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The Impact of Promoting Transcription on Early Text Production: Effects on Bursts and Pauses, Levels of Written Language, and Writing Performance

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Writing development seems heavily dependent upon the automatization of transcription. This study aimed to further investigate the link between transcription and writing by examining the effects of promoting handwriting and spelling skills on a comprehensive set of writing measures (viz., bursts and pauses, levels of written language, and writing performance). Second graders were randomly assigned to 1 of 3 intervention programs aimed to promote handwriting ($n = 18$), spelling ($n = 17$), or keyboarding ($n = 20$) skills. These programs were implemented during 10 weekly units composed of 4 30-min lessons. The most reliable and robust differences were found between the handwriting and keyboarding interventions. Handwriting students displayed greater handwriting fluency, showed longer bursts and shorter pauses, and wrote longer and better stories than keyboarding students. This study supports the contention that transcription is critical in writing by leveraging several aspects of early text production. Specifically, a key finding is that handwriting seems to be causally related to increases in burst length, which is a cornerstone in allowing writing fluency.

Keywords: writing, transcription, handwriting, spelling, bursts

Writing is not simply speech laid down (Olson, 1994, 1996), but putting words on the external world necessitates a cognitive process that is commonly referred to as *transcription*. Transcription is the process through which individuals externalize language in the form of written text. It draws on the integration of the orthographic codes of letters and written spellings with the sequential finger movements required by a particular writing tool (e.g., pen, keyboard) to produce them (Abbott & Berninger, 1993). Therefore, transcription includes both spelling and handwriting (or typing). In adult writers, these processes tend to operate automatically, with minimal attentional requirements. This might explain why they went unnoticed in early cognitive writing models built on skilled writing (Hayes & Flower, 1980). Only when writing researchers turned their attention to the child writer was transcription pointed out as a fundamental process in the development of writing (Bereiter & Scardamalia, 1987; Berninger & Swanson, 1994; Berninger et al., 1992).

As will be reviewed next, there is now a substantial body of evidence documenting the key role that transcription plays in children's writing. Nonetheless, research should delve into this relationship more deeply—for instance, by assessing the impact of transcription on different aspects of writing in addition to overall writing performance. This was the main purpose of the present research, which examined and compared the effects of handwriting and spelling interventions on second graders' writing. We were particularly interested in addressing the effects of promoting transcription on a comprehensive set of writing measures, including real-time measures (viz., bursts and pauses), levels of written language (viz., discourse, sentence, and word), and writing performance (viz., text length, writing fluency, and writing quality).

The Role of Transcription in Children's Writing

During the last two decades, writing research has been accumulating evidence regarding the relationship between transcription

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and writing in children and adolescents with and without disabilities (for a review, see Graham & Harris, 2000). Two studies using large samples and powerful statistical techniques are worth mentioning. Graham, Berninger, Abbott, Abbott, and Whitaker (1997) investigated the contribution of handwriting and spelling to writing performance at two developmental points (Grades 1–3 vs. 4–6). They showed that, in younger and older students, respectively, these transcription skills accounted for 41% and 66% of the variance in writing fluency and 25% and 42% of the variance in writing quality. More recently, Limpo and Alves (2013a) studied the contribution of transcription and self-regulation (viz., planning, revising, and self-efficacy) to writing quality at two developmental points (Grades 4–6 vs. 7–9). Extending the results of Graham et al. (1997), they showed that transcription contributed to writing quality for both grade groups. Importantly, this contribution was found to be direct in younger students ($\beta = .60$) and indirect, via planning ($\beta = .15$) and self-efficacy ($\beta = .21$), in older students.

These results suggest that transcription is a major constraint to children's and adolescents' writing, as it requires sustained practice until becoming fully automatic. It follows that nonautomatic transcription processes impose heavy demands on writers' limited capacity of working memory, resulting in little spare resources for high-level writing processes, such as idea evaluation or language formulation (Bourdin & Fayol, 1994, 2000; Kellogg, 1996; McCutchen, 1996; Olive & Kellogg, 2002). Novice writers need to develop sufficiently fast and accurate transcription processes so they can engage in parallel processing; that is, activate transcription and high-level processes concurrently, as expert writers do (Alves, Castro, & Olive, 2008; Olive, Alves, & Castro, 2009). In support of the contention that transcription influences writing, intervention studies found that promoting automaticity in either handwriting (Berninger et al., 1997; Graham, Harris, & Fink, 2000; Jones & Christensen, 1999) or spelling (Berninger et al., 2002; Berninger et al., 1998; Graham, Harris, & Fink-Chorzempa, 2002) improves overall writing performance (for a review, see Graham, McKeown, Kiuhara, & Harris, 2012).

It is worth noting, however, that in these prior intervention studies, only the amount, fluency, and quality of writing were assessed. Relying solely on these overall measures provides an incomplete picture of the link between transcription and writing. Here, we examined and compared the impact of handwriting and spelling interventions not only on overall writing performance but also on distinct levels of written language. Research found evidence of intraindividual differences in writers' ability to produce text at the discourse, sentence, and word levels (Wagner et al., 2011; Whitaker, Berninger, Johnston, & Swanson, 1994). For instance, being able to create a text with coherently organized paragraphs does not ensure that writers are skilled at crafting syntactically correct sentences comprising appropriate and varied words. Assessing intervention effects according to the framework of levels of language is relevant, as holistic measures might not be sufficiently sensitive to discriminate instructional effects among them (cf. Limpo & Alves, 2013b). In this study, such fine-grained evaluation allowed us to scrutinize the link between transcription and writing and offered a hint at the mechanisms through which effective interventions might work.

Additionally, as promoting transcription is likely to influence the moment-to-moment production of a text, we also investigated the effects of handwriting and spelling interventions on real-time writing measures—namely, bursts and pauses. From a behavioral viewpoint, writers produce text through a linear succession of bursting activity interspersed by long production pauses, usually longer than 2 s. Bursts of written language were first noted by Kaufer, Hayes, and Flower (1986), who showed that adult writers compose texts by adding up segments of about nine words separated by pauses. Importantly, these segments were longer for professional writers compared to college students. Based on this pioneering study and others showing that language skill (Chenoweth & Hayes, 2001) and available working memory capacity (Chenoweth & Hayes, 2003) influenced burst length, Hayes (2009, 2012) proposed that a key source of bursts was translating; that is, the conversion of ideas into linguistic forms (see also Hayes & Chenoweth, 2006, 2007). Nevertheless, recent studies have shown that, when not automatized, transcription also contributes to burst length. Alves (2013) found that hampering adults' transcription skill, by asking them to compose with either an uppercase script or a shuffled keyboard, reduced burst length (see also Alves, Castro, de Sousa, & Strömqvist, 2007).

Studies with children provided additional evidence about the link between transcription, bursting, and writing. Alves, Branco, Castro, and Olive (2012) found that 9-year-olds with high handwriting fluency produced longer bursts than those with low and average handwriting fluency and that longer bursts were associated with better writing quality. Connelly, Dockrell, Walter, and Critten (2012) extended these results by showing that not only handwriting but also spelling were significant predictors of burst length in 11-year-olds and by replicating the positive correlation between burst length and writing quality. Recently, Alves and Limpo (2015) analyzed the relationship between transcription, bursts and pauses, and writing performance in Grades 2–7. They found that bursts increased throughout schooling and that both handwriting and spelling contributed to younger writers' burst length (Grades 2–4), whereas only handwriting contributed to older writers' burst length (Grades 5–7). Nonetheless, neither handwriting nor spelling contributed to the average duration of pauses longer than 2 s. They also found that longer bursts and shorter pauses led to greater writing fluency and better texts, thereby suggesting that bursts and pauses are key markers of writing efficiency.

These three studies provided compelling evidence that children's transcription skills influence burst length, which in turn influences writing performance. Still, it is an open question if it is handwriting, spelling, or both that are causally related to burst length. In other words, what causes bursts to increase during schooling? Here, to ascertain if the relation between transcription and bursts is in place in early text production, we used a randomized controlled intervention study. It seems that nonautomatic transcription constitutes a bottleneck that limits the number of words that can be written without pausing. As previously discussed, when not automatic, transcription may drain resources that cannot be used for other processes, such as keeping a linguistic segment temporarily active in working memory. This may force writers to interrupt their bursting activity and use pauses to reinstate the forgotten message. Thus, it seems plausible that promoting transcription raises writing performance by facilitating the ease with which children can transcribe linguistic segments held in mind, which should behaviorally manifest in longer bursts and shorter pauses.

Present Study

The main purpose of this research was to further investigate the role of transcription in children's writing. For that, we examined and compared the effectiveness of two intervention programs promoting second graders' handwriting or spelling. The handwriting intervention aimed to promote automaticity in orthographic–motor integration. Students received explicit instruction and practice in writing cursive letters, words, and sentences fluently and accurately, through activities in which they were asked to write the alphabet as well as to copy and generate words or sentences. The spelling program aimed to promote students' automatic access to the correct spelling of words, mainly by strengthening their knowledge about the Portuguese spelling system. Students received explicit instruction and practice in the alphabetic principle and its alternations (i.e., different ways to represent a single phoneme) as well as in complex spelling patterns (e.g., *ClV*- and *CrV*-type words). For that, students did phonics, word-sorting, and word-generation activities, in which they trained a set of words carefully selected to fit the content of the lesson. These same words were used in the activities of the handwriting program. In both the handwriting and spelling interventions, students were also provided with frequent composing opportunities.

The two interventions were compared with a keyboarding intervention aimed to speed up typing. This was a robust control condition for four reasons. First, these students received the same attention from instructors and were engaged in stimulating activities like their peers, thus controlling for motivational effects. Second, they wrote the same number of stories and on the same topics as the handwriting and spelling students, therefore controlling for the amount of writing practice. Third, each of the three conditions specifically addressed one transcription process, thereby allowing for precise inferences on the source of the expected effects. Fourth, keyboarding students received training in useful writing-related skills like their peers, thus complying with ethical requirements. This methodological choice does not imply any side taking in the debate about which writing modality should be favored in early schooling. We focused on handwriting because in Portugal, as well as in many European countries, handwriting is the first taught modality and the dominant one throughout schooling. Moreover, although training in handwriting or typing has been shown to improve writing (Graham et al., 2012; Morphy & Graham, 2012), these effects seem specific to the trained modality (Christensen, 2004). These modalities seem to be relatively independent, inclusively with recent studies showing differential effects on literacy attainment (James & Engelhardt, 2012; Longcamp, Zerbato-Poudou, & Velay, 2005).

Hypotheses

Before and after the interventions, all students were assessed on a comprehensive set of writing-related measures, including handwriting fluency, spelling accuracy, real-time measures (viz., burst length, short-pause duration, and long-pause duration), levels of written language (viz., discourse, sentence, and word), and writing performance (viz., text length, writing quality, and writing fluency). Next, we describe the expected posttest differences between conditions.

We anticipated that handwriting and spelling instruction would improve performance in the specific skills taught—in particular, that handwriting students would surpass their peers in time-constrained alphabet and copy tasks, whereas spelling students would outperform their peers in the number of correctly spelled words either in a dictation task comprising both consistent and inconsistent words or within the context of authentic writing (i.e., spelling in context). Several studies showed that interventions addressing handwriting (Berninger et al., 1997; Graham & Harris, 2000; Jones & Christensen, 1999) and spelling (Berninger et al., 1998, 2002; Graham et al., 2002) increase the automaticity and accuracy of these processes.

As mentioned previously, such an increase in transcription automaticity was found to allow child writers to transcribe linguistic segments more quickly and with shorter interruptions (Alves et al., 2012; Alves & Limpo, 2015; Connelly et al., 2012). We thus expected that handwriting and spelling students would produce bursts containing more words than keyboarding students. Evidence on the contribution of transcription to bursts is more consistent than that to pauses. It seems plausible that more automatic transcription, presumably by prompting parallel processing during bursts, should reduce young writers' need to pause. Still, results are mixed, probably because of the use of different pause thresholds. With a 2-s threshold, transcription did not predict pause duration (Alves & Limpo, 2015), but with a 30-ms threshold, children with poor transcription skills were found to spent more time pausing than their typically developing peers (Prunty, Barnett, Wilmut, & Plumb, 2013; Sumner, Connelly, & Barnett, 2013). The current study examined the effects of transcription interventions on the average duration of both short and long pauses, which were respectively defined as periods of inactivity between 30 ms and 2 s and longer than 2 s. In line with the aforementioned findings, we predicted that the average duration of short pauses made by handwriting and spelling students would be inferior to that of keyboarding students. Short pauses seem more sensitive to differences in transcription automatization since they are thought to reflect handwriting and spelling processes, whereas long pauses presumably reflect high-level processes (Alves et al., 2008; Wengelin, 2006). The latter were thus expected to remain uninfluenced by the interventions.

By promoting transcription automaticity, both interventions should reduce the cognitive effort required by transcription processes during composition, allowing spare attentional resources to be used for high-level processes (Bourdin & Fayol, 1994, 2000; Kellogg, 1996; McCutchen, 1996; Olive & Kellogg, 2002). Devoting more attention to these processes, which may include generating and organizing ideas, transforming ideas into language, or evaluating both the ideas and the produced text, is likely to result in enhanced writing. We therefore expected that, compared to keyboarding students, handwriting and spelling students would write texts with more text elements (discourse level), longer clauses (sentence level), more diverse vocabulary (word level), greater text length, and better writing quality. The inclusion of repeated composing opportunities in both programs should be particularly critical for transferring the taught skills to text production. Actually, the absence of composing practice in other transcription programs may explain why some failed to raise writing quality (e.g., Graham & Harris, 2000; Graham et al., 2002).

As bursts of written language were found to be a fine-grained measure of writing fluency (Alves & Limpo, 2015), the increase in burst length, expected in the handwriting and spelling interven-

tions, should be reflected in the number of words written per minute. Consequently, we predicted that handwriting and spelling students would display greater writing fluency than keyboarding students.

Grounded on research showing that, compared to spelling, handwriting has stronger associations with bursts (Alves & Limpo, 2015), levels of written language (Wagner et al., 2011), and writing performance (Graham et al., 1997), we expected that the hypothesized intervention effects in these measures would be stronger for handwriting than spelling students.

In addition to the previous measures, which were collected in handwriting modality, at posttest, we also assessed the typing fluency of all students using the alphabet and copy tasks. This was meant to confirm that the keyboarding intervention improved the targeted skill. We expected that keyboarding students would surpass their handwriting and spelling peers.

Contributions to Extant Research

One of the main contributions of the current study was the examination of the comparative merits of handwriting and spelling interventions. In addition to the few findings regarding the relative contribution of these skills to writing, no intervention study has provided a direct comparison between transcription interventions. Questions remain unanswered as to whether they impact the same aspects of writing and to a similar extent. Also, importantly, this impact was assessed not only on overall writing performance but also on writing as it unfolds in real time and on different levels of language. Such fine-grained analyses may shed light on the role that transcription plays in children's written composition and contribute to the development of interventions tailored to their needs. Crucially, this study focused on typically developing writers (i.e., children not struggling with written language) who have been far less involved in transcription interventions than struggling writers (Graham et al., 2012). Despite the importance of supporting students with poor transcription skills, teachers should also have at their disposal evidence-based practices to boost transcription in full-range students attending regular classrooms.

Method

Participants and Design

All second graders enrolled in a public school in Porto participated in this study. These 71 Portuguese native speakers were randomly assigned to three conditions: handwriting, spelling, and keyboarding. Among these students, there were nine students enrolled in educational support programs who were not eligible to participate in the current study because they were qualified as being at risk for writing difficulties. Due to ethical concerns and as negotiated with the school principal, these students received the intervention along with their peers (two, four, and three students participated in the handwriting, spelling, and keyboarding conditions, respectively). However, data were not collected for these students.

Among the 62 students who qualified for inclusion in the study, there were 21 in the handwriting condition, 20 in the spelling condition, and 21 in the keyboarding condition. Six of these students were dropped from data analyses because they missed a pretest session or more than 15% of the program's lessons (three handwriting students, two spelling students, and one keyboarding student). One additional student from the spelling condition emigrated during the intervention. To determine if these seven students differed from the remaining participants in some significant way, all available information for these children was examined. Their chronological age, mother's educational level (used as a proxy for socioeconomic status), and school marks for Portuguese and mathematics, as well as their pretest scores on handwriting fluency, spelling accuracy, real-time measures, levels of written language, and writing performance, were similar to those who remained in the study. In all of these measures, dropped students scored within ± 1.5 *SD* of the average of the whole group.

Information on the characteristics of the final sample ($N = 55$) by condition is displayed in Table 1. The three conditions did not differ on gender distribution ($\chi^2 < 1$), students' chronological age ($F < 1$), mother's educational level ($\chi^2 = 9.62$, $p = .14$), and school marks for Portuguese ($F < 1$) and mathematics ($F < 1$). Additionally, no pretest differences were found between conditions in any of the analyzed measures (Fs < 2.75, ps $> .07$).

Instructional Context

Portuguese spelling system. Portuguese orthography is best characterized as having intermediate depth (Sucena, Castro, & Seymour, 2009). Portuguese is a romance language with a simple syllabic structure—predominantly open *CV*—and several instances of orthographic inconsistencies and complexities (Seymour, Aro, & Erskine, 2003). Seymour et al. (2003) found that, by the end of first grade, the reading results of Portuguese children were not at ceiling, as typically found in European shallow orthographies such as Italian or Finnish, but were in the range of those shown by French and Danish children. Portuguese children read correctly about 75% of the words and nonwords presented, which contrasts with the 98% accuracy level of Finnish children

Table 1
Demographic Data for Participating Students by Condition

Measure	Condition		
	Handwriting	Spelling	Keyboarding
Gender (*N*s)			
Girls	11	10	11
Boys	7	7	9
Age (in years)			
M (*SD*)	7.5 (.4)	7.5 (.5)	7.5 (.4)
Minimum to maximum	7.02–8.7	6.87–8.70	6.90–8.81
Mother's educational level (%)			
Grade 4 or below	6	6	0
Grade 9 or below	12	35	50
High school	33	24	20
College or above	50	18	20
Unknown	0	18	10
School marks (1–5)			
$M_{\text{Portuguese}}$ (*SD*)	4.3 (1.1)	4.3 (1.0)	4.3 (1.1)
$M_{\text{Mathematics}}$ (*SD*)	4.5 (.9)	4.5 (.9)	4.4 (1.0)

Note. Mother's educational level (%) is used as an index of students' socioeconomic status. For school marks, 1 = *lowest score* and 5 = *highest score*.

and the lower reading level of Scottish children (34% of words and 29% of nonwords correctly read).

Regular instruction in handwriting, spelling, and composing (Reis et al., 2009). Handwriting instruction mainly occurs in Grade 1, in which Portuguese students are introduced to the cursive letters and practice them with cursive letter models and sample words and sentences. In Grade 2, teachers of the participating school tend to devote less than 1 hr per week to handwriting instruction. This focuses on fine motor skills and capitalization rules, usually trained through letter writing and text copying with a "careful calligraphy." Contrary to handwriting, spelling is a main focus of the Portuguese curriculum from Grade 1 onward, with teachers of the participating school devoting about 2 hr per week to it in Grade 2. The teaching of spelling involves explicit instruction of orthographic rules and rote memorization, trained through dictations and error-finding activities. Of interest for the present study is the relative lack of fast-paced exercises to promote handwriting automaticity as well as word-sorting activities to increase orthographic knowledge. Composing instruction typically starts in Grade 2. The curriculum suggests that teachers adopt a process-oriented approach, but few guidelines are provided on how to implement it. Usually, teachers guide students in writing stories, invitations, and descriptions following age-appropriate models. Also important for this study, the primary-grade curricula do not include keyboarding training.

General Instructional Procedures

Within each condition, students were randomly distributed across four small intervention groups (all groups had six children, except one handwriting group that had five children). Four graduate research assistants delivered the interventions to these groups. One pair of instructors implemented the spelling intervention (two groups per instructor), whereas the other pair implemented the handwriting and keyboarding interventions (two groups of each condition per instructor). Instructors were randomly assigned to conditions and groups. Instruction occurred from November to February during the regular instructional school periods. Instructors worked with groups in quiet areas of the school outside the students' classroom (e.g., small meeting rooms or library). To implement the interventions, instructors relied on instructional manuals containing detailed lesson plans. Handwriting and spelling students received notebooks with the activities to be performed. For the keyboarding students, the outputs of the typed activities were printed and collected to form a notebook.

The interventions consisted of 10 weekly units, each comprising four 30-min lessons. Except the first and last units, respectively aimed to introduce and close the program, all other units followed a predictable pattern. The first three lessons involved explicit instruction and practice of the target skills, and the fourth lesson was devoted to story writing. Since this is the most familiar genre for second graders, it would facilitate the enactment of trained skills in text production. The implementation of the three interventions followed key principles of explicit instruction (Archer & Hughes, 2011; Harris & Graham, 2009):

- Motivated practice: Students' motivation to write was promoted by creating a positive and collaborative instructional environment, by proposing appealing and enjoyable activities, and by positively reinforcing students' progress and effort.
- In-context practice: In addition to practicing the target skills in isolation, students were prompted to apply them in the context of authentic writing as well as in their regular classes.
- Guided practice: The introduction of new content was accompanied by high levels of guidance, which were gradually reduced once students were able to work autonomously. They also received continuous and individualized feedback on their performance and progress.
- Hierarchical and distributed practice: The target skills addressed over the program and the activities implemented within each unit followed an increasing-difficulty sequence. Throughout the intervention, students also had multiple practice opportunities, including reviewing lessons.

Handwriting Intervention

In the first lesson, students were introduced to the structure and goals of the intervention and discussed the importance of writing fluently and legibly. The next three lessons of Unit 1 aimed to review the correct production of each cursive alphabet letter in isolation (Lesson 2: *a–h*, Lesson 3: *i–q*, and Lesson 4: *r–z*). The alphabetic order was used since this is a familiar sequence for practicing letters in Grade 2. For each letter, students looked carefully at a lowercase model marked with numbered arrows indicating the order and direction of the strokes and named the letter. Then, they were asked to cover it for 6 s and write it from memory. After repeating this procedure three times, they generated a word starting with the target letter. From this unit on, students practiced handwriting at the word and sentence levels. Any time they were struggling with the correct form of a letter, they could refer to the *Writing Letters* card (adapted from Berninger, 1998), which contained the 26 lowercase cursive letters of the alphabet marked with numbered arrows.

Lessons 1 and 2 of Units 2–10 started with the alphabet warm-up (5 min), which aimed to promote fast access to representations of letter forms in memory as well as to automatize their retrieval and production in writing. Afterward, students performed a word-copying activity (10 min) followed by a word-generation activity (15 min). These practice opportunities in copying and generating single words aimed to increase students' handwriting accuracy and speed. Lesson 3 of Units 2–10 followed the same structure of the previous ones, but activities were more challenging, as they involved handwriting practice at the sentence level and were performed under time constraints (in the copying and generation activities, students had 60 s to write each sentence as many times as possible). A detailed description of the activities is presented in Table 2.

Lesson 4 of Units 2–9 was devoted to training handwriting in the context of text production. Students started by writing a story either in response to a written prompt or to a picture (10 min). Then, they counted and registered the number of words written as well as the number of legible words (10 min). This self-monitoring activity allowed students not only to monitor their progress but also to relate it to the intervention. In the last 10 min of the session, students read their stories to the group. In this lesson, neither

Table 2
Description of the Activities Performed in the Handwriting Intervention by Type and by Lesson

Warm-up activities (5 min)
Lessons 1 and 2: Students were asked to sort a list of words alphabetically, write the letter coming before and/or after other letters in the alphabet, fill out a crossword puzzle with the sequence of the alphabet letters, or decode a mystery sentence by replacing each letter with the next one in the alphabet.
Lesson 3: Students connected dots with the alphabet to reveal a picture while naming each letter orally. Afterward, they wrote the lowercase alphabet during 60 s.
Copying activities (10 min)
Lessons 1 and 2: Students copied colored words in order to sort them according to their color, students were given a list of numbered words to copy on randomly numbered boxes, or students were given sentences with blanks and a list of the missing words to copy.
Lesson 3: Students copied sets of six to eight sentences.
Generation activities (15 min)
Lessons 1 and 2: Students were asked to generate words containing a specific letter, which could either be given by instructors or chosen by the group. Task complexity was manipulated by specifying the number of words to be generated, the letter position within the word, and the semantic category of the word (e.g., names, animals, objects, jobs).
Lesson 3: Students were given a set of pictures and, for each one, they first agreed on the best sentence to describe it and then wrote the sentence.
Composing activity (30 min)
Lesson 4: Students wrote a story (10 min), counted and registered the number of legible and total words (10 min), and shared the story within the group (10 min).

explicit writing instruction nor feedback on writing processes or products was provided besides the handwriting skill that was the target of the intervention.

The last lesson closed the program. Instructors discussed students' progress over the intervention and emphasized the importance of training their handwriting skills beyond the program.

Spelling Intervention

In the first lesson, students were introduced to the structure and goals of the intervention and discussed the importance of spelling words correctly. After this lesson, students were provided with explicit instruction and practice in the alphabetic principle and its alternations as well as in spelling patterns that are a struggle for children learning the Portuguese spelling system. Except for Unit 1, which addressed three pairs of consonants that differ only in voicing (Lesson 2: *b* and *p*, Lesson 3: *d* and *t*, Lesson 4: *v* and *f*), the first two lessons of Units 2–9 always addressed two alternations or spelling patterns, which are detailed in Table 3. The lesson content followed a sequence of increasing complexity from consistent or rule-based alternations or spelling patterns to inconsistent alternations or spelling patterns. Importantly, the words used in these lessons were the same as those used in the handwriting intervention but differed from the keyboarding intervention. This allowed us to test if explicit instruction in spelling is necessary to improve spelling performance or if simple, passive exposure to target words is sufficient to improve it.

All alternations and spelling patterns were introduced and practiced through three activities: a phonics warm-up (5 min), a word-sorting activity (15 min), and a word-generation activity (10 min). The phonics warm-up included a first activity aimed to foster automaticity of the alphabetic principle. This activity was based on the *Talking Letters* card, which included pictures of words containing target phonemes and the associated spelling units (adapted from Berninger, 1998). First, instructors named the picture, produced the target phoneme, and named the letters of the corresponding spelling unit. Then, students were asked to repeat the sequence. In each lesson, students trained 10 to 20 correspondences at a fast and rhythmic pace. The second warm-up activity was designed to introduce the content of the lesson. Instructors read and started writing a sentence with several words fitting the target alternation or spelling pattern. Any time this was found, students discussed the best way to write it using the *Chameleon Sounds* card, which illustrated Portuguese alternations for spelling (adapted from Berninger, 1998). Both the Talking Letters and the Chameleon Sounds cards provided instructional support not only for the warm-up but also for all activities throughout the intervention.

The word-sorting activity was a central one. This activity was implemented in six steps following the guidelines provided by Bear, Invernizzi, Templeton, and Johnston (2012). First, instruc-

Table 3
Description of the Alternations and Spelling Patterns Addressed in the Spelling Intervention in Each Unit

Unit	Lesson	Content
2	1	Alternative spelling units *o* and *u* for the final vowel [u]
	2	Alternative spelling units *e* and *i* for the initial vowel [i]
3	1	Digraphs *lh* and *nh*, respectively ([L] and [N])
	2	Silent *h*
4	1	Use of *m* before *p* or *b*
	2	Alternative spelling units ã*o* and *am* for the diphthong [ãW]
5	1	Alternative spelling units *r* and *rr* for the phoneme /R/
	2	Two-letter consonantal blends (*ClV*- and *CrV*-type words)
6	1	Alternative spelling units *g* and *gu* for the phoneme /g/
	2	Alternative spelling units *j* and *g* for the phoneme /Z/
7	1	Alternative spelling units *c*, *qu*, and *q* for the phoneme /k/
	2	Alternative spelling units *s* and *c* for the phoneme /s/
8	1	Alternative spelling units *z*, *x*, and *s* for the phoneme /z/
	2	Alternative spelling units *ss* and ç for the phoneme /s/
9	1	Alternative spelling units *ch* and *x* for the phoneme /S/
	2	Alternative spelling units *s* and *z* for the phoneme /S/

tors spread word cards out on the table and read each one, ensuring that students knew their meanings. Second, instructors defined the categories using keyword cards, whose target spelling units were highlighted. Third, instructors modeled how to sort two words in each category, verbalizing the reasons for each placement, so that students clearly understood what they were expected to look for. Fourth, students completed the sorting under the guidance of instructors, who asked them to justify their choices. Fifth, students checked their sorting, copied the words to their notebooks, and proposed more words to include in each category. Finally, instructors helped students summarize what the sorting revealed. The alternations or spelling patterns addressed in the sorting activity were then practiced in a subsequent word-generation activity. There were three tasks of this type, in which students (a) completed words or sentences, respectively, with spelling units or words that were missing; (b) generated words or sentences grounded on images that were previously discussed; or (c) generated word families. All of these tasks ended with students presenting and discussing their choices. Whenever needed, instructors helped students either in writing words correctly or in generating appropriate examples.

Lesson 3 of Units 2–9 aimed to review the two previous lessons and was composed of two warm-up activities (10 min) followed by a generation activity (20 min). Whereas the first warm-up activity was the same as that of Lessons 1and 2, the second one was different and more suited for reviewing purposes. In this one, students had several sets of three words; for each, they read the words, identified the one that did not belong to the set, and justified their choice. The odd word could contain either a different representation of the same phoneme or a different phoneme represented by the same spelling unit. In the subsequent generation activity, they performed one of two tasks. In Task 1, students were given a card with several boxes containing different spelling units. After hearing a word, they wrote it in the corresponding box (i.e., the one containing the correct spelling unit) and generated a new one. In Task 2, students played a word game with different challenges: to write words fitting a particular spelling pattern, to describe pictures using target words, or to generate word families.

Similar to the handwriting program, Lesson 4 of Units 2–9 was devoted to story writing. The only difference was that in the self-monitoring phase, rather than being focused on the number of legible words written, students counted and registered the number of correctly spelled words.

Unit 10 was designed to review the program. Respectively, Lesson 1, Lesson 2, and Lesson 3 focused on the contents addressed in Units 2–4, Units 5–7, and Units 8 and 9. In each lesson, students wrote a set of dictated words that fitted the target alternations or spelling patterns. After writing each word, students were encouraged to justify the use of particular spelling units. In the last lesson, instructors discussed students' progress over the intervention and emphasized the importance of training their spelling skills beyond the program.

Keyboarding Intervention

In the first lesson, students were introduced to the structure and goals of the intervention and discussed the importance of typing fluently and accurately. The next three lessons of Unit 1 were designed to acquaint students with a computer's main components (Lesson 2), the keyboard QWERTY-based layout (Lesson 3), and the correct hand positioning to type fast (Lesson 4).

Lessons 1 and 2 of Units 2–10 included a copying (15 min) and a word-generation activity (15 min) aimed to speed up typing. In the copying activity, Rapid Typing 4.6.5 software (Typing Tutor Labs, http://www.rapidtyping.com/) was used. Students were asked to type a set of letters (Units 2 and 3) or words (Units 4–9) that were displayed on the screen. Typing speed and accuracy were registered by the software and discussed afterward within the group. In the generation activity, students were asked to type isolated words for labeling picture elements, describing persons or objects, or naming animals or jobs.

The first activity of Lesson 3 of Units 2–10 was similar to the one of Lessons 1 and 2, but with a higher level of difficulty (15 min). The second activity used Tux Typing 1.8.1 software, (http://tux4kids.alioth.debian.org/tuxtype/4) in which students had to type letters falling down the screen before they reach the bottom of the screen (15 min). The difficulty of this activity was manipulated based on students' progress over lessons. Due to children's low typing skill, Lesson 1–3 activities did not include practice at the sentence level.

Lesson 4 of Units 2–9 was similar to the one implemented in the handwriting and spelling programs with two differences. First, the story was written on a word processor. Second, in the self-monitoring phase, students counted and registered the number of words written. In the last lesson of the program, instructors discussed students' progress over the intervention and emphasized the importance of training their typing skills beyond the program.

Treatment Fidelity

To promote and evaluate intervention fidelity, the following procedures were carried out. Prior to implementation, instructors participated in a 12-hr workshop delivered by the first two authors, which covered the theoretical and empirical underpinnings of the programs and provided intensive training on using the instructional manuals containing detailed lesson plans. Importantly, the value of the three programs was equally emphasized. During the interventions, instructors participated in 3-hr weekly meetings with the first and second authors to discuss the completed unit and prepare the next one. Additionally, instructors were provided with checklists containing lesson steps to be checked off once completed. Instructors were encouraged to fill in the checklists accurately and were not corrected for steps not implemented. Missed steps were discussed, and strategies to avoid them in the future were sought. Checklists for the handwriting, spelling, and keyboarding conditions were examined separately for the four groups of each condition. In the handwriting condition, all lesson steps were completed in three groups (Ms = 100%). In the fourth group, 82% of the steps were completed in two lessons and 100% in all other lessons (M = 99%). In the spelling condition, with the exception of one lesson in which only 68% of the proposed steps were completed in all groups (instructors reported that there was not enough time to implement the generation activity), the percentage of completed steps ranged from 80% to 100% in three groups (M = 97%, M = 97%, and M = 98%) and from 70% to 100% in one group (M = 95%). Notably, in the four groups, all lesson steps were checked off in more than three quarters of the lessons. In the keyboarding condition, all lesson steps were completed in all

groups (*M*s = 100%). Finally, students' notebooks were examined for activity completion in the three conditions. With the exception of the activities or parts of activities whose nonaccomplishment was mentioned on instructors' checklists, the main activities of all interventions were successfully understood and completed by the majority of students.

Testing Sessions

To assess handwriting fluency and spelling accuracy as well as real-time measures, levels of written language, and writing performance in handwritten text production, all students were evaluated before and after the program in two 20-min sessions. Trained graduate research assistants, not delivering the interventions, administered assessments to the instructional groups. In the first session, students were given 10 min to write a story. At pretest, half of the students wrote to the prompt "Tell a story about a child who broke his/her brother's favorite toy," and the other half wrote to the prompt "Tell a story about a child who got angry at his/her best friend." At posttest, half of the students wrote to the prompt "Tell a story about a child who scared his/her younger cousin," and the other half wrote to the prompt "Tell a story about a child who lost his/her pet." The four Portuguese prompts were randomly assigned to intervention groups within each condition and testing time. These prompts were selected among a pool of 12 structurally similar prompts (i.e., including two characters and an action) by a team of psychologists under the guidance of an experienced second-grade writing teacher. They were asked to select four prompts deemed equivalent in difficulty and interest value as well as close to Portuguese second graders' writing assignments. We used different prompts rather than a counterbalancing procedure to impede students from knowing the writing prompt in advance, as they could discuss the writing task among them.

In the second session, students did the alphabet and copy tasks. In the former, they wrote the lowercase letters of the alphabet during 60 s as quickly and legibly as possible (Berninger, Mizokawa, & Bragg, 1991). In the latter, they copied a sentence containing all letters of the alphabet during 90 s as quickly and legibly as possible. At the end of the second session, students completed a spelling test in which the experimenter dictated 24 words at a pace of 15 s. All students also completed the alphabet and copy tasks on a word processor only at posttest. Because keyboarding training was not provided by the school, experimenters made sure that each student was familiar with the keyboard prior to completing these two assessments.

Materials

To collect real-time handwriting data, we used a new web-based system called HandSpy. To write their texts, each student was provided with a digital pen and a sheet of paper. The digital pen was a LiveScribe Pulse of regular appearance with an infrared camera pointed at its nib and running a penlet for logging handwriting data. The paper had a special microdotted pattern printed on it. The combination of the smartpen with the microdotted paper enables the precise recording of spatial and temporal coordinates about the pen trace. These data are then uploaded to the HandSpy application for real-time analyses.

Measures

The written products of half of the students in each condition were rescored by a second judge. The exception to this was text quality assessments, in which all texts were double scored. Interrater reliability was analyzed separately for pretest and posttest data using the intraclass correlation coefficient (ICC), calculated with a two-way mixed-effects model. Reported values are for absolute agreement and for single measures, except for text quality, whose reported values are for average measures. ICC was not computed for measures provided by software.

Handwriting and typing fluency. The alphabet and copy tasks in the handwritten and typed modality were used to measure handwriting and typing fluency, respectively. The final score in the alphabet task was the number of correct letters written. A letter was counted when it was legible out of context and in the right alphabetical order. The final score in the copy task was the number of correct words copied. A word was considered correct when its letters were clearly copied without any mistake. For handwritten tasks, ICC was greater than .99 at pretest and .97 at posttest. For posttest typed tasks, ICC was greater than .99.

Spelling accuracy. To assess spelling accuracy, we relied on students' performance in a dictation task composed of 24 words explicitly trained in the spelling program. The test included 12 consistent words, whose correct spelling could be determined by applying phoneme-to-grapheme correspondences and orthographic conventions, and 12 inconsistent words, whose correct spelling could only be resolved through rote learning. For these two sets of words, we counted the number of words correctly spelled (maximum of 12). ICC was greater than .94 at pretest and .95 at posttest. To assess spelling within the context of authentic writing, we also calculated the percentage of words spelled correctly in the story. ICC was .99 at pretest and .98 at posttest.

Real-time measures. Three measures were obtained from students' stories: burst length, short-pause duration, and long-pause duration. Burst length was calculated by averaging the number of words per burst (i.e., transcription activity between two consecutive pauses longer than 2 s). ICC was .96 at pretest and .94 at posttest. Periods of transcription interruption between 30 ms and 2 s were considered short pauses, and those longer than 2 s were considered long pauses. The average duration of pauses was provided by HandSpy.

Levels of written language. Students' stories were analyzed at three levels of language. At the discourse level, we examined the presence and elaboration of the following eight story elements: characters, time, space, initiating event, attempt, internal response, consequence, and reaction (Stein & Trabasso, 1982). Each element was awarded 1 point if it was present and 2 points if it was present and elaborated. The final score was the total number of points awarded (maximum of 16). ICC was .93 at pretest and .92 at posttest. At the sentence level, we calculated clause length (i.e., average number of words written per clause) using Computerized Language Analysis (CLAN) software (MacWhinney, 2000). A clause was defined as a unit with a unified predicate and expressing a single situation (Berman & Slobin, 1994). ICC was .92 at pretest and .94 at posttest. At the word level, we measured vocabulary diversity with a corrected type:token ratio (Carroll, 1964), which was calculated by dividing different words by the square root of 2 times the total words (different and total words were

provided by CLAN). This set of measures was introduced as a further specification of common writing performance measures (described below), which typically aggregate influences across language levels—for instance, writing quality was evaluated looking at the discourse, syntactic, and lexical levels.

Writing performance. Three product measures were obtained from students' stories: text length, writing fluency, and writing quality. Text length, measured in words, was calculated with CLAN. Writing fluency was measured by the number of words written per minute, which was calculated by dividing text length by composing time. The latter was provided by HandSpy. Two research assistants, blind to study purposes, assessed writing quality. Using a scale ranging from 1 (*low quality*) to 7 (*high quality*), judges were asked to consider and give the same weight to the following factors: creativity (i.e., originality and relevance of the ideas), coherence (i.e., clarity and organization of the text), syntax (i.e., syntactic correctness and diversity of the sentences), and vocabulary (i.e., diversity, interest, and proper use of the words). To remove transcription biases on quality assessments, all texts were typed and corrected for spelling errors (Berninger & Swanson, 1994). The final score was the average across judges ($ICC_{pretest} = .87$; $ICC_{posttest} = .90$).

Results

Analyses Overview

To test for differences across conditions on handwriting fluency, spelling accuracy, real-time measures, levels of written language, and writing performance, we conducted one-way analyses of covariance (ANCOVAs), with the respective pretest score as a covariate (see Table 4 for descriptive statistics). Although we used a true random design, these analyses were used to increase statistical power by reducing error variance. Significant condition effects were followed up through pairwise comparisons. Even though the interventions were delivered to small groups, as there were only four groups per condition, the analyses were conducted at the student level. Thus, all t statistics were corrected for clustering following the guidelines of McCoach and Adelson (2010). Adjustments for multiple comparisons were not made, as these would be very conservative, particularly given the large number of comparisons to be computed (Perneger, 1998). Table 5 displays the p values and effect sizes (Cohen's d; Cohen, 1988) for all pairwise comparisons, but only significant ones are discussed in the text. The unique measures that were not analyzed with ANCOVAs were the alphabet task and writing fluency because the assumption of homogeneous regression slopes was not met (for all other variables, the interaction between pretest scores and condition was not significant, $ps > .10$). Thus, for these measures, we used the nonsimultaneous Johnson–Neyman (J–N) procedure[1] to determine the regions of significance for the Condition × Covariate interaction (Aiken & West, 1991).

As data on students' typing fluency were only collected at posttest, to test for differences across conditions, we conducted one-way analyses of variance (ANOVAs; see the bottom rows of Table 4 for descriptive statistics). Significant effects were followed up through pairwise comparisons with clustering corrections, and effect sizes were calculated (Cohen's d).

Intervention Effects

Handwriting fluency. For the alphabet task, the violation of the homogeneity of regression slopes assumption precluded the use of ANCOVA. The J–N technique was thus used to determine the regions in the range of pretest scores where the effect of condition on posttest scores was statistically significant. Regression lines for the handwriting ($y = 49.72 + 0.09x$), spelling ($y = 15.56 + 0.72x$), and keyboarding conditions ($y = 3.80 + 1.01x$) were determined separately and compared. For the comparison between handwriting and spelling conditions, the region of significance included all pretest scores less than or equal to 35.80, $b = 11.79$, $t = 2.09$, $p = .05$. This means that among students who wrote 35 or fewer letters at pretest (63% of all students), after the intervention, handwriting students wrote more letters than spelling students. For the comparison between the regression lines of the handwriting and keyboarding conditions, the region of significance included all pretest scores less than or equal to 37.90, $b = 11.17$, $t = 1.91$, $p = .05$. This means that among students who wrote 37 or fewer letters at pretest (63% of all students), after the intervention, handwriting students wrote more letters than keyboarding students. Regardless of pretest scores, no differences were found between the spelling and keyboarding conditions.

For the copy task, after adjusting for initial pretest differences, there was a significant difference between conditions, $F(2, 51) = 3.56$, $p = .04$, $\eta_p^2 = 0.12$. Pairwise comparisons showed that handwriting students copied more words than spelling students ($t = 2.19$, $p = .04$, $d = 0.79$).

Spelling accuracy. After adjusting for initial pretest differences, we found intervention effects on the dictation task for inconsistent words, $F(2, 51) = 9.22$, $p < .001$, $\eta_p^2 = 0.27$. Pairwise comparisons showed that spelling students correctly spelled more inconsistent words than students in the handwriting ($t = 2.47$, $p = .02$, $d = 0.63$) and keyboarding conditions ($t = 3.45$, $p < .001$, $d = 0.94$). No effects were found for consistent words or for the percentage of words correctly spelled in the story.

Real-time measures. After adjusting for initial pretest differences, we found significant differences between conditions on burst length, $F(2, 51) = 3.77$, $p = .03$, $\eta_p^2 = 0.13$, and short-pause duration, $F(2, 51) = 3.72$, $p = .03$, $\eta_p^2 = 0.13$. Pairwise comparisons showed that handwriting students produced longer bursts than keyboarding ($t = 2.24$, $p = .03$, $d = 0.62$) and spelling students ($t = 2.12$, $p = .04$, $d = 0.54$). Furthermore, handwriting students' short pauses were smaller than those of keyboarding students ($t = -2.42$, $p = .02$, $d = -0.72$). No differences were found for long-pause duration.

Levels of written language. After adjusting for initial pretest differences, we found significant differences between conditions on vocabulary diversity, $F(2, 51) = 4.03$, $p = .02$, $\eta_p^2 = 0.14$, but

[1] In the J–N nonsimultaneous approach, regions of significance are predicted on the use of an alpha level only valid for a single test, resulting in an accumulation of the Type I error rate. The simultaneous estimation of regions of significance can be computed with the familywise alpha level obtained from the Bonferroni approach (Neter, Kutner, Nachtsheim, & Wasserman, 1996) or with the critical values derived by Potthoff (1964). Such simultaneous approaches were not used because they are overly conservative and yield regions of significance so narrow that they are often of little practical use (Bauer & Curran, 2005).

Table 4
Means, Standard Deviations, and Means Adjusted by Pretest Scores for All Handwriting Measures and Typing Fluency Measures in Each Condition

	Pretest			Posttest			Posttest (adjusted *M*)		
Measures	Handwriting	Spelling	Keyboarding	Handwriting	Spelling	Keyboarding	Handwriting	Spelling	Keyboarding
Handwriting fluency									
Alphabet task[a]	33.11 (10.24)	29.59 (13.11)	31.70 (12.86)	52.89 (11.87)	36.88 (13.42)	35.90 (15.56)			
Copy task	13.06 (4.25)	12.47 (2.81)	12.35 (3.94)	18.83 (3.05)	16.18 (2.83)	16.65 (4.04)	18.59	16.26	16.80
Spelling accuracy									
Consistent words	6.83 (2.33)	7.41 (3.54)	6.45 (3.43)	9.72 (1.78)	9.53 (1.91)	9.60 (2.09)	9.74	9.31	9.78
Inconsistent words	2.56 (2.12)	1.82 (1.43)	2.15 (2.03)	5.67 (2.33)	6.53 (2.79)	4.20 (2.91)	5.28	6.90	4.23
Spelling in context	82.18 (8.66)	83.52 (10.09)	85.17 (10.01)	89.68 (4.81)	90.70 (5.67)	89.70 (6.37)	90.28	90.77	89.11
Real-time measures									
Burst length	2.30 (.99)	2.08 (1.02)	1.86 (.75)	4.76 (2.64)	3.31 (1.53)	2.96 (1.18)	4.48	3.31	3.22
Short-pause duration	533.52 (121.33)	518.03 (88.48)	506.15 (102.53)	404.37 (82.88)	434.52 (91.16)	448.44 (76.92)	397.00	434.90	454.75
Long-pause duration	8.20 (2.78)	8.63 (3.21)	10.92 (5.01)	7.26 (3.49)	6.63 (1.84)	8.91 (4.06)	7.50	6.78	8.56
Levels of written language									
Text elements	5.39 (2.03)	4.53 (1.91)	4.35 (2.11)	7.11 (1.64)	6.29 (1.86)	5.90 (2.38)	6.77	6.41	6.11
Clause length	5.45 (.80)	5.77 (1.19)	5.79 (1.48)	5.75 (1.12)	5.60 (.78)	5.82 (1.52)	5.80	5.58	5.80
Vocabulary diversity	3.42 (.52)	3.23 (.65)	3.17 (.84)	4.31 (.42)	3.91 (.71)	3.70 (.67)	4.25	3.93	3.75
Writing performance									
Text length	54.00 (25.47)	50.06 (23.71)	42.05 (24.70)	109.89 (35.75)	92.24 (33.22)	67.25 (29.33)	106.20	91.16	71.48
Writing fluency[a]	6.52 (3.15)	5.60 (2.28)	5.01 (2.43)	11.49 (3.91)	9.23 (2.49)	8.14 (2.83)			
Writing quality	2.53 (2.29)	2.71 (1.00)	2.35 (1.16)	4.56 (1.07)	4.06 (.93)	3.30 (1.14)	4.55	3.95	3.40
Typing fluency[b]									
Alphabet task	—	—	—	23.22 (11.41)	22.35 (7.75)	29.10 (12.12)	—	—	—
Copy task	—	—	—	5.89 (4.01)	5.82 (3.03)	9.05 (4.21)	—	—	—

Note. Metric and possible range for reported measures are as follows: alphabet task = number of correct letters; copy task = number of correct words; consistent and inconsistent words = number of correct words in the dictated task (0–12); spelling in context = percentage of correct words in the story; burst length = number of words per burst defined with a 2-s pause threshold; short-pause duration = average duration of pauses between 30 ms and 2 s, measured in milliseconds; long-pause duration = average duration of pauses longer than 2 s, measured in seconds; text elements = presence and elaboration of story elements (0–16); clause length = number of words per clause; vocabulary diversity = corrected type:token ratio; text length = number of words; writing fluency = words written per minute; writing quality = scale ranging from 1 (*low*) to 7 (*high*).

[a] Adjusted means by pretest scores are not displayed because the violation of the homogeneous regression slopes assumption precluded the use of analyses of covariance (ANCOVAs). [b] Data only collected at posttest.

Table 5
Cluster-Corrected p Values and Effect Sizes (Cohen's d) of Pairwise Comparisons on Handwritten Measures

Measures	Handwriting versus spelling		Handwriting versus keyboarding		Spelling versus keyboarding	
	p	*d*	*p*	*d*	*p*	*d*
Handwriting fluency						
Copy task	**.04**	**.79**	.08	.50	.63	−.15
Spelling accuracy						
Inconsistent words	**.02**	**−.63**	.12	.40	**<.001**	**.94**
Real-time measures						
Burst length	**.04**	**.54**	**.03**	**.62**	.87	.07
Short-pause duration	.11	−.43	**.02**	**−.72**	.42	−.24
Levels of written language						
Vocabulary diversity	.09	.55	.11	.89	.44	.26
Writing performance						
Text length	.19	.44	**.01**	**1.06**	.06	.63
Writing quality	.06	.60	**.01**	**1.04**	.19	.53

Note. Significant effects are displayed in bold.

not on text elements and clause length. Nevertheless, pairwise comparisons showed no significant differences between groups.

Writing performance. After adjusting for initial pretest differences, we found significant differences among conditions on text length, $F(2, 51) = 6.74$, $p = .003$, $\eta_p^2 = 0.21$, and writing quality, $F(2, 51) = 8.05$, $p < .001$, $\eta_p^2 = 0.24$. Pairwise comparisons showed that stories of handwriting students were longer ($t = 2.59$, $p = .01$, $d = 1.06$) and better ($t = 2.69$, $p = .01$, $d = 1.04$) than those of keyboarding students.

Regarding writing fluency, as the assumption of homogeneous regression slopes was not met, the J–N technique was used to determine the regions of significance for the Condition × Covariate interaction. Similar to the alphabet task, the regression lines for the handwriting ($y = 2.57 + 1.37x$), spelling ($y = 7.22 + 0.36x$), and keyboarding conditions ($y = 5.22 + 0.58x$) were determined separately and compared. For the comparison between handwriting and spelling conditions, the region of significance included all pretest scores greater than or equal to 6.33, $b = 1.72$, $t = 2.03$, $p = .05$. This means that among students who wrote 6.33 or more words per minute on the pretest story (37% of all students), after the intervention, handwriting students wrote more fluently than spelling students. For the comparison between the regression lines of the handwriting and keyboarding conditions, the region of significance included all pretest scores greater than or equal to 6.29, $b = 2.78$, $t = 2.05$, $p = .05$. This means that among students who wrote 6.29 or more words per minute on the pretest story (40% of all students), after the intervention, handwriting students wrote more fluently than keyboarding students. Regardless of pretest scores, no differences were found between the spelling and keyboarding conditions.

Typing fluency. We found a significant difference between conditions on the copy task, $F(2, 52) = 4.46$, $p = .02$, $\eta_p^2 = 0.15$. Pairwise comparisons showed that keyboarding students correctly typed more words than students in the handwriting ($t = 2.36$, $p = .02$, $d = 0.77$) and spelling conditions ($t = 2.04$, $p = .05$, $d = 0.88$).

Discussion

The present study tested the impact of promoting transcription on early text production. Specifically, explicit instruction and practice were provided in handwriting or spelling over 10 weekly units comprising four 30-min lessons (a total of 20 hr of training). These two interventions were compared to a keyboarding control intervention. Intervention effects were assessed on treatment-specific skills, bursts and pauses, levels of written language, and writing performance.

Intervention Effectiveness

Previous research showed that handwriting and spelling interventions resulted in gains in handwriting automaticity and spelling accuracy, respectively (Berninger et al., 1997; Graham & Harris, 2000; Jones & Christensen, 1999). Current findings are partially aligned with these prior studies. Concerning the handwriting intervention, results were dependent on the handwriting fluency measure. Regarding the alphabet task, the interaction between pretest scores and condition suggested that handwriting students with less automatic handwriting benefited more from the intervention than spelling and keyboarding students. Importantly, above a certain degree of automaticity, promoting handwriting resulted in no gains in alphabet writing. With respect to the copy task, although handwriting students clearly outperformed spelling students, their superiority over keyboarding students did not reach statistical significance ($p = .08$), despite the effect size of 0.50. Overall, these results indicate that the handwriting intervention led to moderate increases in handwriting automaticity.

Concerning the spelling intervention, effects on spelling accuracy were only found for inconsistent words. Spelling students correctly spelled more trained inconsistent words than their peers. Since handwriting students were exposed to the same words, our findings suggest that the explicit teaching and practice in alternations and complex spelling patterns were necessary for raising performance. The absence of differences between handwriting and keyboarding students indicates that simple exposure to selected

inconsistent words was probably not sufficient to improve spelling. This agrees well with the main conclusion of Graham (2000) on the importance of explicit and systematic spelling instruction. Contrary to our predictions, no differences between conditions were found for either trained consistent words or spelling in the context of story writing. This might be related to the spelling instruction that all children received in their regular classes (see the Method section for a description), as revealed by the overall growth in performance. Indeed, at posttest, all students correctly spelled about 80% of the consistent words in the spelling test and about 90% of the words in their stories. In addition, individual variability on these measures was greatly reduced. This suggests that, in regard to consistent words, Portuguese standard spelling instruction probably overrode intervention effects. Moreover, it draws attention to the need for specific training with spelling inconsistencies and interestingly seems to point to a strategic behavior of very young writers, who may select words whose spellings are mastered (Graham & Santangelo, 2014).

A main finding of the present research was that, at posttest, handwriting students produced longer bursts than both keyboarding ($d = 0.62$) and spelling students ($d = 0.54$). After the intervention, handwriting students wrote an average of 4.76 words per burst. As predicted, this increase in bursts was paralleled by a reduction in the duration of short pauses (i.e., between 30 ms and 2 s). At posttest, the short pauses of handwriting students, presumably devoted to transcription processes, were briefer than those of keyboarding students. The longer bursts and shorter pauses of handwriting students confirmed our initial predictions that fast and accurate handwriting facilitates the process of putting words onto paper. More automatic handwriting may lessen the effort required to fully capture the language segment briefly held in working memory, thereby increasing the speed and ease at which it is transformed in written language. Spelling does not seem to have a similar role in writing dynamics, as the spelling intervention showed no impact on bursts and pauses. Overall, these results are in line with those of Alves and Limpo (2015), who found a progressive increase of burst length from Grades 2–7 and who found that handwriting was a stronger predictor of burst length than spelling in Grades 2–4 ($\beta = .33$ vs. $\beta = .19$, respectively), whereas spelling did not contribute to burst length in Grades 5–7. To our knowledge, this is the first study reporting increases in burst length after handwriting training.

Regarding intervention effects on levels of written language, contrary to our predictions, the handwriting and spelling interventions had no effects on the measures selected to assess discourse, sentence, and word levels. This should be cautiously interpreted, as only a single measure was used to assess each level. Nevertheless, this is in line with Berninger, Whitaker, Feng, Swanson, and Abbott's (1996) suggestion that explicit teaching and guided practice in different language levels are needed to improve composing (see also Ahmed, Wagner, & Lopez, 2014).

Intervention effects on writing performance provided further support for the contention that transcription is a critical ingredient in writing skill and suggested that the role of handwriting may be more pronounced than that of spelling. As expected, promoting automaticity in handwriting resulted in longer and better texts. In addition to the exercises focused on the fast and accurate production of letters, words, and sentences in isolation, the repeated composing opportunities may explain the large effect sizes found for text length and quality (1.04 and 1.06, respectively). Although the spelling intervention effects were not statistically significant, the effect sizes of 0.63 on text length and 0.53 on text quality suggested a meaningful superiority of spelling over keyboarding students. Actually, these effects were very similar to the average effect size of 0.55 reported by Graham et al. (2012) in a meta-analysis of transcription interventions. Regarding writing fluency, handwriting students surpassed their counterparts in the other programs. Nevertheless, this difference was only reliable for students who displayed a pretest writing fluency of six words or more. It is likely that the growth in handwriting fluency and burst length resulting from the handwriting intervention was not sufficiently large to impact the compositional fluency of very slow writers, who may need more intensive training in handwriting or in other skills required for fluent writing.

Limitations

The findings of this study should be considered in view of at least five limitations. First, there was an overall attrition rate of 11%, with relative attrition rates of 14%, 15%, and 5%, respectively, in the handwriting ($n = 3$), spelling ($n = 3$), and keyboarding ($n = 1$) intervention groups. It is, however, worth restating that the group of seven students removed from data analyses did not differ from the rest of the sample in any significant way. Thus, attrition seems not to compromise the generalizability of the current findings.

Second, the practical constraints imposed by the randomized design of this study resulted in a small sample size, thereby weakening its statistical power. This may explain the reported discrepancies between p values and effect sizes (Sun, Pan, & Wang, 2010). Indeed, lack of sufficient statistical power may yield less accurate estimates of effects and increase the likelihood of Type II errors (Abraham & Russell, 2008). Another implication of the sample size was that, even though interventions were delivered to small groups of students, effects were examined at the student rather than at the group level. Not accounting for the nested nature of the data violates the assumption of independence of ANOVA-based models, which may bias standard error estimates and increase the Type I error rate (McCoach & Adelson, 2010). For this reason, as detailed in the Results section, we computed clustering-corrected statistical significance estimates for differences between conditions. All in all, further studies with larger sample sizes are warranted to detect interventions effects more reliably, as well as to enable the use of powerful statistical techniques that adjust for and model nested data (e.g., hierarchical linear modeling). Importantly, when planning such studies, researchers should use power analysis methods to guide their decisions concerning design and data analytic approaches.

Third, the checklists used to provide a quantitative indicator of treatment fidelity were only completed by instructors without ensuring interrater reliability. Although this could raise questions about implementation integrity, it is worth mentioning that two other procedures confirmed that the interventions were implemented not only as planned but also as reported on the checklists. These procedures included (a) weekly meetings of the first and second authors with the instructors, which encompassed thorough discussions about the implementation of lesson steps and, critically, (b) the examination of students' notebooks, which provided

further evidence that the main activities of the interventions were successfully implemented and completed.

Fourth, we only used researcher-constructed tests because there is a paucity of norm-referenced measures in Portuguese. Consequently, we were not able to examine whether intervention students' normative standing changed as a result of the intervention. A norm-referenced spelling test would have been useful to examine the impact of the spelling intervention beyond the trained words.

Finally, we did not control for variables known to play key roles in writing, such as working memory (Kellogg, 1996). Because of the randomized design and lack of pretest differences among groups, we do not think that this absence compromises the findings reported here. Nonetheless, the administration of a working memory measure could have provided valuable information about the relationship between transcription and writing.

Educational Implications

Corroborating the pivotal role of transcription in children's writing, this study confirmed that interventions aimed to promote automaticity in transcription had positive impacts on students' writing. Importantly, these interventions were implemented with a sample of typically developing writers. Thus, the reported findings extend prior research, mostly focused on struggling writers, by suggesting that these programs can complement the regular writing curriculum and maximize writing development in the full range of students. If promoting fast and accurate transcription processes is dismissed in school settings, they are likely to impede writing development extensively throughout schooling. This is problematic since, as a building block of written composition, transcription should facilitate writing, not hinder it.

In line with previous results (Alves & Limpo, 2015; Graham et al., 1997; Wagner et al., 2011), those of this study have also suggested that handwriting automaticity may be more critical for writing than spelling accuracy. Handwriting seems causally connected to expanding burst length, diminishing short pauses, increasing writing processes' recursiveness, and ameliorating writing performance. This is not to say that spelling has no importance in writing. On the contrary, our results also suggest that from very early on, children seem to avoid words of whose spelling they are unsure. This strategy employed by students signals a need for spelling instruction that promotes vocabulary diversity and nurtures confidence in their spelling ability. Indeed, both handwriting and spelling seem to be powerful sources of young students' self-efficacy beliefs, which are strongly related to writing performance (Limpo & Alves, 2013a).

In addition to relying on fast and accurate transcription processes, skilled writing is also heavily dependent upon the strategic activation of high-level processes, such as planning or revising (Graham & Harris, 2000). Confirming their importance in composing, it has been shown that promoting them through strategy instruction is an effective way to boost writing from very early on (for meta-analyses, see Graham et al., 2012; Graham & Perin, 2007). As handwriting and spelling are critical to writing development, the positive effects of strategy-focused interventions might be augmented by embedding instructional components aimed to promote automaticity in transcription. The tailoring and testing of such comprehensive writing interventions, along with a deeper exploration of early text production dynamics, are of the utmost importance for promoting early writers' capabilities and informing models of writing development.

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