; Perfetti et al., 1997; Bryant and Nunes, 2004; Nunes and Bryant, 2004; Treiman and Kessler, 2005; Verhoeven and Carlisle, 2006; Senechal and Kearnan, 2007; Ravid, 2012; Treiman, 2017; Perret and Olive, 2019). This study extended this conclusion to Arabic (a non-alphabetic script). Even after 4 years of formal schooling, children are still far from achieving spelling mastery.

The findings across the three grade levels regarding the proportion of visual-orthographic spelling errors relative to the six additional categories (phonological, spelling conventions, morpho-orthographic, morpho-syntactic, diglossic, and other) revealed that the *visual-orthographic category* ranked the second most frequent category, accounting for over one quarter (27.2%) of all spelling errors. This substantial proportion supports the view that there are significant script-specific dimensions of writing system complexity that pose obstacles for young spellers, alongside spelling (and reading) universals such as the representation of sound (phonology) and meaning (morphology) (Perfetti and Harris, 2013; Daniels and Share, 2018). Turning to the more traditional categories of *non*-visual-orthographic errors, the most common errors were violations of *spelling conventions*, comprising between one third and one-half of all errors. The *phonological* category was the third most prevalent error category accounting for around one quarter of all spelling errors. An unexpected outcome was the fact that errors in the combined visual-orthographic category were more prevalent than phonological errors, and continues to trouble young Arabic-speaking spellers throughout most of their elementary years. This finding diverges from the Anglophone emphasis on the phonological category as the most important and common category of spelling errors (Frith, 1985; Ehri, 1989; Nunes et al., 1997). It is also inconsistent with previous studies of Arabic spelling development which also concluded that phonological errors are the most common category of spelling errors committed by native Arabic-speaking children (Abu-Rabia and Taha, 2004, 2006; Abu-Rabia and Sammour, 2013). This inconsistency may stem from the fact that these studies largely ignored the unique visual-orthographic features of Arabic. For example, Abu-Rabia and Taha (2006) examined the spelling errors of Arabic-speaking children in the first through ninth grades. In addition to the conventional phonological categories, their reference to the visual-orthographic category was limited to the similarity between letter forms alone. There was no reference to the other specific visual-orthographic features of Arabic that were the special focus of the present study such as ligaturing, allography, or non-linearity. Another factor that may explain the inconsistency in the frequency of phonological errors in this study's results vs. those of previous studies (such as Abu-Rabia and Taha, 2004, 2006; Abu-Rabia and Sammour, 2013) is the difference in the way the errors were categorized, specifically the classification of morphological spelling errors as phonological errors. For example, in our study, when a pupil wrote the word يصططيع ***/yasˤtˤat*ˤi:ʕ/** instead of يستطيع, */yastatˤi:ʕ/* "can," the errors were classified as morpho-orthographic, because they occurred due to a lack of reliance on the appropriate verbal word-pattern letters (see "Error Analysis" in the "Materials and Methods" section). In contrast, previous studies classified spelling errors of this type as phonological, as the phonological similarity between the emphatic consonants and their non-emphatic counterparts (e.g., ت/*t*/- ط/*tˤ*/, س/*s*/- ص/*sˤ*/), as well as the emphatic consonants, affect the boundary and/or neighboring syllables (This phenomenon of "velarization spread" is discussed in detail by Saiegh-Haddad, 2013). Hence, it is not surprising that their results showed that phonological spelling errors predominated over other error categories.

Within the broad category of visual-orthographic spelling errors, the most common error types were ligaturing errors and letter shape formation, each accounting for around one-third of all visual-orthographic errors across grades. The letter shape formation category had not been planned prior to conducting this study but emerged in the course of data coding. This category involving the addition or omission of an integral feature of letter shape (mainly the existence or absence of a small horizontal line, see examples in **Table 1**) was not discussed by Daniels and Share (2018) who focused on reading rather than writing. This type of error testifies to another dimension of difficulty (production difficulties) faced by the children in learning to spell. This error may also be a product of the high degree of similarity between many of Arabic's cursive letters. This high rate of shape formation errors may also be related to the fact that at the onset of literacy acquisition, teachers may not emphasize the importance of adding this small horizontal line to letters. An unexpected finding was the significant *increase* in the error rate across age in the combined visual-orthographic category along with the developmental change in *ligaturing* errors which also *increased* significantly from first to second grade. We suspect that this counter-intuitive increase may stem from the fact that the task was a written expression task – focused on meaning-making. None of the instructions mentioned the issues we addressed in our study, or even the subject of spelling or handwriting legibility. It seems possible, therefore, that in the higher grades, children invested more effort in the content of their productions than in the mechanics of writing, leading to an increase in error rates. However, in first grade, at the onset of formal instruction in reading and writing, instruction focuses on learning the principles of the Arabic writing system. Thus, it is reasonable to assume that the younger children placed greater emphasis on the "mechanics" and "technical" or non-meaning-making aspects of writing than the older children. If this is correct, this would parallel the initial instructional emphasis on the "mechanics" of decoding or the "technical" side of reading in Israeli reading instruction when children are first introduced to reading and writing. We predict that in a traditional "pure" spelling dictation task, the older children would give greater attention to "mechanics" and produce significantly lower rates of ligaturing.

Our study represents a first foray into dimensions of writing system complexity that have, understandably, been largely ignored in research on spelling in English and other Western European alphabets which have primarily focused on the issue of phonology, and, to a lesser extent, morphology. Arabic is often described as a unique writing system, but many of the visual-orthographic features that are pervasive in Arabic, can be found, in varying degrees, in many of the world's writing systems (Daniels and Bright, 1996), particularly the non-alphabetic systems which constitute a majority of the world's scripts. Thus, the present investigation is not merely an investigation of an exotic or exceptional script, but represents one of the first steps (see also Nag et al., 2014; Chang et al., 2016) toward understanding dimensions of writing system complexity that have largely been ignored until now. Furthermore, the present findings are clear that these additional (visual-orthographic) dimensions have non-trivial ramifications for acquiring basic skills that are essential for competent written language production.

Implications, Limitations, and Future Directions

The main pedagogical implication that may follow our findings is that more importance should be allocated to the instruction of the visual-orthographic aspects of the Arabic writing system that children find difficult (mainly ligaturing and shape formation) from the onset of literacy acquisition. This implication is supported by Treiman's (1993) conclusion that children can master and gain knowledge of the easy aspects on their own, but they need direct instruction regarding difficult aspects that they struggle with.

As indicated earlier, the present investigation is one of the first steps toward understanding the impact of Arabic's unique visual-orthographic features on the early development of spelling, so our emphasis was on examining the proportion of visual-orthographic spelling errors and their development across the three grades. We found that these errors constitute a significant proportion of children's spelling errors at least from Grades 1 to Grade 4 and possibly beyond. However, this study did not address other important factors involved in spelling, such as handwriting (Graham, 1999; Graham et al., 2002). Future studies should examine the role of handwriting and kinesthetic-motor skills in this class of spelling errors. Another issue which merits pursuing is the impact of these visual-orthographic spelling errors on the quality of reading and writing.

We also need to acknowledge that our study was based on only a single sample of children's naturalistic written productions. Future research will need to establish whether our results can be generalized to other genres of written productions. It is possible that certain types of errors – such as morphological or morpho-syntactic errors could be influenced by text genre (e.g., narrative vs. expository) but we see no reason to believe that the visual-orthographic errors which were the focus of this study would differ across genres.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

This study was approved by the Office of the Chief Scientist – Ministry of Education (permit #9667) as well as by the Research Ethics Committee of the Department of Education at the University of Haifa. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

DS conceived the study. RY recruited the children and collected the data. RY and YS-A coded and analyzed the data. RY, YS-A, and DS wrote the manuscript. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2020.02059/full#supplementary-material

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Early Context-Conditioned Orthographic Knowledge in European Portuguese: The Spelling of the Schwa

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This longitudinal study examined how the phonemic-orthographic context affects the spelling of the schwa (/ɨ/) by Portuguese beginning spellers at two time points in the first school grade. The schwa is phonetically unstable and phonologically ill-defined, has an unpredictable realization, is frequently deleted at the syllable's end, and is often spelt as <e>, a very high frequency grapheme with numerous phonological renditions. In addition to cognitive and other alphabetic tasks, 41 first graders were asked to spell 40 consistent words of medium-low frequency: 5 CV.CV (consonant, vowel. consonant, vowel) with well-articulated vowels; 10 C/ɨ/C.VC, the first vowel being a schwa, thereby creating potential phonological consonantal clusters, half legal (/fɨliʃ/, /fliʃ/), half illegal (/pɨdal/, /pdal/); 10 CV.C/ɨ/, the last vowel being a schwa, potentially creating phonological monosyllables half with a legal coda (/mɔlɨ/, /mɔl/) and half with an illegal coda (/n'avɨ/), (/nav/); in addition, the children spelt 15 CVC ending with /l/, /ɾ/ and /ʃ/, the only legal Portuguese codas. Participants were also asked to spell equivalent pseudowords at a second point in time. Our results show that children were sensitive to allowable letter patterns from the Time 1 assessment point. Although alphabetic spelling was not entirely mastered, children used <e> more in first syllables than at the end of the word, and more in illegal than in legal phonological consonantal clusters, although the pattern of significant differences did change over time. The results were similar for pseudowords. Also, children used <e> more at the CV.C/ɨ/ words whose last C was /l/, than in monosyllabic CVC words ending with /l/. This was not observed with pseudowords, where the grapheme <e> was used with a similar frequency in the two types of items. Overall, these results show that children's acquisition of this kind of context-conditioned orthographic knowledge occurs simultaneously with alphabetic letter-sound learning and depend largely on intuitive statistical learning reflecting the regularities of the written code to which they are exposed.

Keywords: spelling, context conditioned spelling, schwa spelling, spelling development, orthographic regularities, European Portuguese, early spelling

INTRODUCTION

At the beginning of formal schooling children rely heavily on phonology when spelling words, trying to match each sound they can detect in a word to a non-arbitrary letter (Caravolas, 2004; Pollo et al., 2005; Fernandes et al., 2008; Sargiani and Albuquerque, 2016; Chaves-Sousa et al., 2017).

Phonology is an essential component of early spelling and may be the most relevant information source when children begin the journey of making sense of how alphabetic systems work. Thus, learning the phonological underpinning of spellings and the relations between sounds and letters constitutes an initial key acquisition in spelling development. Accordingly, different accounts of spelling development agree on the idea that this phonological pathway is a core mechanism both for grasping the alphabetic principle (Treiman, 2017a, 2018) and developing the ability to spell correctly (Vale, 2000; Caravolas, 2004; Ehri, 2005; Barbosa et al., 2016; Albuquerque and Alves Martins, 2019; Treiman et al., 2019a).

Yet early spelling is not based purely on phonology (Caravolas et al., 2005; Treiman, 2017a; Treiman et al., 2018). Recent work (Treiman et al., 2019b) has shown that 3–6-year old Portuguese-speaking Brazilian pre-phonological spellers do not choose letters at random when writing letter sequences that do not represent any sound of the words they were asked to spell. Older children tend to use letters and digrams more frequently than younger children, in proportion to their frequency of occurrence in the texts to which they are exposed. Similarly, a comparative study showed that, corresponding to the orthographic features of Portuguese, 4–5-year old Brazilian children used more vowels and more consonant-vowel (hitherto referred to as CV) alternation than did US children (Pollo et al., 2009). These findings reflect young children's ability at a very early age to detect and extract letter patterns from inputs, and show that they may learn graphotactic aspects of writing, that is which sequences of letters go and do not go together, even before they learn how letters represent sounds (Treiman, 2017b). Taken together, the above-mentioned evidence raises the question of how children deal with these two sources of information (phonology and graphotactics) in early spelling, before either has been firmly acquired and therefore may compete with each other.

Sometimes orthographic patterns include letters that have minimal or no phonological support. For instance, in Portuguese the <e> in <mole> (soft) is not relevant for reading but represents the schwa in the word. The schwa may or may not be pronounced (respectively, /mɔlɨ/ or /mɔl/) depending on the speech rate. Essentially in colloquial speech rate the difference between the two oral productions is mostly undetectable without the use of the acoustic analytical techniques used in a speech laboratory. In this study we aimed to examine how soon Portuguese beginning spellers marked phonologically absent (or minimal) segments, such as schwas, that ought to be written if the canonical orthographic form of the word is to be preserved.

Phonological Information in Early Spelling

Most studies undertaken in different alphabetic orthographies find learning to spell follows similar developmental paths. Children typically progress from spellings that predominantly capture partial phonological patterns of words, to phonologically plausible complete spellings that are orthographically incorrect, before reaching a reliable capacity to produce the majority of standard correct spellings (Abreu et al., 2004; Ritchey et al., 2010; Bahr et al., 2012; Dich and Cohn, 2013; Sucena, 2017; Treiman, 2017b). There is also good evidence that these qualitatively different types of spelling can coexist and that beginning spellers can use different kind of orthographic knowledge, such as accurate written forms of specific words and graphotactic information (Martinet et al., 2004; Deacon et al., 2008; Conrad et al., 2013). Nevertheless, the phonological perspective on development emphasizes the idea that there exists a phonological foundation of spelling that requires the youngest spellers to conscientiously analyze word structure and select letters to represent it.

Studies of invented spelling show that children with little knowledge of letters and little alphabetic instruction create their own spellings using phonological information as an important base for choosing letters. The numerous examples in the literature regarding the use of letter names is an eloquent illustration of this. For instance, US kindergarten children may spell <cr> for *car* in which <r> stands for /ar/, the name of the letter <r>; or they may produce the spelling <t> for the non-word /tib/ which has the letter name /ti/, but be unable to spell any phonological structure of /mib/ or /feb/ which do not have letter names (Read, 1986; Treiman, 1994; Treiman and Tincoff, 1997; Read and Treiman, 2013). Comparable findings are to be found in research into other languages, such as French, Spanish, Japanese, Greek, Mayan (Fijalkow, 2007, journal special issue), and Hebrew (Levin et al., 2002).

Likewise, a similar significant proportion of phonologically motivated spellings has been observed in early spelling by Portuguese children. Five-year old kindergartners with very little tuition in written language but knowing some letters, would spell <HR> for the word *agarre* (/ɐgaR/-grasp) using the name of the first consonant (/ɐga/) and the sound of the second one (/R/), a phonologically high salient trill; the same children would spell <SD> for *sede* (/sedɨ/-thirst) where the first consonant name may be known as /se/ (there is another name too, /ɛs/) and the last consonant sound is /dɨ/, the latter possibly processed as a near syllable-like structure due to the schwa (Vale, 2000). Sargiani and Albuquerque (2016) verified that in a group of Brazilian kindergartners who knew an average of 20.6 out of 26 letters, 76.3% could represent some part or the entire sound sequence of words. Most of them (57.9%) used mainly letter names but also letter sounds (<dto> for /dedu/, finger; <kblo> for /kabelu/, hair) to assist their spellings.

In the same vein, a few studies of Portuguese first graders 3 months after starting formal alphabetic instruction (Vale and Cary, 1998; Vale, 2000) showed that children chose an appropriate letter significantly more often (81.8% of the time) to spell the first consonant of a word if it matched a full letter name (<p> for /penɐ/, feather) or was followed by a schwa (<p> for /pɨdal/-pedal) than if the letter did not have those features (64.7% of the time; /põtɨ/-bridge). Other studies of Portuguese speaking pre-literate Brazilian children have come to similar conclusions (Cardoso-Martins and Batista, 2005; Pollo et al., 2005).

In their initial attempts to spell, children sometimes mark letters that do not pertain to the written word (that often have an infrequent orthographic pattern) but that represent individual sounds in the pronunciation of the word. First grade Portuguese children may spell <tacsi> (instead of <táxi>) for /taksi/, using a graphemic pattern (<cs>) that does not exist in the Portuguese orthography (Vale, 2000). Portuguese-speaking Brazilian children spelt the sequence /ks/ in the non-word /fɔks/ as <cs>, <qs> and <ks>, all of which contravene standard orthography (Pinheiro, 1995). Treiman (1993) showed that these kind of sound-based graphemic substitutions linked to pronunciations also occur among English speaking children (e.g., <chruk> for *truck*, since *truck* and *chuck first* sounds are similar). These findings highlight the significant weight given to phonology among younger spellers.

Furthermore, Treiman et al. (2019a) have shown that beginning spellers do better on representing all the sounds in a word than on registering all its letters. For instance, if a child spells <bak> for *back*, the entire phonological sequence is represented but not the entire sequence of letters. Portuguese first graders at the beginning of the school year wrote 22.4% of consistent words in a phonologically-plausible complete form (<tor> for *torre*-/toRɨ/-tower), only 8.7% of which were orthographically correct (<torre>) (Vale, 2000). These findings concur with earlier research in California by Ehri and Wilce (1982) showing that second graders found silent letters significantly harder to remember than pronounced letters when shown a letter on a card and asked if it was in a word they had previously read.

When formal reading and spelling training begins, explicit teaching of phoneme and grapheme correspondences arguably strengthens children's capacity to use sounds in words to choose letters in spellings. Most Portuguese teachers state they use phonic methods (Spear-Swerling et al., 2016) which in children's first attempts to deal with the alphabet focuses their attention on letters and sounds. This agrees with data showing that early first grade Portuguese children can correctly identify 66% of consonant graphemes by their sound (Pedro et al., 2017) and about 88% of all letter sounds by the end of first grade (Duncan et al., 2013). Letter knowledge and phonological skills are well-known correlates and predictors of early spelling (Caravolas et al., 2001; Caravolas, 2004). Taken together, these two components explained 75.3% of the variance in Portuguese-speaking Brazilian first graders' spelling of a list of words (CVCV and CVCVCV) that included between one and three letter names each (Barbosa et al., 2016). In sum, the above-mentioned studies indicate that, in line with their counterparts learning to spell in other alphabetic orthographies, when Portuguese-speaking children begin acquiring their alphabet, they make substantial use of the sounds of words when spelling (Fernandes et al., 2008; Sucena, 2017).

One aspect of the phonologically-attuned way children ground their early spellings is that the phonological properties of the sounds contribute to the children's ability to represent them. Treiman et al. (1995) found that first graders had difficulty in spelling the nasal consonant segments in final consonant clusters, especially when preceding voiceless obstruents (e.g., spelling <vos> for /vans/). According to the authors, this difficulty reflected the fact that in this context the nasal consonant is a minimal segment that children may confuse with the nasalized vowel. Those children also tended to omit the liquids /r/ and /l/ in final consonant clusters (e.g., <pit> for /pIlt/), probably because these segments are phonologically close to the vowels and thus were processed as being part of it. Similar findings have been reported in other studies (van Bon and Uit De Haag, 1997, for Dutch; Read and Treiman, 2013). Syllable stress affects early spellings as well. Treiman et al. (1993) showed that first graders and kindergartners dropped unstressed vowels more often than stressed ones and omitted reduced vowels (schwas) with particular frequency. These evidences are not English specific, as the following examples in Portuguese will show, and they are particularly relevant to the current study that seek to examine how Portuguese schwas are processed by early spellers.

In Portuguese, there are only a few studies that have addressed the issue of the spelling of phonemes that are harder to isolate. A study by Miranda and Veloso (2017) of about 1,000 spontaneous texts written by Brazilian first and second graders showed that 77% of the observed errors in CVC orthographic syllables related to nasal vowels. The largest part of these errors concerned substitutions of /ẽ/ by /e/ (e.g., spelling <mega> instead of <manga>, /mẽge/-sleeve). This kind of orthographic error seems to indicate that, for those children, the nasal quality of the vowels was not clearly established and that these two vowels were phonologically processed as being similar to each other. Another study (Alves, 2012) showed that Portuguese first graders spelt orthographically-consistent fricative onsets more accurately than orthographically-consistent plosive ones. Fricatives are phonologically more accessible than plosives because the latter cannot be pronounced in isolation. Thus, fricatives may have been easier for children to identify and to learn to match with an appropriate letter (Byrne and Fielding-Barnsley, 1990; Kolinsky et al., 2018). There is also evidence that Portuguese schwas are challenging for beginning spellers. Rosa and Nunes (2010) presented first graders with oral sentences that included both a stem-word and its derived form containing a schwa (e.g., *martelo*, /meɾtɛlu/-hammer; *martelar*, /meɾtɨlaɾ/-to hammer), and asked them to spell the derived word. Children produced errors on 57% of the schwas, even though the derived words preserved the spelling of the full-articulated respective stem vowel.

The above-mentioned studies point directly or indirectly to the fact that, when beginning to learn how words are written, children largely rely on sound-related information that can be readily perceived, and experience difficulties in cases where sounds are harder to hear, to identify, to distinguish or to process in isolation.

Graphotactic Information in Early Spelling

Like it was briefly stated when presenting this study framework at the beginning of the Introduction, graphotactic regularities provide children with a very early means of shaping the information they need for spelling, as can be confirmed in the example of the respective proportions of consonant-and vowel-alternation in the letter patterns produced by pre-phonological spellers (Treiman et al., 2019b). Another aspect of graphotactic knowledge, sensitivity to legal combination of letters, is also apparent from very early attempts to write. Non-phonological features of the spellings of young US children already using phonology to support their productions include, for example, avoidance of spelling the doublets <hh> and <yy>, which do not occur in English (Treiman, 1993). Evidence also exists that US 6 year-olds more frequently spell double consonants in the final position than in the initial position of CVC items, in line with English orthography (Wright and Ehri, 2007). In the same vein, Gingras and Sénéchal (2019) showed that more frequent double consonants had a facilitative effect on French first graders' spelling accuracy: for each 1% growth in frequency, there was an increase of 0.65% in spelling accuracy. First graders are also aware of contextual features of orthography. Hayes et al. (2006) observed that children spelt the sound /k/ more often using <k> before <i> and <c> before <a> which reflects a regularity of English orthography. Pacton et al. (2005) reported similar findings with French first graders, who spelt <-ette> after <v> more often than after <t>, consistent with French orthography. Recently Gingras and Sénéchal (2019) found that silent letters reduced the spelling accuracy of French first graders by 6.49%, with those occurring more frequently (such as <tt>) being less prone to errors than less frequent ones (such as <dd>).

In European Portuguese there is strong competition between the grapheme <u>, whose name and sound is /u/, and the grapheme <o>, whose name is /ɔ/ but which is much more frequent in representing /u/ (Gomes, 2001). A study run with first graders (Vale et al., 2018) showed that, from the middle to the end of the school year, children significantly increased the use of the letter <o> to spell the sound /u/ (42.7–59.6% across different positions) reflecting the high frequency of the letter <o> to spell /u/ in Portuguese. However, children increased the error rates too because they bypassed the rule that when the /u/ sound is part of a stressed syllable it is always spelt with /u/, an overly sophisticated piece of knowledge for Portuguese beginning spellers.

Given the critical role of phonological information in tandem with graphotactic sensitivity effects in early spelling, it was of interest to investigate how Portuguese children begin the process of spelling schwas. In Portuguese, the schwa is phonetically unstable and phonologically ill-defined, has an unpredictable realization, and is frequently deleted at the syllable's end (Veloso, 2012). However, the schwa is a segment that occurs very frequently: in Porlex, a computerized lexical database of European Portuguese (Gomes, 2001), 40% of the words have at least one schwa. In addition, very frequent words, such as prepositions (e.g., *de*, /dɨ/, of; *que*, /kɨ/, that), pronouns (e.g., *ele*, /elɨ/, he), a multitude of different verb forms, and many nouns also contain it. The orthographic counterpart is that virtually all schwas are spelt with <e>, the second most frequent grapheme in the Portuguese orthographic system, and the third most frequent in word final position (Quaresma and Pinho, 2007). For instance, as the only three legal codas in Portuguese are /r/, /l/, and /ʃ/ (the exception being circa two dozen words that end with /n/ as in <glúten>, <cólon>), other phonological codas must be written adding an <e> after the consonant, as in *chave* (<chave>, /ʃavɨ/ or /ʃav/, key). Furthermore, out of six alternatives, the rendition of <e> as a schwa is the most frequent one (Gomes, 2001; Gomes and Castro, 2003). Schwas also occur in between consonants and this is another relevant characteristic of the Portuguese language to the present study. According to the theoretical principles of Portuguese phonology descriptions, onset clusters have no more than two consonants (CC) and only allow /l/ or /r/ in the second position (C+/l/ or C+ /r/). But, in fact, contrary to this phonological principle, when a schwa is theoretically supposed to occur in between two consonants, due to its non-pronounceable nature (Veloso, 2012, 2016) many words beginning with a Cɨ.CV structure are often produced as starting with a phonologically complex onset, an illegal one if C_2 is not /l/ or /r/ (e.g., *remetente*, /Rɨmɨtẽtɨ/ or /Rmtẽt/, sender; *pescar*, /p1Skaɾ/ or /pʃkaɾ/, to fish). Orthographically, this kind of "illegality" is not observed because the schwa in these words is always represented with an <e> which changes the phonological consonantal cluster into a written canonical CV syllable.

In view that the input to spelling given to children in this short-longitudinal study involves a sequence of phonemes where schwas are very unlikely, as it has been explained previously, to be conscientiously perceived, we aimed at examining if and when Portuguese first graders showed sensitivity to graphotactic contextual constraints by using <e> to represent the schwa. Would children more frequently use <e> in words where the theoretical schwa risked creating a phonologically illegal coda (e.g., /dosɨ/ or /dos/, sweet) than in words where it might create a legal one (/mɔlɨ/ or /mɔl/, soft)? Would children use <e> in the first syllable, where the theoretical schwa risked a phonologically illegal onset (/pɨdal/ or /pdal/, pedal) more frequently than when they perceive a legal onset (/fɨliʃ/or/fliʃ/, happy)? Would children's productions differ over time? As all the words used in the study to answer these specific questions had theoretical schwas, thus keeping the target phonological structure constant, the differences detected in the spelling of the <e> would improve our understanding of the relative unique importance of orthographic input on spelling development. In addition, as CV.C/ɨ/ and CVC items could be processed as phonologically similar we sought to examine whether children would add an <e> after a "true" CVC word (pseudoword). Again, the question concerns how, over time, inputs of letter patterns might shape the spelling of phonological codas (e.g., /l/) that can sometimes be part of orthographic C+ <e> sequences (e.g., <mole>, soft).

The relevance of this study is 2-fold: contributing to a better understanding of spelling development in European Portuguese and also contributing to learning how graphotactic context sensitivity interacts with phonological information in early phases of spelling development in an intermediate consistent orthography. In such an orthography we would expect to have alternative orthographic patterns for a number of phoneme sequences within a moderate ratio when compared to other orthographies. That is exactly what occurs in Portuguese when contrasted with French and Spanish. The phoneme-grapheme ratio is 1:1.9 in Portuguese, 1:1.4 in Spanish and 1:3.7 in French (Serrano et al., 2010).

TABLE 1 | Spelling conditions and examples of words and pseudowords used in spelling tasks.

Spelling conditions		N (W+Pw)	Words	Pseudowords
CV.CV orthographically consistent with two fully articulated vowels		5 + 5	<viga>-/vigɐ/	<niga>-/nigɐ/
C/ɨ/.CVC, first vowel being a schwa may create a phonological cluster onset (CCVC)	Legal onset	5 + 5	<feliz> /fɨliʃ/;/fliʃ/	<beliz> /bɨliʃ/;/bliʃ/;
	Illegal onset	5 + 5	<pedal> /pɨdal/;/pdal/;	<depal> /dɨpal/; /dpal/
CV.C/ɨ/, last vowel being a schwa may create a phonological monosyllable (CVC)	Legal coda	5 + 5	<mole> /mɔlɨ/; /mɔl/	<pole> /pɔlɨ/; /pɔl/
	Illegal coda	5 + 5	<nave> /navɨ/; /nav/	<mave> /mavɨ/; /mav/
CVC "true" monosyllables	/l/coda	5 + 5	<til>-/til/	<dil>-/dil/
	/r/coda	5 + 5	<cor>-/kor/	<nor>-/nor/
	/ʃ/coda	5 + 5	<luz>-/luʃ/	<fuz>-/fuʃ/

MATERIALS AND METHODS

Participants

A group of 41 first graders, of which 22 were girls, participated in the study. Children attended two parallel classes in the same school. At the first assessment point (December–January), 3 months after the school year began, their ages varied between 6;0 and 6;11 years, with a mean of 6;6 (standard deviation of 0;4). General cognitive ability scores ranged between percentiles 10 and 99, with a percentile mean of 44 (standard deviation of 26;13). The students were all native speakers of European Portuguese and information gathered informally from parents indicated that families had mostly low socioeconomic status, with the majority of parents having non-differentiated professions such as cleaners, craft workers, rural workers, or machine operators. Children with sensory or motor disabilities that prevented their autonomy and/or with a diagnosis of developmental disorder were not included. Teachers used an unsystematic albeit predominantly synthetic phonic method to teach reading and writing.

Tests and Tasks

In addition to the experimental spelling tasks, participants underwent a general cognitive ability test as well as having their letter knowledge and reading assessed in order to characterize their general cognitive and alphabetic profiles.

General Cognitive Ability

The Raven Colored Progressive Matrices—Parallel Form (Raven et al., 2009) was used. The test measures non-verbal general cognitive ability and is composed of three series of 12 items each. The maximum score is 36 points and scores were transformed into a percentile using Portuguese norms.

Letter Sound Knowledge

Letter Sound Spelling—In this task children were asked to spell from dictation 33 grapheme sounds [all the Portuguese phonemes except the four glides (Gomes, 2001)], eight of them requiring a complex grapheme (five nasal vowels and three consonants). One point was given for each correct answer. All the possible graphemes for representing a phoneme were accepted. The test was carried out both at the beginning and end of the study (hitherto referred to as T1 and T2, respectively).

Reading Level

Ten-Words reading task—This was a list of 10 highly frequent monosyllabic and disyllabic content words chosen from ESCOLEX (Soares et al., 2014), a computerized grade-level lexical corpus developed from Portuguese Elementary and Middle School textbooks. It was used to assess children's early reading ability at T1. Children were given one point for each correct production.

Word Reading Test —1 [Teste de Leitura de Palavras (TLP-1), Viana et al., 2014]—This is a standardized 30 single word reading test with 1st grade norms for accuracy. Item difficulty analyses were used to select words from an initial pool of 142 words. The test's psycholinguistic features are as follows: 17 short and 13 long words (above two syllables); 17 high-frequency and 13 low-frequency words; 21 regular and 9 irregular words (Chaves-Sousa et al., 2017). The test was taken at the end of the school year, at T2. The scores of TLP-1 are standardized ones.

Word and Pseudoword Spelling Tasks

Word spelling task—Children spelt a list of 40 words at T1 and T2. The words were selected from ESCOLEX (Soares et al., 2014). SFI (Standard Frequency Index) was used as an index of the frequency of first grade written words. SFI is a simply presented index derived directly from *U*, and thus takes into account the estimated frequency per million and the dispersion across different books. ESCOLEX also provides the percentile values for the statistical index of frequency.

Examples of stimuli per condition are presented in **Table 1**. There were four types (conditions) of words: (a) 5 CV.CV orthographically consistent disyllables containing two fully articulated vowels. These words were included to obtain a spelling ability baseline; (b) 10 C/ɨ/.CVC words. As the first vowel position (V_1) in these words was filled with a theoretical schwa, these could be processed as CCVC syllables. In half of the words, the schwa could prompt a phonological sequence where the first and second consonants would form a legal phonological (e.g., /fɨliʃ/, /fliʃ/) and orthographic (e.g., <fl>) cluster onset. In the other half, the schwa could prompt a frequently heard but theoretically illegal phonological cluster onset (/pɨdal/, /pdal/) that is never observed orthographically (e.g., <pd> is an illegal orthographic sequence); (c) 10 CV.C/ɨ/ words. As the last vowel position (V_2) in these words was filled with a theoretical schwa, these could be processed as CVC syllables. In half of the words, the schwa could motivate a phonological monosyllable (e.g., /mɔlɨ/, /mɔl/) that can be represented by an orthographically legal coda (e.g., <l>). In the other half the schwa could motivate a frequently heard but theoretically illegal phonological coda (e.g., /n'avɨ/, /nav/) that is never observed orthographically (e.g., there is no <v> codas).These schwas did not result from vowel reduction processes (observable in derived words) and therefore did not represent a subjacent fully specified vowel [for instance, knowing that *martelar* [/mɐɾtɨlaɾ/, /mɐɾtlaɾ/]—to hammer, should be spelled with an <e> to represent the schwa as the word derived from *martelo* [/meRtɛlu/]—hammer]; rather, they are phonological vowels *per se*, the European Portuguese empty "non-pronounceable" vowel (Veloso, 2012, 2016); (d) 15 CVC monosyllables, five for each of the three legal codas, /l/, /r/ and /ʃ/. "True" monosyllables were included in order to examine the extent to which children would place an <e> grapheme after the coda, and then to compare their use with that in the CV.C/ɨ/ (CVC) words.

The mean frequency across disyllable words containing two fully articulated vowels was in the $\geq 25 \leq 50$ percentile range. In each condition of the words with theoretical schwas (four: C/ɨ/.CVC legal and illegal onset; CV.C/ɨ/ legal and illegal coda; see **Table 1**) the mean frequency of words fell into the percentile range of $\geq 25 \leq 50$. A Kruskal-Wallis one-way ANOVA test showed that the distribution of frequencies was statistically equal for the different conditions [$H(3) = 0.976$, $p = 0.807$]. For the monosyllables, the mean frequency of words in each condition (three codas: /l/, /r/ and /ʃ/; see **Table 1**) was also situated in the percentile range of $\geq 25 \leq 50$ and the distributions of the frequencies were statistically equivalent [$H(2) = 0.857$, $p = 0.652$].

The spelling of the CV.CV words with two fully articulated vowels was scored two ways. One was the traditional method using the correctness criterion, with one point awarded for each word spelt correctly. As correctness may not be the best measure for reflecting beginning spellers' knowledge, because it neglects differences between a fully and a partially correct or a phonologically plausible spelling (Ritchey et al., 2010), we also used Letter Distance scoring, a non-binary measure based on the concept of string edit distance. Letter distance (LD) refers to the number of letter deletions, additions, and substitutions when comparing the child's spelling with a word's conventional spelling. Each deletion or addition is penalized one point and a substitution 1.4 points (Treiman et al., 2019a). For example, considering the word <tela> (screen), <el> was given 2 points (2 deletions), <vela> 1.4 points (substitution) and <tel> 1 point (deletion). Thus, the lower the score, the higher is the quality of the spelling. We computed the mean LD score across words written by each child.

Regarding the experimental stimuli, we used three scoring procedures. We used two non-binary measures to examine the children's ability to spell the items: the LD, as described above, and the Phoneme distance (Treiman et al., 2019a). Phoneme distance (PhD) is the number of transformations needed to convert the child's spelling into the closest phonologically plausible spelling of the word. As in the case of LD, there were penalties for substitutions (1, 4 points), deletions (1 point) and additions (1 point). For example, for the word <veloz> (fast), the spelling <velox> no points were deducted because <x> can be phonologically equal to <z> in that position, and <volo> was deducted 2.4 points (a substitution and a deletion).

In order to examine the spelling of the schwa with <e>, the aim of this study, we used Target scoring, awarding (a) one point for the <e> grapheme in each word if it occurred after a consonant in the correct position, even if the word was not entirely represented (e.g., <feli> instead of <feliz>, happy; <ave> instead of <nave>, spaceship); (b) one point for the <e> grapheme in each word even if the consonant was not accurately represented but the word structure was correct (e.g., <bedor> instead of <redor>, around). However, if the spelling seemed to be produced randomly it was given zero points (e.g., <pepo> for <ferir>, to hurt). It was also given zero points if the <e> was not written (e.g., <fliz> instead of <feliz> or <nav> for <nave>) or was not preceded by a consonant (e.g., <erire> for <ferir>). This last condition was taken out of caution. Given the schwa nature, to spell a schwa for its own sake, without the previous adjacent consonant, seems logically odd, suggesting the child would be using <e> randomly because of its high frequency and not because it represented a necessary orthographic feature.

Pseudoword spelling task—At T2, children were also asked to spell 40 pseudowords, in order to control for the potential impact of acquired lexical knowledge. Those were created by changing the first consonant or switching the consonants of a real word, while maintaining its phonological and orthographic features. The pseudowords scorings were the same as those used with the words from which they were built. **Table 1** presents the stimuli conditions and examples.

General Procedure

Children were tested twice in the first grade. They were tested in December/January, about 3 months after the start of the school year (T1) and again during the last 2 months of the school year (T2). All testing sessions took place in a quiet location in their own school.

At T1, there were two testing sessions of circa 20 and 45 min, respectively. In the first session, the Raven CPM-P and the Ten-words reading task were carried out individually; in the second session the Letter Sound Spelling and the Word Spelling tasks were administered. At the end of the school year (T2), a further two sessions were undertaken. In the first, lasting about 30 min, children individually underwent the Word Reading Test (TLP-1) and the Pseudoword Spelling task; in the second, the Letter Sound Spelling task and the Word spelling task were completed, together lasting circa 30–35 min.

The Word and Pseudoword Spelling tasks and the Letter Sound Spelling tasks were administered in small groups of between five and seven children. The stimuli were recorded and presented to children in a random order for each group using a laptop and speakers. All the words and pseudowords were presented in a colloquial prosodic manner, by a female voice. We emphasize that all the orthographically disyllabic experimental stimuli had theoretical schwas (C/ɨ/.CVC and CV.C/ɨ/) and that there is no context that makes its production or deletion predictable, although they are frequently deleted and considered "non-pronounceable" (Veloso, 2010, Veloso, 2012), specially when produced in a colloquial manner as we have presented them to children. As it was stated above, to distinguish between the production or non-production of a schwa in a word is very hard, or impossible, even for a trained person, let alone for young children with a very weak alphabetic knowledge.

When asked to spell the pseudowords, children were told they were invented words that could be spelt with the same letters as used with real words. A training item was used before the spelling task. For each spelling task children were given a lined sheet of paper with a number in each line and were asked to spell an orally presented item on each line as accurately as they could. Only when children had finished spelling one item would another be presented. The children's work was closely monitored in order to prevent them skipping lines.

RESULTS

Alphabetic Knowledge Level

Descriptive alphabetic profiles at T1 and T2 are presented in **Table 2**. As we can see, the children studied had only an incipient alphabetic knowledge at T1. They decoded and spelt less than half of the short consistent words. At T2 they performed at a typical level in the TLP-1 reading test and they significantly progressed from T1 to T2 in terms of representing sounds by letters, achieving very good, though not perfect, levels of consistent CV.CV word and pseudoword spelling. The children spelt words and pseudowords at the same ability level, as can be seen by one-way repeated-measures ANOVA [$F_{(1,40)} = 2.71$, $p = 0.108$], suggesting they were using a predominantly phonological alphabetic mode of rendering speech in written form.

Letter and Phoneme Distance Scores

Before analyzing the spelling of the schwa, we first examined the degree of proximity between the spelling of the items produced by the children and their conventional spelling (words only) and with its plausible fully phonological spelling (both words and pseudowords). The spelling correctness of the experimental words posed a bigger challenge to the children than the simple CV.CV words with fully articulated vowels. This occurred because there were words with a complex syllabic structure and because all had theoretical schwas. **Table 3** shows the LD and PhD scores obtained at T1 and T2 for the words and pseudowords containing a theoretical schwa.

As we aimed to verify the learning progression and compare the two distance scores a series of repeated-measures ANOVA were implemented. A two-way 2 (time: T1 × T2) × 2 (scoring procedure: LD × PhD) repeated-measures ANOVA was performed on the written productions. As expected, children spelt better in T2 than in T1 [$F_{(1,40)} = 67.96$, $p < 0.001$, $\eta^2_p = 0.63$] and obtained lower scores on Phoneme distance than on Letter distance [LD × PhD, $F_{(1,40)} = 410.33$, $p < 0.001$, $\eta^2_p = 0.91$], signaling that at these early phases of learning, strict alphabetic knowledge surpassed orthographic contextual and lexical ability. As expected, the difference between the scoring measures was larger at T1 than at T2 [time × scoring procedure: $F_{(1,40)} = 16.39$, $p < 0.001$, $\eta^2_p = 0.29$], reflecting increases in orthographic knowledge over time.

In comparing the words' syllabic structure, two two-way 2 (time: T1 × T2) × 2 (word structure: CV.CVC × CV.CV) repeated-measures ANOVAs showed that the two scoring measures (LD and PhD measures) revealed the same main effects. Spelling improved significantly over time [LD: $F_{(1,40)} = 67.64$, $p < 0.001$, $\eta^2_p = 0.63$; PhD: $F_{(1,40)} = 58.32$, $p < 0.001$, $\eta^2_p = 0.59$] and, at T2, PhD was close to zero for the majority of the words, indicating that children sought to represent every sound of the words better than at T1. CV.CVC structure was more prone to errors than CV.CV [LD: $F_{(1,40)} = 28.91$, $p < 0.001$, $\eta^2_p = 0.42$; PhD: $F_{(1,40)} = 37.31$, $p < 0.001$, $\eta^2_p = 0.48$]. This effect was qualified by time when using LD scoring [time × LD scoring: $F_{(1,40)} = 16.46$, $p < 0.001$, $\eta^2_p = 0.29$] reflecting the fact that at T2 there was no significant difference between word structures [paired-$t_{(40)} = 1.58$, $p = 0.123$]. With PhD scoring, the interaction was marginally significant [time × PhD scoring: $F_{(1,40)} = 3.99$, $p = 0.052$, $\eta^2_p = 0.09$] indicating that CV.CVC words were a little more difficult to spell at both T1 and T2 than CV.CV ones.

Pseudoword spelling, assessed at T2 only, was scored using the PhD criterion. The pattern of results for syllable structure was similar to the one obtained with words: the CV.CVC structure was found to be more difficult to spell than CV.CV one [paired-$t_{(40)} = 3.37$, $p = 0.002$, $d = 0.36$]. A one way repeated-measures ANOVA (lexicality: words × pseudowords) showed that pseudowords had lower scores than words [lexicality: $F_{(1,40)} = 5.70$, $p = 0.02$, $\eta^2 = 0.13$] suggesting that familiarity possibly helped to retain phonological strings in the children's memory, thereby increasing the accuracy with which the words' sounds were written when compared with pseudowords.

Spelling the Schwa With <e> in C/ɨ/.CVC and CV.C/ɨ/ Items

Statistical analyses of spelling the schwa with an <e> examined three main effects: Time, Schwa position, and Orthographic legality. The orthographic legality effect refers to the comparison of words (and pseudowords) that potentially could be processed as containing illegal as opposed to legal orthographic onsets or codas created by the theoretical yet non-pronounceable schwa (**Table 1**). As we aimed to compare scores at different conditions over time a series of repeated-measures ANOVAs were performed.

We calculated the mean <e> production across words written by each child under each condition (**Table 4**) which were analyzed using a three-way 2 (time: T1 × T2) × 2 (orthographic legality: legal × illegal) × 2 (schwa position: C/ɨ/.CVC × CV.C/ɨ/) repeated-measures ANOVA. The three main effects were significant [time: $F_{(1,40)} = 21.24$, $p < 0.001$, $\eta^2_p = 0.35$; orthographic legality: $F_{(1,40)} = 25.44$, $p < 0.001$, $\eta^2_p = 0.39$; schwa position: $F_{(1,40)} = 13.37$, $p = 0.001$, $\eta^2_p = 0.25$]. The analysis produced also a significant triple interaction [$F_{(1,40)} = 20.76$, $p < 0.001$, $\eta^2_p = 0.34$]. As our main aim was to

TABLE 2 | Scores on ancillary alphabetic tasks at T1 and at T2.

	T1		T2			
	M	**SD**	**M**	**SD**	***F* (1, 40)**	**η²**
Reading						
Ten-words reading CR	3.92	3.36				
TLP-1 (standardized score)			101.1	8.68		
Letter sound spelling**	12.19	6.04	27.83	4.03	387.53*	0.91
Word spelling***						
CV.CV-2 fully articulated vowels CR	2.32	1.66	3.76	1.28	41.37*	0.51
CV.CV-2 fully articulated vowels LD	1.37	1.15	0.42	0.53	45.05*	0.53
Pseudoword spelling***						
CV.CV-2 fully articulated vowels CR			3.44	1.47		

*$p < 0.001$; **33 maximum; ***5 maximum; M, mean; SD, Standard deviation; CR, Correct response; LD, Letter distance.*

TABLE 3 | Spelling means and standard deviations using letter distance and phoneme distance scorings.

		T1		T2			
		Words		Words		Pseudowords	
Spelling conditions		**M**	**SD**	**M**	**SD**	**M**	**SD**
C/ɨ/.CVC	Letter distance	2.49	1.30	1.11	0.81		
	Phon. distance	1.52	1.07	0.62	0.69	0.76	0.84
CV.C/ɨ/	Letter distance	1.66	1.09	0.96	0.45		
	Phon. distance	1.04	0.88	0.39	0.40	0.51	0.58
CVC	Coda /l/ LD	1.41	0.69	0.72	0.53		
	Coda /l/ PhD	0.84	0.76	0.24	0.33	0.24	0.33
	Coda /r/ LD	1.90	1.11	0.79	0.74		
	Coda /r/ PhD	1.17	1.19	0.37	0.54	0.36	0.53
	Coda /ʃ/ LD	1.94	0.66	1.13	0.55		
	Coda /ʃ/ PhD	1.43	0.81	0.25	0.38	0.25	0.38

LD, Letter Distance; PhD, Phoneme Distance.

examine if, and in what orthographic conditions, children spelt the schwa at the two Time Points and since an effect attributable to Time was detected, the data was subsequently analyzed using a two-way 2 (orthographic legality: legal × illegal) × 2 (schwa position: C/ɨ/.CVC × CV.C/ɨ/) repeated-measure ANOVA for each Time Point.

For T1, we counted all the vowels spelt in the <e> position across words in each of the four types of words with schwa, using the criteria mentioned for Target scoring. On average, children marked 3.4 vowels out of 5, of which 2.6 were <e>, showing that vowels were produced more often than not at the schwa position.

A two-way 2 (orthographic legality: legal × illegal) × 2 (schwa position: C/ɨ/.CVC × CV.C/ɨ/) repeated-measures ANOVA was applied to the <e> spelling. Children marked <e> more often in the context of the potentially illegal orthographic structure than in the legal context [legality: $F_{(1,40)} = 7.53$, $p = 0.009$, $\eta_p^2 = 0.16$] and an equivalent amount in each of the schwa positions [schwa position: $F_{(1,40)} = 1.42$, $p = 0.240$]. The fact that the interaction was non-significant [legality × schwa position: $F_{(1,40)} = 3.03$, $p = 0.089$] shows that more <e> were marked in the potentially illegal context in both schwa positions.

The same analyses were performed at T2. Except for the potentially legal context of CV.C/ɨ/, almost all the schwas were spelt and therefore all the effects were significant. Children spelt <e> more often in the context of the potentially illegal orthographic structure than in the legal context [legality: $F_{(1,40)} = 29.87$, $p < 0.001$, $\eta_p^2 = 0.43$]. They also spelt more <e> in the first syllable position (potential phonological CC onset: C/ɨ/.CVC) than in the final word position (potential phonological coda, CV.C/ɨ/) [schwa position: $F_{(1,40)} = 43.44$, $p < 0.001$, $\eta_p^2 = 0.52$]. The interaction [legality × schwa position: $F_{(1,40)} = 14.82$, $p < 0.001$, $\eta_p^2 = 0.27$] shows that the difference between legal and illegal contexts was larger in the final word position, which means that children considered the words that could prompt a phonological legal coda to be true codas [legality in final position: paired-$t_{(40)} = 5.07$, $p < 0.001$, $d = 1.07$] more often than they considered potentially legal onsets to be true complex onsets [legality in first syllable: paired-$t_{(40)} = 2.17$, $p = 0.036$, $d = 0.34$].

TABLE 4 | Means and standard deviations of the spelling of the schwa with <e> in C/ɨ/.CVC (CCVC) and CV.C/ɨ/ (CVC) stimuli and the spelling of <e> after CVC coda.

		T1		T2			
		Words		Words		Pseudowords	
Spelling conditions		M	SD	M	SD	M	SD
C/ɨ/.CVC (CCVC)	Legal onset	2.15	1.85	4.22	0.91	4.32	0.96
	Illegal onset	3.00	1.97	4.54	0.954	4.29	0.84
CV.C/ɨ/ (CVC)	Legal coda	2.66	1.79	2.27	1.91	1.83	1.88
	Illegal coda	2.88	1.50	3.98	1.19	3.70	1.20
CVC	/l/ coda	2.34	1.94	1.78	1.89	1.85	2.06
	/r/ coda	1.97	1.85	1.44	1.84	1.41	1.88
	/ʃ/ coda	0.70	1.15	0.39	0.77	0.70	1.38

Note: the maximum punctuation for each set of items was 5.

With pseudowords, as had been the case with words, a two-way 2 (orthographic legality: legal × illegal) × 2 (schwa position: C/ɨ/.CVC × CV.C/ɨ/) repeated-measures ANOVA was performed on the spelling of <e>. The pattern of results was comparable to that obtained with words. Children wrote <e> more often in the potentially illegal contexts than in the potentially legal ones [legality: $F_{(1, 40)} = 28.30$, $p < 0.001$, $\eta^2_p = 0.41$] and more in first syllable position than in word final position [schwa position: $F_{(1, 40)} = 53.63$, $p < 0.001$, $\eta^2_p = 0.57$]. The interaction [legality × schwa position: $F_{(1, 40)} = 28.05$, $p < 0.001$, $\eta^2_p = 0.41$] reflects the fact that the difference between legal and illegal contexts was significant in word final position as it was shown by a paired-*t* test [$t_{(40)} = 5.63$, $p < 0.001$, $d = 1.18$] but not in first syllable position where the schwa was represented with <e> independently of context's legality [paired-$t_{(40)} = 0.21$, $p = 0.838$].

When comparing the spelling of schwa with <e> between words and pseudowords a lexicality effect was observed [legality: *paired*-$t_{(40)} = 2.23$, $p = 0.031$, $d = 0.28$] showing that children spelt more <e> in words than in pseudowords.

Relations Between Alphabetic Knowledge and the Spelling of the Schwa

To examine the relationship between basic alphabetic knowledge and the spelling of the schwa, a series of zero order correlations as well as a regression analysis were conducted. Accuracy on reading, letter sound knowledge and spelling of orthographically consistent CV.CV words/pseudowords with two full vowels were correlated with the total amount of <e> produced by children to represent the schwa at each assessment Time point. In addition, general cognitive ability was also entered in order to test for its role in schwa spelling. None of the measures taken at T1 correlated significantly with T2 spelling of the schwa with <e> and thus only concurrent correlations of each Time point are presented in **Table 5**.

At T1 all the alphabetic task performances were significantly associated with the production of <e>. To further ascertain which of these early alphabetic measures could explain alone, or combined, the amount of <e> spellings to represent the theoretical schwas a multiple linear regression was carried out. Using the forward method, the regression model only kept the variable "letter sound spelling" which predicted 25.5% of the variance [$F_{(1, 38)} = 13.02$, $p = 0.001$, R^2 change = 25.5], removing the other two (consistent CV.CV words spelling: $B = 0.28$, $p = 0.07$; Ten-Words reading: $B = 0.037$, $p = 0.844$). At T2 only the consistent CV.CV word spelling obtained weak-medium significant associations with the total of <e> spellings in words, explaining 10.3% of its variance. The same pattern was obtained with pseudowords, as only CV.CV spelling accuracy explained 10.1% of the individual differences of the total <e>s produced. Cognitive general ability did not significantly correlate with the spelling of <e>s although there were significant correlations between this measure and the alphabetic task' performances.

Spelling an <e> After CVC Codas

We also examined whether children spelt the <e> grapheme after "true" CVC codas. As these analyses were run on a target structure of the words first we checked for children ability to spell the words using LD and PhD measures. A two-way 2 (time: T1 × T2) × 2 (scoring procedure: LD × PhD) repeated-measure ANOVA showed that, as had occurred with the other words, children significantly progressed from T1 to T2 [time: $F_{(1, 40)} = 85.98$, $p < 0.001$, $\eta^2_p = 0.68$] and their scores suffered fewer penalties using the PhD than the LD measure [scoring procedure: $F_{(1, 40)} = 253.41$, $p < 0.001$, $\eta^2_p = 0.86$] at both the time points [time × scoring procedure: $F_{(1, 40)} = 0.01$, $p = 0.920$]. We can see from **Table 3** that at T1 their spelling ability was incipient but at T2 their PhD score was close to zero, meaning they could represent most of the sounds of the words they were asked to spell.

At T2 pseudowords were also spelt. A one-way 3 coda type (Coda type:/l/ × /r/ × /ʃ/) repeated-measures ANOVA run on the PhD measure showed children were equally able to spell the different type of pseudowords [$F_{(2, 80)} = 2.15$, $p = 0.123$], as can be seen in **Table 3**.

In examining the production of <e> in CVC items, a two-way 2 (Time: T1 × T2) × 3 (coda type: /l/ × /r/ × /ʃ/) repeated-measures ANOVA applied to the mean number of <e>. The

TABLE 5 | Correlations between ancillary alphabetic measures and the total amount of <e> spelling representing the schwa at T1 and at T2.

Time 1—Words	**1**	**2**	**3**	**4**	**5**
1. Raven-CPM		0.201	0.382*	−0.118	0.297
2. Ten-words reading			0.641**	−0.390*	0.346*
3. Letter sound spelling T1				−0.419**	0.505**
4. CV.CV-2 full vowels CR T1					0.461**
5. Total of <e> spelling T1					
Time 2—Words	**1**	**2**	**3**	**4**	**5**
1. Raven-CPM		0.372*	0.354*	−0.117	0.211
2. TLP-1 (word reading)			0.651**	−0.575**	0.180
3. Letter Sound Spelling T2				−0.429**	0.031
4. CV.CV-2 full vowels CR T2					0.321*
5. Total of <e> spelling 2					
Time 2—Pseudowords	**1**	**2**	**3**	**4**	**5**
1. Raven-CPM		0.327*	0.354*	0.324*	0.115
2. TLP-1 (word reading)			0.651**	0.542**	0.060
3. Letter sound spelling T2				0.556**	0.017
4. CV.CV-2 full vowels CR T2					0.319*
5. Total of <e> spelling T2					

*$p < 0.05$; **$p < 0.01$; CR, Correct response.*

analysis showed that the frequency of addition of <e> after the last consonant did not change significantly with time [time: $F_{(1,40)} = 2.83$, $p = 0.095$] but it was not the same for the three codas [coda type: $F_{(2,80)} = 36.20$, $p < 0.001$, $\eta_p^2 = 0.48$] both at T1 and T2 [time × coda type: $F_{(2,80)} = 0.27$, $p = 0.739$]. Pairwise comparisons with Bonferroni adjustments revealed that the number of <e> was smaller for /ʃ/ than for /l/ and for /r/ ($p < 0.001$ for each case) which did not differ from each other ($p = 0.115$) at either assessment time point.

We also computed the mean number of the <e> graphemes that children wrote after CVC codas and the mean number of consonants in final position (codas) without the <e> grapheme across words by type of coda (/l/, /r/ and /ʃ/). These results were compared with paired-*t* test analyses for each coda type. At T1, there were more <e> after /l/and /r/ than final consonants but the differences were not significant [/l/: $t_{(40)} = 1.37$, $p = 0.178$; /r/: $t_{(40)} = 1.64$, $p = 0.109$]. For the /ʃ/ coda, children spelt significantly more consonants than <e> after the consonant [$t_{(40)} = 2.61$, $p = 0.013$, $d = 0.65$].

At T2, children spelt the coda more frequently with the consonant only than added an <e> after the consonant. The differences were significant for /r/ [$t_{(40)} = 2.63$, $p = 0.012$, $d = 0.79$] and /ʃ/ [$t_{(40)} = 9.95$, $p < 0.001$, $d = 2.78$] but not for /l/ [$t_{(40)} = 1.74$, $p = 0.09$].

At T2, children were asked to spell pseudowords. A one-way 3 coda type analysis showed that the frequency with which <e> was written after codas differed according to coda type [$F_{(2,80)} = 12.03$, $p < 0.001$, $\eta^2 = 0.23$]. Pairwise comparisons using Bonferroni adjustments showed that, as with words, <e> was produced with less frequency after /ʃ/ when compared to /l/ and to /r/ ($p < 0.001$ and $p = 0.017$, respectively). The spelling of <e> did not statistically differ when comparing /l/ with /r/ ($p = 0.07$).

As had been observed with words at T2, children marked more consonants in the final position, the codas, than they marked <e> after the consonant for each of the three codas. Paired-t analyses showed that these differences were significant for /r/ [$t_{(40)} = 2.61$, $p = 0.013$, $d = 0.78$] and /ʃ/ [$t_{(40)} = 2.56$, $p = 0.014$, $d = 0.64$], but not for /l/ [$t_{(40)} = 1.39$, $p = 0.172$].

At T2, CVC words and pseudowords were spelt with the same level of ability, as revealed by a 2-way 2 (lexicality: words × pseudowords) × 3 (Coda type: /l/, /r/ and /ʃ/) repeated-measures ANOVA using the PhD measure [lexicality: $F_{(1,40)} = 1.00$, $p = 0.323$]. Additionally, the coda type did not influence the quality of spelling [coda type: $F_{(2,80)} = 2.17$, $p = 0.121$] either in words or pseudowords [lexicality × coda type: $F_{(2,80)} = 1.00$, $p = 0.372$].

The frequency of <e> being written after the last consonant in words and pseudowords did not differ [lexicality: paired-$t_{(40)} = -0.98$, $p = 0.332$].

Spelling of <e> in CV.C/ɨ/ and CVC Items

All the CV.C/ɨ/ stimuli had /l/ as a last consonant (e.g., *mole* /mɔlɨ/-, soft). This is because in the Portuguese orthography there is only one very infrequent CV.CV noun that ends in a schwa after /r/ (<gare>) and two that end in a schwa after /ʃ/ (only one which could be considered as having medium frequency (<duche>-/duʃɨ/), but is a potential homophone of <dos>-/duʃ/-, "of the").

CV.C/ɨ/ stimuli having /l/ as last consonant were compared with the "true" CVC ones having /l/ as coda (e.g., *sul*, /sul/, south) regarding the amount of <e> children spelt in final position for each type of words. The frequency distributions of occurrence of the two kinds of words did not differ significantly ($U = 12.00$, $z = -0.104$, $p = 0.917$). The mean provision of <e> across type of words was compared using two-way 2 (time: T1 × T2) × 2 (word type: CV.C/ɨ/ × CVC) repeated-measures ANOVA. Children spelt a similar amount of <e> over time [time: $F_{(1, 40)} = 1.67$, $p = 0.204$] but more <e> in CV.C/ɨ/ than in CVC words [word type: $F_{(1, 40)} = 10.17$, $p = 0.003$, $\eta^2 = 0.20$] at both T1 and T2 [time × word type: $F_{(1, 40)} = 0.83$, $p = 0.369$].

A paired-*t* test run with pseudowords comparing CV.C/ɨ/ with CVC items revealed that, unlike the test performed on words, no significant difference was observed between the two types of structure in the frequency with which <e> was added after the last consonant [$t_{(40)} = 0.14$, $p = 0.888$].

DISCUSSION

The aim of this study was to examine how children in early phases of learning how to spell would cope with a specific task, that of orthographically representing the schwa.

The European Portuguese schwa (/ɨ/) is a very frequent segment that, at the phonetic level, has the lowest intensity and duration values, has an unpredictable realization and is often subject to deletion. At the phonological level, it is ill-specified (an empty vowel). This set of properties makes it "non-pronounceable" (Veloso, 2012, 2016). In current language production these features result in rearrangements of the words' syllabic structure that change simple onsets into complex ones (e.g., Cɨ in CɨCV words became a CCV structure), sometimes creating illegal Portuguese onsets (e.g., *pequeno*, /pkenu/, small) or changes CV syllables into codas, sometimes illegal ones (e.g., *nove*, /nɔv/, nine). In both circumstances, the pronunciation of the words with or without the schwa is not altered, or only minimally so, to the ears of a regular listener. In order to tell that a Portuguese schwa is being produced there is need for an in-depth highly conscious speech analysis and people often disagree about the result. Thus, this seems a precarious phonological basis for young learners to spell this vowel since research has massively shown that children beginning to learn to spell rely heavily on the speech "sounds" they can isolate in order to choose the appropriate letters to write (Treiman, 2017a). Moreover, many studies have also demonstrated that less accessible phonemes are more prone to spelling errors, often being deleted from written productions.

However, Portuguese children are frequently exposed to words with schwas both orally and, from the very beginning of schooling, also in written materials, as there are very frequent words that contain at least one schwa. Furthermore, the schwa is always written with an <e>.

In this short-longitudinal study, first graders were asked, 3 months after spelling instruction had begun and again at the end of the same school year, to spell words and pseudowords with different orthographic structures, some with schwas. Examining if and in what syllabic structures beginning spellers used <e> to represent the schwa provided further and deeper understanding the extent of the contribution graphotactic input makes to early spellings.

Descriptive results from the first assessment time point (T1) showed that children had only incipient alphabetic knowledge. On average, when asked to spell, they knew less than half of the sound-letter correspondences, they could only read four out of ten short frequent words, and the Distance scorings of their word spellings revealed they were able to represent roughly half of each word's letters. As expected at early phases of spelling development, children were better at representing the sounds of the words (with any possible letter) than their letters (the canonical orthographic form), and words with complex syllabic structure (CV.CVC) gave rise to more errors than words with simpler ones (CV.CV) in both Distance scorings. This indicates that children were trying, although with difficulties, to capture each sound of a word and producing the respective graphemic string via assembling phoneme-grapheme conversion processing. Other studies (Sprenger-Charolles and Siegel, 1997; Serrano et al., 2004; Fernandes and Martinelli, 2018) have found a similar pattern of performance in early spelling showing that, even imperfect, phoneme analyses and its grapheme correspondence explained a great amount of written productions. CV.CVC words, besides having a more demanding syllabic structure to analyze, are also longer than CV.CV words. The interaction between syllabic structure and phonological length at such an early phase of learning also impacts on spelling accuracy as was shown in a study recently run with Portuguese elementary school children (Mesquita et al., 2020) and also in previous ones (Serrano et al., 2010; Notarnicola et al., 2012).

In spite of their weak alphabetic knowledge, when spelling the words with schwa each child marked, on average, 13.68 out of 20 vowels representing the schwa, of which 10.69 were <e>. Thus, even at an early phase of their formal alphabetic learning, children tended to represent schwa vowels, mostly with the appropriate letter <e>. Since the schwa lacks phonological value, and the children's alphabetic knowledge was still incipient, this result is fairly surprising. In line with recent work (Kessler et al., 2013; Kessler et al., 2018, Kessler et al., 2019b; Treiman and Kessler, 2013), a statistical learning perspective on early sensitivity to letter patterns would seem to provide a plausible account of this finding. According to these authors children develop very early, from the initial exposures to written materials, an intuitive sense of fitting letter sequences, even when their phonological analytic abilities are minimum.

Interestingly, we observed that children used <e> more in the potentially illegal orthographic contexts than in the legal ones, both in the first syllable position (C/ɨ/.CVC) and in the final word position (CV.C/ɨ/). Since all the words in this comparison had schwas and children had been formally taught about written words for such a short time, this finding is also remarkable and concurs with the statistical learning perspective of spelling development mentioned above. From a phonological perspective, it is difficult to conceive that such a non-existent, or such a minimal amount of, acoustic information could provide children with the basis for attempting to represent an empty vowel at a point in their spelling development where phonemes are so hard to process. Alternatively, the idea that children could be using their lexical knowledge to spell the <e> in those words is hardly acceptable as an explanation. First of all, the words with potentially orthographically illegal patterns and those with potentially legal ones were equally frequent and thus lexical knowledge would theoretically be similar for the two kind of words; and secondly, since children spelt, on average, only half of the letters each word comprised, they were as yet unaware of how they were spelt. Rather, it seems more likely that those beginning spellers were already able to perceive certain prominent graphotactic regularities of their language's orthography, in line with the recent findings of Treiman and colleagues that show that knowledge of letter patterns may be the first source of children learning about orthographic regularities (Pollo et al., 2009; Kessler et al., 2013; Treiman et al., 2019b). This means that children have become aware that some letters "go together" and others do not, i.e., as early as 3 months into formal training in spelling, children were already becoming sensitive to which consonants are accepted as a cluster or a coda and which ones need a "silent" <e> in order to conform to graphotactic input.

Regarding the schwa position in the C/ɨ/.CVC structure, if the <e> is not spelt, a CC onset will result. Portuguese CC onsets are infrequent, constituting only about 5% of the syllabic structures [PORLEX (Gomes, 2001)] and, more crucially, with very few exceptions, the C_2s allowed are <l> or <r>. In addition, in 88% of the C/ɨ/.CVC words in PORLEX, the second consonant is neither /l/ nor /r/. This means that if the <e> is omitted in such words, the two first consonants would create an illegal onset. So, most of the time that there is a schwa in first syllable, children see a written form where there is an <e> between two consonants they never see as a written cluster. This suggests that while they have virtually no exposure to CC onsets other than C+/l/ and C+/r/, they frequently encounter C<e>C in word beginnings.

Concerning the schwa in the CV.C/ɨ/ words, a similar explanation is plausible. More than 50% of the Portuguese syllables are CV strings (Freitas, 2017), 81% of syllable types are open syllables and 71% of schwas occur in C/ɨ/ syllables (Gomes, 2001). Crucially, only /l/, /r/, and /ʃ/ are allowed as codas. Thus, by the time they were tested, children may have already noticed the dominance of CV structures (Treiman et al., 2019b) and the role of <e> as a resource to use when last consonants do not conform to their expectations.

The dominant role of the canonical CV structure is reinforced to a certain extent by the results obtained with "true" CVC words. When the codas were /l/ or /r/, children added <e> more than spelt final consonants only, although the differences were not statistically significant. The differences in both cases were nevertheless of medium size ($d = 0.39$ and $d = 0.44$, respectively) suggesting a possible trend to adopt the CV template, adding an <e> when what they had heard did not clearly prompt the use of any other vowel. However, when the coda was /ʃ/, the situation was reversed, with children marking more consonants only than adding <e> to the last consonant. The reason may be related, once more, to frequency. The coda /ʃ/ is the most frequent one in CVC monosyllables (Gomes, 2001) and some of the monosyllables ending in /ʃ/ are the most frequent in first grade textbooks. For instance, the words *mas* (but), *das*/*dos* (of the), *nas*/*nos* (in the), to name just a few, are all in the 90th percentile of frequency (ESCOLEX, Soares et al., 2014). Also, if we consider that virtually all plurals end in /ʃ/, orthographically represented by <s>, it is reasonable to claim that children have frequently been exposed to many instances where written words end with a consonant with the sound /ʃ/. This could also explain why, in all the analyses performed, the frequency of <e> in CVC items was lower after the /ʃ/ coda than after any other coda.

At the end of first grade (T2) children had more solid alphabetic knowledge. They read words at the typical level, according to a standardized reading test, and their spellings were closer to the established orthographic form. PhD scorings were close to zero, reflecting that children had become more skillful at spelling phonemic sequences. Scoring for PhD revealed that CV.CV words were easier to process than CV.CVC ones. In contrast, LD scoring showed that the two syllable structures prompted a similar level of difficulty. This difference between score measures was probably due to the fact that children produced more <e> in CV.CVC than in CV.CV structures. This caused the number of penalizations to converge in both syllables types in terms of LD scoring (i.e., more correct letters in CV.CV but more <e> in CVC.CV).

At T2 children also spelt pseudowords. As with words, CV.CV pseudowords were easier to spell than CV.CVC, replicating the pattern of results obtained at T1 and also the known effects of syllable structure/length mentioned above. Phoneme distance scorings showed that words were better spelt than pseudowords, indicating that lexical knowledge helped children, at least, to retain the phonemic sequences in their memories and then translate them into graphemic sequences.

Having verified that at T2 children could spell almost all the phonemes of the words and pseudowords, let's focus on our target issue, the spelling of the schwa. Compared with the first assessment, the quantity of <e> in written productions improved significantly at T2. However, even though all these words (CV.C/ɨ/ and C/ɨ/.CVC) contained theoretical schwas, children did not mark the <e> equally in all the orthographic contexts. Once again, they produced <e> more often in potentially orthographic illegal contexts than in legal ones. This suggests that, beyond phonology, graphotactic input was a critical source of information guiding children to spell the schwa, reflecting their knowledge about letter sequences. Supporting this perspective is the fact that children marked <e> more in words than in pseudowords, indicating that some of the <e> schwas they included in the words they wrote were based more on orthographic knowledge than on phonological information.

A different trend from T1 emerged however. Unlike T1, where the difference between illegal and legal orthographic contexts regarding the production of <e> was equal in both first syllable and word final position, at T2, the difference in the amount of <e> produced between potential illegal and legal orthographic contexts was greater in words' final position than in their first syllable. A similar pattern of results was observed with pseudowords, which rules out a putative influence of lexical knowledge in explaining differences between the two types of words. This pattern of results at T2 suggests that children perceived the words that could prompt a phonologically legal coda more often as true codas than they interpreted potentially legal onsets as true complex onsets. This would be a fair representation of the orthographic system features as it will be argued below.

The difference between <e> productions in words' first syllable and in final position mentioned above may reflect different aspects of the orthographic regularities to which children were being exposed. First, children marked an <e> more often in first syllables, where non-representing the schwa could potentially create complex onsets. In marking the <e> they maintained the initial CV structure. This concurs with the bias displayed by Portuguese children to often transform written CC onsets into CV structures (Vale and Cary, 1999; Santos et al., 2014; Mesquita et al., 2020). Transforming CC onsets in CV syllables is a more frequent error than deleting one of the consonants (usually the second). In a study by Vale and Cary (1999), first graders at the end of the school year inserted an <e> between the two consonants of a legal CC onset in 48.6% of their productions creating CV syllables (e.g., <cerus> instead of <cruz>, cross, or <celase> instead of <classe>, class). Santos et al. (2014) documented that this kind of spelling error lasts at least until fourth grade, adding that, when first graders are asked to spell "problematic consonantal groups," such as /pnew/ (<pneu>, tire/tire) or /aft*e*/ (<afta>, cold sore/mouth ulcer), they tend to insert an <e> between the two consonants more often than when the consonantal groups conform to phonological theoretical principles (C+/l/; C+/r/). Inserting <e> in between consonant clusters has been explained on the basis of a phonological restoration strategy children would use to preserve the canonical phonological CV input. By using this strategy, children would add a phonological schwa between the consonants and then would spell the schwa usually with <e> (Santos et al., 2014). However, these authors acknowledge that the addition of <e> in spelling is more frequent than the addition of the schwa in oral productions for the same children, which lessens the explanatory power of the phonological explanation. Thus, when spelling the words with schwa in C/ɨ/.CVC structures, the reason why the first graders in the present study tended to maintain the CV format by inserting the <e> was probably (as indicated above) that they were reproducing the CV syllable structure that they have noticed is so dominant in the Portuguese orthographic system, and not so much that they had detected an empty vowel. Crucially, children adopted this practice more often with the words that had the potential to prompt an illegal onset, suggesting that they perceived, as they had already demonstrated at T1, which letter sequences are more likely to be accepted. In addition, complex onsets are infrequent (5% of the syllabic structures) and children's spellings tended to mirror that orthographic trait. This line of explanation seems more plausible than the proposition that, at such an early stage of learning, children were able to detect a vowel with no phonological value so as to use it in spelling. Other studies have already documented young spellers' sensitivity to the occurrence of letter sequences and their specific positions in words (Cassar and Treiman, 1997; Pacton et al., 2001; Caravolas et al., 2005).

In the case of CV.C/ɨ/ items, children marked an <e> after almost all consonants that could be processed as illegal codas. Otherwise, the <e> was written only in half of those that could prompt legal ones. This was probably due to the fact that, in those legal contexts, all words ended theoretically with /lɨ/, being that the orthographic patterns <l> and <le> have similar frequencies in representing short words whose last consonant is a lateral one, as it will be discussed next.

Some Portuguese linguistic studies have shown that when there is place for a theoretical /ɨ/, the consonant that precedes the schwa has a longer duration than when the phonological forms have two consecutive consonants, even when the schwa is not produced. For instance, the difference between /kɨrer/ (to want) and /krer/ (to believe) would be the duration of /k/, observed in spectrographic analyses (Andrade, 1993). According to Veloso (2003) and Santos et al. (2014) these acoustic cues would also explain the differences between words ending in /ʃ/ and ending in /ʃ/+ <e>, as well as ending in /r/ and /r/ + <e> in Portuguese pre-literate children's segmentations of words in syllables and in written productions of literate children, even when those children did not produce the schwas orally. The same kind of explanation, however, does not seem to fit the /l/ vs. /l/ + <e> case since, according to Veloso (2003), Portuguese children do not process these two kinds of words with lateral consonants in any systematically different way. The mixed way in which children sometimes differentiate, sometimes do not between words ending in /l/ and those ending in /l/ + <e> led Veloso (2003) to suggest that, nowadays, the distinction between these two phonological contexts may no longer be relevant. At this light, the differences in the adding of <e> among coda contexts has a phonological explanation. According to Veloso (2003), the schwa has probably ceased being part of the children's phonological implicit knowledge in the context of the lateral consonant but it still remains in the other two contexts.

Again, these phonologically-based explanations for preliterate children and beginning spellers explicit processing of speech ought to be taken with caution. One reason is that, as mentioned above, for children without the support of orthographic knowledge, it seems reasonable to admit that the phonetic/phonological differences between produced or not produced schwas, and also between the acoustical length of a consonant followed or not followed by a schwa are difficult, if not impossible to detect explicitly. If it is difficult for an educated adult, Veloso himself (Veloso, 2003), to be sure about the production or non-production of a schwa, how can we expect that a beginning speller count such a non-pronounceable, elusive, probably deleted, segment as a "sound" to be written? It is well-established that the explicit representation of phonemes is the harder cornerstone of the alphabetic principle acquisition (Morais et al., 1979; Morais, 2018) and that schwas are hard to spell (Treiman et al., 1993; Rosa and Nunes, 2010). Moreover, it is not clear why the provided explanation by Veloso (2003) would work for /ʃ/ and /r/ but not for /l/.

The results obtained by Veloso, and indeed the findings of the present study, may have other, perhaps more plausible, explanations if we were to examine orthographic regularities.

Since CV.C/ɨ/ items sound as monosyllables in current language use, it is important to consider children written experiences with monosyllables. At the end of school year, first graders were already taught about final <V+l>, <V+r>, <V+s>, and <V+z> patterns. Thus, they had trained the spelling of several CVC words and they have surely noticed that the final consonants are virtually only <s>, <z>, <r>, or <l>. Although monosyllabic words are not frequent, some CVC words are very frequent [e.g., <ler> [to read], <ter> [to have]; <mar> [sea]; <sol> [sun]; <mil> [thousand]; see above for those ending in /ʃ/]. Except for a scant number of verbal forms that end in <re> [e.g., <pare> [stop]; <tire> [take it]] or with <che> [e.g., <feche> [close it]: <lanche> [a verb and a noun: snack]], the short words that end in /r/ or /ʃ/ are mostly written with a final consonant. Comparatively, there are more short nouns ending in /l/ that are spelt with <le>: <pele> (skin); <mole> (soft); <vale> (valley) and also several verb forms. Even a brief look at the ESCOLEX grade 1 written lexical database will confirm these differences. Thus, we have tallied 20 phonological monosyllables that, in singular form, end in /ʃ/ written with a final consonant (<z> or <s>), and two written as <che> (<feche> and <lanche>). We counted 21 phonological monosyllables that, in singular form, end in /r/ written with a final consonant (<r>), and three with <re> (<gire>, [spin]; <chore>, [cry]; <pare>, [stop]). Finally, we totaled 15 phonological monosyllables ending in /l/ in singular form written with a final consonant (<l>) and 13 written with <le> [e.g., <cole>, [glue]; <nele>, [in it]]. It is clear that children are exposed to different frequencies of CVC and CVC+ <e> orthographic patterns for the three legal phonological codas. Children's spellings in the current study for CV.C/ɨ/ and CVC items mirrored the pattern of CVC orthographic word endings found in their books: more spellings of /ɨ/ and /r/ without <e>, a mixture of spellings of /l/, some with, some without <e>; massive adding of <e> with other final consonants. Of course, first graders at the end of the school year are also acquainted with the final consonant of phonological disyllables and their written representation, being that the <le> pattern is more frequent than that of <re> or <che> (Gomes, 2001). An analysis of the frequencies of letters in the absolute final position shows that <s> is the fourth most frequent, <r> is the sixth and <l> is the ninth (Quaresma and Pinho, 2007).

Consistent with the above statements, by the end of the school year (T2), in contrast to the study's starting point (T1), when spelling "true" CVC items, children more often correctly left the final consonant alone, rather than adding an <e> after it, except when the final consonant was /l/. Importantly, as the frequency of written <e> after the last consonant in the present study was similar for both words and pseudowords, as were the orthographic effects referring to the different codas comparison, we may argue that lexical knowledge was not a determining factor for the differences observed among codas.

Thus, while we cannot discard the influence of phonology in spelling different codas of CVC items, we clearly need to take into account the frequency with which its specific letter patterns occur in order to better understand spelling development and the difficulties children may face. Each of these three Portuguese phonological codas may be spelt with different orthographic patterns (with or without <e>) and these results suggest that the frequency of their occurrence seemed to help the children to spell these types of words. The improved spellings at the end of the school year, with a lower incidence of <e> after "true" codas, except for /l/, indicates the growing role and importance of graphotactic sensitivity over time.

One last comparison was made in order to test whether phonology was the key support for spelling. A comparison of CV.C/ɨ/, where the last C was /l/ [/mɔlɨ/, [soft]], with CVC items, where the coda was /l/ [/sɔl/, [sun]], showed that children used more <e> in spelling CV.C/ɨ/ than in CVC words. Crucially, this did not occur with pseudowords, where a similar number of <e> was deployed in both types of items. This suggests that, when frequency was controlled (pseudowords), phonology appeared not to be the leading principle in spelling this specific kind of coda (the "lateral plus schwa" ending). On the contrary, these results suggest that, unless the word was known, children did not really know whether to mark or not the <e> after the /l/, because they had been exposed to a mixture of <l> alone and <l+e> to represent that particular phonological input.

In sum, Portuguese children showed significant sensitivity to orthographic input frequency beyond phonology information from the beginning of spelling development as it was observed by the pattern of <e> spellings to represent schwas in different orthographic conditions and in comparisons between CVC monosyllables ending in /l/ and CV.C/ɨ/ where the last C was /l/.

The children's individual differences in spelling the <e> graphemes to represent the schwas at T1 were significantly predicted by foundational alphabetic knowledge expressed by the ability to choose any appropriate letter to represent a phoneme (a letter sound). At T2 the spelling of the <e> was moderately associated with the ability to spell consistent short CV.CV items which involved mainly the use of the alphabetic principle, that is the knowledge about regular phoneme-grapheme correspondences. These results are interesting for different reasons. First, they indicate that the two types of knowledge, alphabetic, and letter pattern knowledge, may in fact be associated and second, they suggest that that association may change with development. The relationship between alphabetic principle knowledge and knowledge about allowable letter patterns is not yet well-understood. Some studies' results support the idea that there are moderate associations between the two skills (Conrad et al., 2013: Kessler et al., 2013) and, on the other hand, there are data that suggest that a dissociation could exist between the ability to attend to the appearance of writing and the skills to learn phonological based spelling (Treiman et al., 2019b). While it seems reasonable to think that when children spell or decode a word correctly this reinforces their knowledge about letter patterns and conversely when they apply their knowledge about letter patterns this improves their spelling, we believe the exchange between the two skills remains to be determined. Furthermore, the reciprocity between the two may differ with the letter pattern complexity. A letter pattern linked to word position may be easier to extract from input than a letter pattern linked to vowel stress and this difference may impact the relationship between alphabetic knowledge and letter pattern knowledge. The results of this study showed that early knowledge about how to represent sounds by letters explained 25% of variance of schwa spelling with <e>. It also showed that the strength of the association between the two type of skills decreased over time. This suggests that this type of context-conditioned letter pattern knowledge may depend largely on information beyond phonology-orthography correspondences that grows with exposure to written language.

Unlike basic alphabetic knowledge, general non-verbal cognitive ability was not associated with the <e> spelling suggesting that the implicit learning mechanism supporting graphotactic knowledge may be independent of intelligence (Siegelman and Frost, 2015). The low magnitude correlations observed between letter sound spelling and general cognitive ability were in line with several studies (Caravolas et al., 2001; Cardoso-Martins et al., 2001) showing, as the present study, that those associations did not translate to general cognitive ability being a significant factor of variance in spelling, which means that orthographic knowledge seems to involve more language and specific knowledge than a sound relation to intelligence.

Overall, this study showed that knowledge about letter patterns is gained very early in spelling development. As children did not spell the expected <e> in all the orthographic conditions, the findings of this study contributed to showing that when children begin to learn to spell, phonology is not the only support for their spelling efforts, even in an orthography of intermediate consistency, such as the European Portuguese one. In some conditions, for instance the spelling of the schwa, graphotactic learning plays a unique role from the very first attempts to spell. This result concurs with recent findings showing that the frequency of letter patterns has a facilitative effect on spelling accuracy beyond orthographic consistency (Gingras and Sénéchal, 2019).

Although the findings of this study are stimulating, it must be admitted that the study involved a relatively small sample of children mainly from relatively poor backgrounds. As foundational literacy achievement is related to family socio-economic status (Duncan and Seymour, 2000; Fluss et al., 2009; Buckingham et al., 2013) it seems worthwhile replicating this type of study with a larger and more diverse sample of children. Future research would also benefit from employing other types of manipulation of words and pseudowords such as for example, using the same consonants before the schwa and without schwa in order to control for consonant phonological length. Such studies would have theoretical and practical importance since they could better inform us regarding the main drivers of spelling development, as well as helping to identify more precisely the conditions most conducive to the facilitation and hindering of spelling acquisition. For instance, the content of intervention programs, like the Portuguese GraphoGame Fluent (Carvalhais et al., 2020) which has proven to be helpful in improving spelling levels of poor readers, would benefit from specific information such as the one shown in this study regarding the conditions more prone to elicit the schwa spelling errors. Also, the results we obtained clearly suggest that practice/exposure to written language is a powerful tool to learn about the orthographic system and thus teachers should be aware of the great value of systematic daily work with written language.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

AV designed the study, co-created the stimuli, conducted the literature review, analyzed the data using SPSS, and drafted and revised the manuscript. RP co-created the stimuli, collected the data, and co-analyzed the data using SPSS. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2020.513577/full#supplementary-material

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Supporting Acquisition of Spelling Skills in Different Orthographies Using an Empirically Validated Digital Learning Environment

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This paper discusses how the association learning principle works for supporting acquisition of basic spelling and reading skills using digital game-based learning environment with the Finland-based GraphoLearn (GL) technology. This program has been designed and validated to work with early readers of different alphabetic writing systems using repetition and reinforcing connections between spoken and written units. Initially GL was developed and found effective in training children at risk of reading disorders in Finland. Today GL training has been shown to support learning decoding skills among children independent of whether they face difficulties resulting from educational, social, or biological reasons.

Keywords: reading acquisition, dyslexia, intervention, digital learning game, GraphoLearn technology, GraphoGame, writing system, orthography

INTRODUCTION

Our experience with teaching alphabetic reading and spelling in a transparent writing system (Finnish) provides a basic model of how digital training can be used when instructing less transparent writing systems such as English. Our work demonstrates how learning can occur almost as rapidly in English as in Finnish.

The GraphoLearn technology (GL) is a digital learning environment that assists with literacy acquisition that can be applied globally. GL grew out of the Jyväskylä Longitudinal Study of Dyslexia (JLD), which followed children at familial risk for dyslexia from birth to adulthood (Lyytinen et al., 2006, 2009). The main goal of the JLD means to identify them prior to school entrance and learn to understand how to help children at risk for dyslexia [Lyytinen et al., 2007; Lyytinen, 2010; for a most recent summary, see Lyytinen et al. (2015b)]. Subsequently, the work developed GraphoGame (GG) to support at-risk children outside Finland with the research version called GraphoLearn (GL) adopted for several additional languages beyond Finnish. Once empirical effectiveness has established a specific language, the game is made available to the general public as GraphoGame (GG). Empirical validation for GL has been established in more than 20 languages (for publications on which this all is based, see https://info.grapholearn.com/research/publications/).

Upon completion of GL training, learners remember the connections between units of spoken and written language. In orthographically consistent written languages, students learn the sound represented by each letter (or graphemes of several letters). In contrast, for languages with less consistent orthographies at the phoneme–grapheme level (i.e., English), letters do not consistently represent the same sound requiring additional instruction. Association learning requires the use of consistent connections to be effective; thus, for the connections between oral and written English to be appropriately stored, substantially larger units utilizing rimes are required [see Ziegler and Goswami (2005)]. Using this approach, the GraphoLearn method has been empirically validated to support the development of reading and spelling skills in English (e.g., Kyle et al., 2013; Ahmed et al., 2020). Based on this research, we hypothesized that there are universal rules that are appropriate to learning, irrespective of the specifics of the writing system.

Richardson and Lyytinen (2014) describe the basic principles of how the GraphoLearn (GL) technology can be used. The successful effects of training basic reading and spelling skills have been documented in several research studies conducted in different countries and alphabetic orthographies varying in transparency. In countries with effective school instruction, GL is meant to help early learners who have reading/spelling acquisition originating from biological etiologies (dyslexia) as well as other compromising conditions (e.g., poor or no instruction, poverty, and lack of social support). This essential connection-building operation has been empirically validated to apply to almost any language. Longer instructional times are required for children with severe learning difficulties using GL. Moreover, typically developing children can acquire fluent reading skills in less time than usual instructional techniques.

Recent GL studies reveal that severe dyslexia is very difficult to overcome when intervention is started after the child has been affected by the related failures during the first semester (Ronimus et al., 2019). Thus, the optimal starting time is when children enter school. When adults motivate the child to use GraphoGame/GraphoLearn, successful learning is more likely to occur (McTigue et al., 2019). We have observed that the very same GL versions implemented with appropriate language content help learners in Africa [for a most recent review of studies, see Lyytinen et al. (2019a,b)] where instruction is not always optimal and who in Latin America are failing to learn to read due to insufficient social support (Ecochard, 2015), as the game keeps them engaged in training long enough to reach the goal.

ACQUISITION OF BASIC READING SKILLS IN TRANSPARENT WRITING ENVIRONMENTS

As noted, Finnish orthography has a straightforward relationship to spoken Finnish where a particular sound is consistent in all contexts. Thus, Finnish is extremely easy to master once the sounds for the 23 Finnish letters are learned. In Finland, approximately half of children learn to read before entering school without formal instruction. For the remaining children who do not readily learn to read, the use of the beginner's version of the GraphoGame (called Ekapeli Alku in Finland) helps them stay in pace with their classmates. Even a brief exposure to the program often results in significant reading gains (Richardson et al., 2011). The optimal use of this program includes starting at the time the learner enters school, when children tend to be most interested in developing their reading skills, which has been documented using stored data (i.e., detailed learning logs) from all users.

The main idea of the game is to motivate the learner to choose from (2–8) alternative letters (or letter sequences) the one which represents the sound the player is hearing at the same time through headphones. The trials these children play are analyzed using the correct/incorrect selections of the written item for each target sound (phoneme, syllable, or word). Additionally, the response times the learner needs for selecting the written item are stored to find out how the automatization is developing.

Using the collected logs, it has been possible to see that during a single day one third of the age cohort in Finland has been using the program. This number of users is observed close to the time children enter primary school. The use of the game also supports fluency of reading and spelling (Heikkilä et al., 2013), which makes it understandable that some of the players may have been second graders. Practically all Finnish-speaking children are accurate (but not necessarily fluent) readers already during the first school semester. However, even during the later months of the 1st grade as well as during the 2nd grade some children are still interested in using the program for acquiring more fluency.

While relatively short use of the game helps most children, those who have severe difficulties due to biological reasons need more time to overcome their problems. Most children using the GL in transparent writing environments in the developed world get sufficient help, preventively using it to follow the mainstream learning curve in the basic reading/spelling skills. This finding is true concerning children with dyslexia if GL is used when the child first begins school and the game is used for 10–15-min sessions (preferably more than one) per day for several weeks. Children facing severe difficulties most often require continuation until the third grade especially if the game is used only relatively infrequently (i.e., a few short sessions per week). This program is most effective when the game is used in the context of face-to-face remedial teaching. We have found that remedial teaching is strongly enhanced when the game is utilized as an addition to that remediation. Our studies have revealed that if the training game is used for at least a quarter of the time (10–15 min) the child is in the special education session, learners improve their spelling skills to the level of the mainstream children by the end of the third grade (Saine et al., 2010, 2011, 2013).

Our studies provide strong evidence that support with GL needs to start early in the primary school grades in order to be optimally effective. If learners start the program too early, the risk increases that the child may not be motivated to continue using it; they become bored with the task as too many repetitions are required before the goal is reached. This could be because many children with dyslexia have delayed brain development reflected by accompanying delayed development of spoken language (e.g., Lyytinen et al., 2015a); thus, starting this game too early may not be effective because the child is not ready yet to learn the connections without very numerous repetitions.

McTigue et al. (2019) conducted a metastudy of GraphoGame which provides additional guidance for teachers on the use of the game. These suggestions work in whatever orthography children are getting help *via* GraphoLearn technology, particularly with children with dyslexia.

Well-timed, the combination of GG and remedial teaching is highly effective with children with dyslexia because the game is highly enjoyable and focuses specifically on the individuals' "bottlenecks," areas which still need training (at an individual level), without spending precious time on irrelevant activities (i.e., which are not directly supporting the connection building). Decoding bottlenecks are overcome by continuing the repetition of tasks by concentrating on each aspect of difficulty separately (e.g., using so-called minimal-pair training when needed). Only 20% of the trials are chosen to be focused on contents where the learner tends to make repeatedly incorrect choices (i.e., getting thus negative feedback), to keep playing enjoyable. The crux of the program rests on positive feedback, to motivate the learner to continue practicing the task until the goal is reached. GL's effectiveness results from the real-time adaptation to every individual's actual needs rather than on traditional remedial activities that do not directly build the still compromised aspects of literacy-related skills for children who require remediation.

Thus, it is easy to understand that spelling has been found to improve more significantly using GL compared to typical remediation strategies used in special education classes (Saine et al., 2011). In contrast, spelling performance under solely traditional remedial teaching did not improve significantly by the end of Grade 3 (Saine et al., 2011). Main findings were that children with specific learning difficulties who were given an opportunity to replace such training with the game sessions (taking ¼ of the remediation time) reached the spelling level of their non-learning-impaired classmates.

The JLD study's findings have led to the development of this learning game. The JLD study revealed that about half of the children whose parent and his/her close relative had serious difficulties in learning to read had faced problems in early literacy. Our observations based on a very early (at the age of 3–5 days after birth) recording of event-related potentials (ERPs) revealed that when newborns were exposed to streams of sinusoidal sound pips which contained repeated standard stimuli (whose pitch was 1,000 Hz) with infrequently (12%) presented deviant sounds (of 1,100 Hz) revealing so-called mismatch negativity (MMN)-type response, we found a clear difference. Children with such familial risk who at the age of 8 years were typical learners showed reliable MMN to such deviant sounds as newborns. In contrast, the children belonging to the other half who were diagnosed with dyslexia at school age failed to show the same MMN pattern (Leppänen et al., 2010). This finding reveals that auditory insensitivity underlies a key bottleneck, making learning the earliest steps of literacy difficult (i.e., learning the sounds of the letters). These bottlenecks can be overcome with intensive use of GL (i.e., sufficient repetitive practice) as the learners are repeatedly taught to differentiate acoustically similar speech sounds (such as those represented by letters l, m, and n) as the logs reveal (Niemelä et al., 2020) and then connect these sounds reliably to their corresponding letters. This necessary first step is required to learn the basic reading/spelling skill in any transparent alphabetic orthography where the sizes of to-be-connected spoken and written items are small (i.e., single sounds/phonemes and letters/graphemes).

CONTRASTS BETWEEN TRANSPARENT WRITINGS AND NON-TRANSPARENT ENGLISH ORTHOGRAPHY

Transparent writing systems have received little attention in relation to more opaque or less consistent orthographies (especially English). While a substantial majority of reading research has focused on English, a majority of learners of alphabetic writings acquire literacy skills based on transparent orthographies. However, most reading research authors working and writing in languages with transparent orthographies (i.e., German, Italian, Spanish, and Finnish) continue to refer to research results based on reading acquisition of English. This practice continues although there is a huge difference between how English and transparent orthographies are learned. The crucial importance of phonological awareness problems, which is very central in English, is not comparably predictive in Finnish. When phonemic awareness is the most direct predictor of reading acquisition (referring here specifically to knowledge of the sounds of the letters or even well-chosen names of the letters), the predictive effect of typical phonological awareness measures disappears, as shown in **Figure 1**. The knowledge of letter names can predict how reading skill will be acquired with rapid naming, improving the prediction slightly.

Figure 1 reveals that reading acquisition in transparent orthographies mainly requires phonemic awareness (i.e., knowledge of the sound for each letter or grapheme of more than one letter). After the phonics knowledge of the letters of a word has been stored, the learner needs only to understand how to apply this knowledge to sound out each letter (or more than one letter grapheme) to read the sequence of letters. What is important to observe is that the early learner who has taken these two steps will be able to sound out whatever (pronounceable) sequence of letters he/she sees, independent of the length of the word or the meaning of the word. This generally results in letter-by-letter reading which may compromise the speed of the reading. If the speed of reading is then too slow, the child may have difficulty fully comprehending reading passages (even if the learner understands these words in the spoken form) due to working memory limits affecting comprehension.

Thus, the tendency of early learners of transparent orthographies to proceed *via* letter-by-letter reading/spelling leads to compromised literacy. This procedure leads to difficulties in following the meaning of the text, due to insufficient automaticity (i.e., fluency). Rapid reading makes reading enjoyable, as the child can then understand the content fully and without the need of using too much effort. Continuing to proceed using letter-by-letter reading often reduces motivation to do a sufficient amount of reading, a necessary precondition for reaching full literacy.

Learning to decode less transparently written orthographies often relies partly on meaning. This motivates the child to

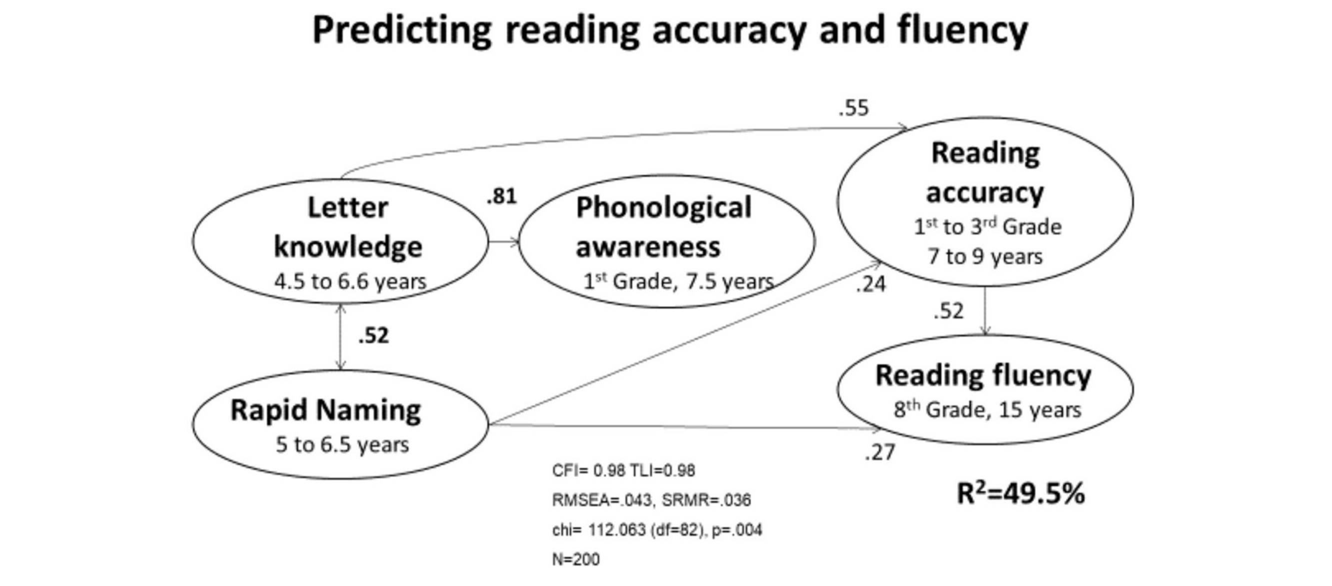

FIGURE 1 | Predicting reading accuracy and fluency.

read more because comprehension is reached faster after the decoding skill has been acquired to the level of sufficient fluency. Understanding such orthography-related differences guides the training of literacy skills and is important for successful learning in different orthographies.

When the child is beginning to learn to read, the focus is on decoding. This early focus means that one can learn to spell and read more rapidly in transparent orthographies, because the number of the to-be-stored letter sounds is, on average, ∼30 or fewer. In contrast, English has hundreds of connections between spoken and written units that need to be stored (Seymore et al., 2003). Consistent writing systems do not require the learner to know what a word means as it can be sounded out without such knowledge. The context in which the word occurs usually helps the learner to guess the meaning of a single unknown word (if the word is not in learner's spoken vocabulary).

It is important to note that in most languages including Finnish there are some aspects which are more difficult to learn than one would expect (Lyytinen et al., 2019a,b). Even typically learning children tend to make spelling errors associated with the variation of phonemic duration during the first grade. This aspect is the most difficult to learn in the spelling of Finnish. There are two phonemic lengths in Finnish: long and short, represented in their written form by repeating the letter when the sound is long. Thus, Finnish has words such as tuli (fire), tuuli (wind), and tulli (customs). The only differences appear in the context associated with repetition of the same letter. All vowels can have such a repetition. The same is possible concerning consonant letters k, l, m, n, p, r, s, and t. Related challenges usually require slightly more practice as the learner observes that one has to pay attention to not only the quality but also the duration of the sound, and for instance by sounding out the item silently to "hear" the difference to spell the word accurately for the context. Most Finnish-speaking children are sensitized to these differences (with exception of some children with dyslexia as illustrated in Richardson et al., 2003).

ORTHOGRAPHIC CONSISTENCY

As noted, accurate spelling of transparent orthographies is relatively easier to accomplish than that of less transparent ones. Because reading skill in non-transparent orthographies is acquired by relying on larger units stored in memory and requires acquiring orthographic word knowledge, learning becomes more demanding due to a larger number of the to-be-stored connections. This difficulty is naturally also reflected in the time needed for training the skill using GraphoLearn (GL) technology-based learning environments.

Approaching the learning of larger units such as rimes (e.g., "ong") in non-transparently written language provides more effective training than attempting to proceed *via* smaller units because consistent connections can be learned efficiently while practically no single letter behaves consistently in English. Kyle et al. (2013) found that the gains achieved by learning small units (phoneme-grapheme connections) using GL technology were 0.47 standard score (SS) points per training hour while implementing the connection-building trials using the larger rime units (see **Figure 2**) leads to gains of 0.68 SS points per hour. In non-transparent writing environments, such a connection-building approach between spoken and written units was shown to be more effective than has been achieved *via* the published traditional reading interventions offered by expert remedial teachers (as we have shown also to be the case in learning transparent writing among children with dyslexia). As mentioned, the change in learning to read English per intervention hour in rime-GL game was 0.68 SS units while the

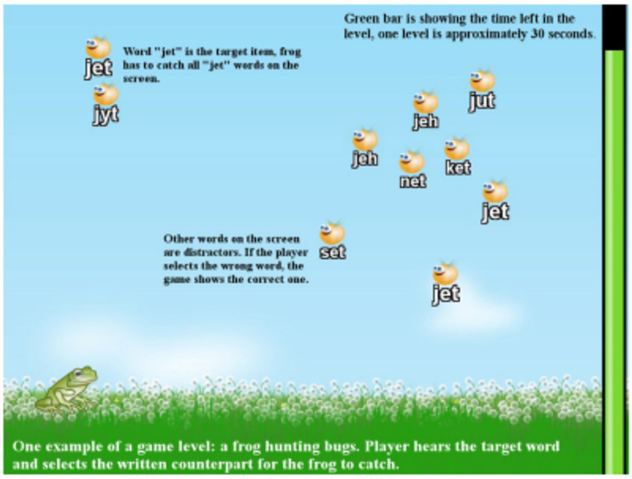

FIGURE 2 | Introducing connections between spoken and written in English in the GG.

comparable learning effect in a traditional intervention approach (Hatcher et al., 2006) reached gains of only 0.23 SS points per hour of training. Also, the traditional intervention was relatively time consuming and expensive. In contrast, in the GL intervention the children are training themselves, and a license to use the GG is inexpensive per learner. If licensing is made similar to that in Finland, as some kind of "state procurement," it would be free to everyone and would include support from top experts on reading instruction such as that provided by the Niilo Mäki Institute (https://en.nmi.fi/) in Finland. This kind of expert support has been required only a few times during the more than 15 years Ekapeli (the Finnish GraphoGame) has been available in Finland.

Some alphabetic writing systems are fully consistent symmetrically to both reading and writing directions while some others behave fully consistently only for reading or spelling (e.g., not to spelling direction). German is an example for which spelling of words is not fully transparent although the reading of words is transparent. This issue does not lead to any difficulties in implementing German content in the GL-based game. In fact, the use of this GL-based game is well-documented (e.g., Brem et al., 2010, Brem et al., 2013, Mehringer et al., 2020) and is likely to be soon in wide use in Switzerland as the German GraphoGame. Neuroimaging findings also support the use of this program where good decoding gains were associated with increased activation of key left-hemisphere ventral circuits important for fluent reading (e.g., Brem et al., 2010).

The GraphoLearn technology has also been documented as efficient in helping children in France (Ruiz et al., 2017) where GraphoGame has now been in wide use already for some time. Although French has a relatively non-transparent orthography for the reading direction, French learners have been shown to acquire reading skills faster than English-speaking children learn to read in English (Seymore et al., 2003). A critical difference concerns the higher consistency of sounds represented by vowel letters in written French which lowers the burden of learning of connections between spoken and written language. This is a good example of how the content of the to-be-trained connections defines what needs to be chosen for training.

A DETAILED DESCRIPTION OF THE GL-TECHNOLOGY LEARNING GAME

Figure 2 provides an illustration on how the game works when the to-be-learned connections are larger, as in the case of English. The general principle of training spelling skills using GL technology to support learning to read and spell English is that letter sequences such as ung, ang, ing, in, and ig are shown as alternatives on a display while the learner hears a sound such as /ing/ from the headphones during a trial. Such trials are repeated, helping the learners to store the most consistently behaving connections.

For a transparent orthography, the GL training usually begins with trials that contain target sounds (given *via* headphones) that are easily distinguishable phonetically (such as /a/ and /i/) so that these cannot be easily confused. At the same time, learners concurrently see on the display 2 to 3 alternative letters and must choose the one representing the given sound. The training trials progress to presenting sounds representing phonemes acoustically closest to each other such as those represented by letters l, m, and n. After minimal pairs of the items most difficult to differentiate are successfully learned, the next trials present a larger number of alternatives from which to choose, to assess the reliability of the learning. The next step is word assembly; the learner is shown written items containing sequences of several letters (forming a syllable or even a short word). With this approach, the learner begins to understand how the sounds of the letters correspond to the written stimuli when more than one letter is sounded out and assembled into a word represented by these letters. When such syllable or word-size item is presented orally as a target spoken unit, the learner succeeds by choosing the correct alternative; thus, s/he demonstrates an understanding of the alphabetic principle. This can (and has) been done for a variety of languages. In general, the processes included in the GL method demonstrate that the training supports accurate and fluent spelling not only of the smallest units (phoneme/grapheme) but also of syllables or words after the child has learned sounds associated with single letters as well as larger units.

In a sense, the game introduces a type of simple dictation task. It is made easier by requiring that the learner choose from the appropriate alternative written items the one that is spelled accurately according to the sound received from the headphones in each trial. This very simple principle is working for all levels; students learn of the connections, assembling the smallest items to form syllables and words and then developing fluency (speed) at each level. The final level—supporting reading comprehension—is under development.

In order to demonstrate the use of the GL method in transparent orthographies beyond Finnish, the following sections will discuss its application to Chinese, Japanese, and sub-Saharan

African languages. In these very dissimilar languages, the GL method has been shown to be helpful for children with and without learning problems.

SUPPORTING EARLY STEPS OF LITERACY LEARNING OF ASIAN ORTHOGRAPHIES

Chinese writing presents a different situation compared to European languages as the orthography is non-alphabetic. Chinese and Japanese have a consistent first step in written language acquisition by using a sound–symbol system to get children started. In Mainland China, such a first step is similar to alphabetic writing systems. Children learn to connect sounds and written alphabetic symbols; later, they will learn the characters used in writing. This system, Pinyin, is used to introduce children to principles of reading by teaching the Chinese sounds (phonemes) with corresponding Chinese symbols. Pinyin GraphoGame is in wide use in Mainland China after having been documented as effective (e.g., Li et al., 2016). Pinyin sounds to symbols can be easily acquired by using the GraphoGame (see (Graphogame.com) .

In Japanese, the Kanji writing system is close to Chinese characters, while Hiragana/Katakana writing behaves similar to Pinyin but uses larger units. This more alphabetic orthography, which connects spoken to written units, is used in Japanese to spell foreign names. The alternative way of using analogy for Kanji-related sounds or sounds of Chinese characters does not work as accurately in helping to sound out foreign names. Individual spellers frequently wind up using different ways to write the same names when Chinese characters or Kanjis are used for that purpose.

As the Pinyin system provides a close association with the way alphabetic writings work, so also do Japanese Hiragana and Katakana, which are almost the same as syllable-like units of transparently written alphabetic orthographies (i.e., instead of being represented by a sequence of several letters, here only one written symbol represents a syllable size sound unit).

Although Hiragana spellings may be the easiest to learn, the system is more limited than alphabetic orthographies. The use of the GL technology has been documented in an article published in Japanese (under the supervision of Uno Akira) but not translated into English at this time. Spelling in this system is as easy to learn as the symmetrically consistently written orthography of Finnish, which is illustrated in detail below. Skilled readers of Japanese must use both Hira/Katakana and Kanji writings in day-to-day reading in Japan. Chinese readers are using only Chinese characters (which are like Kanjis) without relying on the Pinyin system, which is used only as an introduction to reading skill. A different approach to reading is present in Hong Kong where Pinyin learning is not included in reading instruction. Children are generally exposed to alphabetic writing of English that connects written symbols to sounds, a comparable connection between written symbols and sounds which Pinyin introduces to Mainland children who are not exposed comparably to English.

As stated above, Chinese and Kanji symbols represent more than sounds. These languages may contain cues for sounding out words, bringing the reader often close to the meaning of the sentence because some of the symbols are similar to pictures (called pictographs) of the concepts they represent. Research is continuing using the GraphoLearn technology for teaching Chinese writing beyond the use of Pinyin, and it is currently being refined.

GL FOR CHINESE SPELLING

Compared to learning to read and write alphabetic languages, learning to read Chinese is much more of a challenge. The Chinese orthography is often described as logographic or morphosyllabic. The basic graphic unit in Chinese is a character. Each Chinese character, morpheme, and syllable share a one-on-one correspondence. There are about 3,500 simplified Chinese characters in daily use in Mainland China and about 4,500 frequently used traditional characters in Taiwan. While Chinese characters are well-known for their visual complexity, spoken Chinese has a relatively simple phonological structure. A syllable consists of an optional initial and final sound segment (e.g., onset and rime). Mandarin contains only 403 syllables, and the total number rises to about 1,200 distinct "tone syllables" when the four tones, or voice inflections—high, rising, low then rising, and falling—are taken into account.

The script–meaning relationship in Chinese is similar whereas the script–sound correspondence is arbitrary. One advantage of the logographic and morphosyllabic nature of Chinese is that the same script can be used with a large population in which people speak different dialects. The disadvantage is also obvious. Learning to read Chinese depends on memory and integration information about orthography, phonology, and semantic meaning of thousands of characters in the early stages of reading Chinese. Thus, schoolchildren in Chinese need a longer period to complete reading acquisition.

Considering the less reliable orthography–phonology connection in the Chinese writing system, Pinyin (a consistent and transparent phonological coding system) is used to provide the sound information of characters for beginning readers. The Pinyin system roughly corresponds in appearance to the Western alphabet. It represents single phonemes as in alphabetic scripts, but it is taught in a syllabic way, dividing a syllable into onset and rime. First graders in mainland China usually learn Pinyin in the first 8 weeks of school. Following initial instruction, Pinyin is written above new characters during reading for young children as they move on to character reading.

An increasing number of studies have shown that Pinyin instruction enhances both phonological awareness (e.g., Chen and Yuen, 1991; Cheung et al., 2001; Xu and Ren, 2004; Ren et al., 2006; Shu et al., 2008) and character reading (e.g., Shu and Liu, 1994; Siok and Fletcher, 2001; Lin et al., 2010) in Chinese children. Mastering Pinyin is a crucial component of Chinese literacy development in early school years (e.g., McBride-Chang et al., 2012). Children typically receive intensive Pinyin training for 10 weeks at the beginning of grade one (Wu et al., 1999). This typical 10-week Pinyin instruction may not be sufficient for children with poor reading skills, given that some children still experience difficulties in acquiring Pinyin skills at the end of the first grade (Li et al., 2016). In order to help these Chinese children, especially poor readers, to improve Pinyin skills, we have developed a Pinyin GraphoGame and examined the effects of it with typical intervention designs.

Li et al. (2016) provided an intervention for first graders who performed poorly with traditional teaching of Pinyin instruction as provided by their schools. These children used Pinyin GL-based game for a 4-week period. All played the game on computers at home. Compared to their peers in a control condition, the children in the training condition outperformed controls on both Pinyin reading accuracy and fluency. In another study, Li H. et al. (2017a) provided an 8-week period of having Pinyin GL available for first-grade children with poor Pinyin skills. This intervention improved Pinyin reading accuracy for all participants. Yue et al. (2019) made the Pinyin GLe intervention available for 8-week- to 6–12-year-old children diagnosed to represent both reading disabilities and ADHD. Results showed that the intervention improved the children's phonemic awareness and Pinyin recognition. These results indicate that the Pinyin GraphoGame is a cost-effective method to enhance Pinyin and literacy outcomes for underprivileged children in China.

Although the research discussed has provided evidence that Pinyin is beneficial to Chinese readers as a starting point, Pinyin is not a common writing system for formal documents. Chinese children must learn characters, and to do so they must store thousands of connections between the writing symbol and sound to accomplish basic reading skills. Successful Chinese character acquisition depends upon being able to activate and maintain three representations, visual (i.e., character), verbal (i.e., pronunciation of the character), and semantic (i.e., meaning of the character), and to form a new association between the first two in long-term memory. Indeed, it has been suggested that paired associate learning may be particularly important for children learning to read Chinese (Ho et al., 2006), precisely because of the relatively arbitrary nature of verbal–visual correspondences in the pronunciation of some Chinese characters, especially for learning to read irregular characters for which no clue to pronunciation is available.

The GraphoGame may be an effective intervention tool to effectively support Chinese children to learn the necessary basics for acquiring reading and spelling skills in Chinese. The development of this program will take time because the number of connections one has to store is many times larger than learners need for acquiring the skills needed in transparent orthographies. It is also substantially larger than required for learning the connections between spoken and written English.

GRAPHOLEARN RESEARCH OF READING AND SPELLING SKILLS IN AFRICA

In Africa, teaching reading and writing is interesting and complicated. Most African countries begin reading instruction using a carefully chosen language from the typically huge number of local languages in each country. The local Sub-Saharan languages have transparent writing, which frequently is present solely in written form in the Bible translated into the native language. Often, this language can be one language (such as Kiswahili in Tanzania) or several (such as the seven languages in Zambia that have been chosen to be used during first grades for teaching). These languages become the foci of reading instruction for these children with needs to be used for the initial literacy learning in home languages (Lyytinen et al., 2015a, 2019a,b).

Prior to 2000, teachers in today's Zambia were instructed to learn to read English at the beginning of their own school career. The result of this training is that many of these teachers, if not most of them, have not learned how to teach fully transparent African local languages. In English, the sound of a vowel can depend on the context for the word while in fully transparent in Sub-Saharan African orthographies each letter consistently represents only one phoneme in any context. Thus, in African orthographies reading instruction is built *via* the connection-building approach where the learner has sufficient exposure to the sounds of the language s/he is learning to read and the corresponding written units (Lyytinen et al., 2019a,b). The traditional reading instruction used in Sub-Saharan African countries is based on teaching English has not been successful teaching reading in a transparent orthography (Lyytinen et al., 2019a,b). Using this approach in Zambia has resulted in almost every learner requiring additional help to learn to read and write mainly because of the mismatch between teaching a non-transparent orthography (English) to teach a totally different type of orthographies (Sampa et al., 2018). As a result, very few children have learned the basic foundations of reading prior to third grade (i.e., the time when the reading instruction focusing on local languages ends), resulting in poor performance on the main measure of academic achievement; the Early Grade Reading Assessment (EGRA) (Sampa et al., 2018).

A very serious problem in many places of Africa is that the children in most need of help live outside large cities, making access difficult. The finding that practically all families own a sufficiently usable mobile phone in which the game works allows the game to be distributed. One challenge still remains, however. We need to find a way which would work for providing sufficient instruction to families and teachers on how to use the digital learning environment, especially in cases where families live outsides cities and do not have proper access to the Internet. For this reason, we are collaborating with internet network-building experts to provide guidance from a distance by well-trained experts in the country, such as those who conducted the validation research in each country.

For the purpose of providing experts in GL in Sub-Saharan Africa, together with the local experts we helped to create the Center for the Promotion of Literacy in Sub-Sahara (CAPOLSA) in the context of University of Zambia (UNZA) in Lusaka. At this center, there are several PhDs who have published the set of 3–4 international papers each according to Finnish standards for their PhD theses which they have defended in Finland. All of these publications are based on experimental studies made for validating of the efficiency of the game to support learners in learning to read. The experts in CAPOLSA are ready to help not only in Zambia but also in other Sub-Saharan countries.

Research conducted for one of the dissertations has found that illiterate parents are readily able to learn the basic reading skills in a manner similar to that through which their children learned using the GraphoLearn technology (Nshimbi et al., 2020). Thus, it may be that the impact of such a simple learning game, which works on inexpensive phones owned by most families in Africa, will involve entire families in the near future.

The GL system, tailored to the specific language, provides basic phonics instruction in a very concrete, consistent, and effective way using widely available, inexpensive mobile phones [e.g., Jere-Folotiya et al., 2014; see for a review of our related African studies, Ojanen et al. (2015a,b) and Lyytinen et al. (2019a,b)]. This program is most advantageous when children use the GL game at the same time as their teachers are teaching effective phonics instruction in their native language using the program (Jere-Folotiya et al., 2014). When the name of each letter is related to the sound of that letter (if chosen carefully as done in Finland), children readily learn to read when exposed to letters and sounds within the preschool class environment even when not taught formally how to read. When a child fails to store letter names under such conditions in preschool, s/he often face problems in learning to read (e.g., Lyytinen et al., 2015a). Ojanen et al. (2015a,b) and Lyytinen et al. (2019a,b) provide summaries of the results of African studies associated with the use of the GL technology. Following the validation of the program, the technology is now made available asGraphoGame (GG, see graphogame.com). It is hoped that this program will be implemented in more schools compared to the typical instruction used unsuccessfully in Zambia.

In a writing system such as that of Finnish or sub-Saharan African (e.g., Bantu) languages, the connections between spoken and written units behave consistently at the phoneme–grapheme (letter) level. The Finnish Ekapeli Alku (initial steps of the Finnish GraphoLearn) can be used to teach African local languages such as those belonging to the Bantu group because the sounds of the letters and syllables work the same way. Learning is made simpler if the instruction is organized by first learning letter names (but not those used in English, which is a misleading approach used in some countries of Africa). The names of letters in Finnish writing have been chosen to represent relatively close matches to the sounds of those letters. Typically, the letter symbols are present on the classroom walls of the preschool environments. Thus, these visual cues these letters represent encourage the child to wonder what these figures are called, which motivates them to learn the names of all such figures. These letter-figures often are connected to pictures of familial objects such as animals whose names children know. These figures are typically located next to the letters on the classroom walls in such a way that the child sees a picture representing a picture whose name starts with the letter adjacent to it. This practice ensures that children learn most of the names of the Finnish letters before entering school. Those few who have not learned them 1–2 years before they enter school at age 7 face more difficulty when learning basic reading skills (Lyytinen et al., 2015a). The JLD study has revealed that the age at which a child has spontaneously learned the letter names predicts accurately the time s/he needs for learning to read (Lyytinen et al., 2015a).

Because of the difficulties these Zambian children are experiencing, the GL-based research in Zambia has become a priority and a large number of studies have supported the program for instruction [see a review of the results, see Ojanen et al. (2015a,b) and Lyytinen et al. (2019a,b)]. Because of the difficulty these children are experiencing, we are moving as fast as possible from research to the distribution of the GraphoGame learning environment for which we have given rights to the Grapho Group Ltd company. The company now uses the name GraphoGame for the learning environment because the owners of the intellectual property rights (University of Jyväskylä and Niilo Mäki Foundation) transferred the rights to the company to provide international delivery of the digital learning environment. The strategy of the Grapho Group company is to distribute the game without seeking for profits to countries UNESCO defines as poor. Moreover, the company has agreed to make it available as widely as possible to all in need once the research has documented the efficacy *via* its GraphoLearn research process for any particular country/language. Therefore, the program (GraphoGame) will soon be available (e.g., in Tanzania and Namibia, after we have documented how GL can also most efficiently be delivered in rural Africa).

The next goal in Africa is to start using GraphoLearn technology for teaching second-language reading of English, French, Spanish, and Portuguese according to the prevailing preferences of each country. Naturally, the final goal of all reading is full literacy, comprehending different types of texts which one reads. This final version of the game is under development, first using the most widely spoken alphabetic languages.

USE IN LATIN AMERICA

Several ongoing projects at the Haskins Global Literacy Hub (HGLH) at Haskins Laboratories, a Yale University and University of Connecticut-affiliated research institute, have been exploring the efficacy of GraphoLearn in English speaking learners. In one NIH-funded treatment study, GL is paired with an in-school treatment program (EMPOWER developed by Lovett and colleagues) for remediating reading difficulties in children and uses neuroimaging at frequent intervals to better understand how treatment moderates brain circuits for literacy and why some children respond better than others despite similar behavioral profiles. A second study, also funded by the NIH, involves a larger number of children participating in the Healthy Brain Network study at the Child Mind Institute in New York, each with intensive gene-brain-cognitive profiling. The impact of GL on different subtypes of struggling readers with varied comorbidities is being investigated. Moreover, GL is serving an important function in three HGLH projects associated with the COVID-19 crisis. In one NSF-funded project (Pugh and Hoeft directors), GL is being used for groups of children at risk for the expected COVID reading slide (given up to 6 months during which students are unable to attend in-person schooling). Online reading assessments before, during, and after 12 weeks playing GL are assessing the mitigating effects of ED tech on reading. Finally working with GraphoGame, the HBLH has been able to provide free access to the game in the U.S. (English), Brazil (Portuguese), and Argentina (Spanish) during the COVID crisis. Thus, the use of GL to serve children at need is a major priority for the hub.

LEARNING TO SPELL NON-TRANSPARENT ENGLISH AS A SECOND LANGUAGE

In many, if not most, countries English is the second language a child learns. Typically, reading in English is taught through the use of whole words, a practice that has been successful in Finland. A learner who knows the sound and meaning of a spoken word in a foreign language can store the written form of that word. As an alternative way to learn to read a foreign language, our game program introduces reading in the foreign language using optimal phonics. In the game, whole words can be used together with smaller units such as rimes, following the more traditional method for learning to read a foreign language because these learners already have a level of phonological awareness, an understanding of the alphabetic principle, and a basic understanding of language (that it is made up of sounds, words, and phrases and sentences) from their native language.

Whole-word learning can be encouraged especially if the L2 reading starts later than first grade. At that point, the child is readily able to store spoken words, the meaning of which s/he has learned and can store the written word in one's lexicon. When the written word is presented together with the spoken word, young learners acquire the accurate sounding of the foreign word more easily than older learners, likely because they store the sound of the word simultaneously with the meaning. Thus, beginning to learn a foreign language begins early in life and learning to read using a phonetic approach. For this purpose, GraphoLearn technology is ready to be tried. Versions of English (e.g., Kyle et al., 2013), French (Ruiz et al., 2017), German (e.g., Brem et al., 2010), Spanish (Rosas et al., 2017), and Portuguese (e.g., Carvalhais et al., 2020) are available for GL studies for the support of learning to read a second language.

CONCLUDING REMARKS

We have developed GL-based learning tools supporting acquisition of the basic reading skills which can run on inexpensive smartphones and tablets (Android and iPhone/iPad) and computers using Windows and Mac operating systems. These tools have been shown to work in tens of countries to help children to learn to the basic reading and spelling skills. Beginning in 2020, more than 10 countries widely use the program under the label GraphoGame.

The new challenges associated with the validation research include countries like India that has a large number of different writing systems or China whose writing systems are exceptionally complex. Importantly, children in China and India also can use GL to help practice English as a second language, so that they can acquire basic reading skills of English much faster than with more traditional school instruction. This improvement, however, requires that they use GL/GG optimally. Excellent suggestions on implementation and usage of GG are available from the meta-analysis published by our Norwegian colleagues (McTigue et al., 2019).

When attempting to use GL/GG to help children with dyslexia, it is important to note that the training must be started prior to school entrance. Thus, whatever risk factors (such as familial risk, delayed development of spoken language, poor instruction, difficulties in storing the letter names) must be identified before entering school to be able to start preventive training at the optimal time. Using the GL learning environment as a dynamic assessment method during the 1st days of school if the child is at risk of familial dyslexia has been shown to be very successful for noting whether one needs it and at the same time for helping the child to learn (unpublished Zambian PhD thesis by Munachaka). The use of this dynamic assessment (DA) can be helpful for differentiating between educational insufficiencies or biological etiologies for reading difficulties. When there are poor instructional conditions, the use of DA soon reveals that children would be able to learn efficiently if instructed optimally, but if the learner is facing biological difficulties even a short use of the game as DA tool shows that the readiness of learning is compromised as shown by the mentioned data from Zambia. Children he followed for 6 years from school entry showed improvement despite poor teaching. However, when the GL-based dynamic assessment was used at school entry, it was shown that children with poor readiness to store the sounds of letters when using the game in DA mode did not progress in learning to read during the following 6 years of school instruction (i.e., could be defined learners with dyslexia).

If learning does not proceed relatively rapidly under GL/GG-based training during the 1st days of school, our recommendation is that the use of the learning game be continued for about 10–15 min sessions at least 2–3 times per day on consecutive days weekly. Its use is recommended to be continued at least until progress is made in the acquisition of the connections between spoken and written units so that the child feels her/his performance equals the progress of typical learners among the first grade classmates. This type of start may allow at-risk children to avoid facing negative learning experiences when they become aware that they are reading more poorly than their peers. Negative early experiences for reading acquisition affect not only training for literacy skills and interest in reading but also all learning in school. Our program is designed to avoid these secondary difficulties which can often lead also to emotional problems.

AUTHOR CONTRIBUTIONS

HJ wrote most of the text. MS-C cleaned it and made it written with perfect English. HL wrote the part which is associated with learning to read Chinese. KP helped adding content concerning the part of activity led by his network and accepted the content as it is. UR cleaned what she saw being in need of doing that. All authors contributed and approved the submitted version.

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