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Written Language Bursts Mediate the Relationship between Transcription Skills and Writing Performance

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Abstract

It is established that transcription skills (handwriting and spelling) constrain children's writing. Yet, little is known about the mechanism underlying this relationship. This study examined the mediating role of bursts and pauses on the link between transcription skills and writing fluency or text quality. For that, 174 second graders did the alphabet task and wrote a story using HandSpy. Path analyses indicated that writing fluency and text quality models were excellent descriptions of the data, with 80% and 46% of explained variance, respectively. Results showed that handwriting and spelling influenced writing fluency only indirectly via burst length and short pauses duration (full mediation); and that whereas only handwriting contributed to text quality directly, both handwriting and spelling contributed to text quality indirectly, via burst length (partial mediation). These findings suggest that better transcription skills allow students to write more words without pausing, which in turn results in more fluent and better writing.

Keywords: handwriting, spelling, bursts and pauses, writing fluency, text quality, mediation

Written Language Bursts Mediate the Relationship between Transcription Skills and Writing Performance

In the long road to writing expertise, one of the first processes that beginning writers need to master is transcription. Transcription refers to the transformation of language representations in working memory into written text, which draws on the integration of two processes: the retrieval, assembling, and selection of orthographic symbols (i.e., spelling) and the execution of fine motor movements required by the particular writing tool used to produce those symbols (i.e., handwriting/typing; Abbott & Berninger, 1993). Mastering transcription is important because, until being fast and accurate, the act of putting words onto the page is a major constraint to writing (Fayol, 1999; Kellogg, 1996; McCutchen, 1996; Olive & Kellogg, 2002). Indeed, as reviewed next, there is sound correlational and experimental research showing an association between transcription skills and writing in primary and middle grades. Specifically, students with better handwriting and spelling skills produce more fluent and better texts. However, the mechanism underlying this link between transcription skills and writing performance has received little research attention, particularly in primary grades. Here, we focus on the transcription-writing link in beginning writers (Grade 2, age 7-8), by testing the role that bursts and pauses play on this relationship.

Relationship between Transcription Skills and Writing Performance

For the last two decades, it has been consistently demonstrated that transcription skills are associated with writing performance (for reviews, see Graham & Harris, 2000; Graham & Santangelo, 2014; Santangelo & Graham, 2015). This relationship is particularly patent in beginning and developing writers, who have not mastered transcription yet. Three large-scale studies testing the transcription-writing link through structural equation modeling are noteworthy. 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, respectively, in primary and intermediate grades, these two transcription skills accounted for 41% and 66% of the variance in writing fluency, and 25% and 42% of the variance in

text quality. Limpo and Alves (2013) studied the contribution of transcription skills (modeled as a second-order factor comprising handwriting and spelling), planning, revising, and self-efficacy to text quality at two developmental points (Grades 4–6 vs. 7–9). Extending the results of Graham et al. (1997), they showed that transcription skills contributed to text quality in 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. Recently, Limpo, Alves, and Connelly (2017) provided further evidence on the relationship between transcription skills and writing in Grades 7-8, by examining the mediating role of planning (i.e., generation and organization of ideas) and translating (i.e., conversion of ideas into well-formed syntax) processes. Results showed that the effects of transcription skills on writing were fully mediated by these processes. Specifically, handwriting contributed to text quality through planning ($\beta = .31$), whereas spelling contributed to text quality through translating ($\beta = .12$). These correlational findings have been consistently supported by interventions studies, showing that promoting either handwriting or spelling skills produced visible improvements in writing performance (for meta-analyses, see Graham, McKeown, Kiuhara, & Harris, 2012; Graham & Santangelo, 2014; Santangelo & Graham, 2015). These findings were interpreted according to a capacity theory of writing (McCutchen, 1996). That is, non-automatic transcription skills impose heavy demands on writers' limited capacity of working memory, resulting in little spare resources for processes critical to produce high-quality writing, such as planning or translating.

Bursts of Written Language

Bursts refer to graphomotor activity in-between two consecutive pauses above 2 s. Pauses correspond to periods of graphomotor inactivity according to a stated threshold. Two kinds of pauses commonly used in prior research are considered here: short pauses that correspond to inactivity periods between 30 ms and 2 s and seem to reflect transcription processes; and long pauses that correspond to inactivity periods longer than 2 s and seem to reflect higher order cognitive processes, such as planning or revising (Alves, Castro, & Olive, 2008; Wengelin, 2006).

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 longer than 2 s. That is, writers produce a sentence part, then pause, produce another part, pause again, and so on. Hayes (2009, 2012) hypothesized that written language bursts were indicative of skilled writers' text production process from pre-linguistic ideas to written text. This pathway was illustrated by Chenoweth and Hayes (2001, 2003) in a model including four homunculi processes: proposer, translator, reviser, and transcriber. Aligned with task goals, the proposer generates and selects an initial set of ideas to be expressed. This pre-linguistic idea package is then passed to the translator, which will draw on its long-term and working memory resources to convert those ideas into linguistic strings. The reviser then examines the translated package for acceptability. Accepted packages are sent to the transcriber, to be externalized into written language. The authors also proposed that each process is influenced by the next process in line and that material selected for the text could depend on either the proposer or the translator.

Chenoweth and Hayes (2003) suggested that bursts depend on the capacity of the translator for finding appropriate linguistic strings to encode complex ideas. Specifically, their claim was that, when converting ideas into language, the translator can only deal with a limited amount of input. When that limit is reached, translation stops and the sentence part is ready to be transcribed. Several studies supported Hayes's suggestion that bursts occur due to capacity limits of the translator (Chenoweth & Hayes, 2001, 2003; Hayes & Chenoweth, 2006, 2007). Hayes and Chenoweth (2007) showed that bursts were present in writing tasks that did not involve the proposer (i.e., when ideas to write were included in the assignment). On the contrary, bursts were absent in a copy task that did not call on the translator but only on the transcriber (Hayes & Chenoweth, 2006). Authors interpreted these results as evidence that neither the proposer nor the transcriber were involved in the generation of bursts. Further evidence supported this claim, by showing that available resources of the translator were associated with burst length. In particular, it was found that restricting working memory resources through articulatory suppression reduced burst length (Chenoweth &

Hayes, 2003) and that writers produce longer bursts in L1 than in L2 (Chenoweth & Hayes, 2001). Critically, burst length has been linked to writing fluency. Specifically, it seems that the longer the bursts, the greater the fluency (Chenoweth & Hayes, 2001; Hayes & Chenoweth, 2007). These findings make sense to the extent that writers who are able to produce larger chunks of written language with fewer interruptions will be able to produce a higher number of words per minute during writing.

Association of Bursts with Transcription Skills

Based on the above-reviewed evidence, Hayes (2009) proposed that translating was a key source of bursts (see also Hayes, 2012; Hayes & Chenoweth, 2006, 2007). Extending that proposal, recent studies have shown that, when not automatized, transcription skills also contribute to burst length. Alves (2013) found that hampering adults' transcription skills, by asking them to compose with either an uppercase script or a shuffled keyboard, reduced the number of words that writers could put in a burst (see also Alves, Castro, Sousa, & Strömqvist, 2007). Recent studies looking at written language bursts in children provided further evidence on their association with transcription skills and two important indicators of writing performance, namely, writing fluency and text quality.

Based on the screening of 264 fourth graders (age 9-10), Alves, Branco, Castro, and Olive (2012) selected 80 students that were distributed across three groups, according to their handwriting skill (viz., low-, average-, and high-skill groups). These three groups were compared on several writing measures, including bursts and pauses, which were extracted from a story-writing task. They found that, despite the groups did not differ on average duration of long pauses, there was a reliable group effect on burst length. Specifically, children in the high-skill group produced bursts containing more words than children in both the average- and the low-skill groups. Furthermore, Alves et al. (2012) found that the texts written by the high-skill group were produced at a higher fluency and were rated of better quality than both the average- and low-skill groups. In addition to relating children's handwriting skills to burst length, writing fluency, and text quality, authors also showed that longer bursts were associated with increased writing fluency and better text quality.

Connelly, Dockrell, Walter, and Critten (2012) extended these results by considering not only the role of handwriting but also that of spelling, and by comparing 33 children with specific language impairment with an age-matched group of typically developing 11-year-old children (n = 33) and a group of younger, language skill-matched children (n = 33). Four main findings were noteworthy. First, both the group with specific language impairment and the language skill-matched group produced shorter bursts and wrote poorer texts than the age-matched group of typically developing children. Second, for all groups, both handwriting and spelling skills were significant predictors of either burst length or text quality, above and beyond language proficiency. Third, average duration of long pauses was negatively related to text quality and burst length, but was neither associated with handwriting nor spelling. Finally, authors replicated the positive correlation between burst length and text quality reported by Alves et al. (2012).

Alves and Limpo (2015b) analyzed the relationship between transcription skills, bursts and pauses, and writing performance in a cross-sectional sample of 249 children from Grade 2 (age 7-8) to Grade 7 (age 12-13) writing a narrative and an opinion essay. Irrespective of genre, they found that bursts increased throughout schooling, from about two words in Grade 2 to about six words in Grade 7; and that average duration of long pauses decreased across grades and had negative correlations with burst length. Also, they showed 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 above 2 s. They also found that longer bursts and shorter pauses were associated with greater writing fluency and better texts.

Two recent intervention studies provided additional evidence on the association of transcription skills with burst length, writing fluency, and text quality. Alves et al. (2016) conducted a randomized-controlled intervention study, in which they examined the impact of transcription training on a comprehensive set of writing measures. Specifically, they randomly assigned second graders to three intervention groups receiving a program aimed to promote handwriting (n = 18),

spelling (n = 17), or keyboarding (n = 20) skills. These programs were implemented during 10 weekly units composed of four 30-min lessons. After the interventions, the most reliable and robust differences were found between the handwriting and keyboarding interventions. As predicted, in comparison to students in the keyboarding intervention, those in the handwriting intervention displayed greater handwriting skill, produced bursts containing more words, made shorter pauses between 30 ms and 2 s, and wrote longer and better stories. Handwriting students also displayed greater writing fluency than keyboarding students, even though this difference was only observed for students with a pretest writing fluency of six words or more. The effects of the spelling intervention on bursts and pauses as well as on writing performance measures were not statistically significant. Still, as discussed by authors, particularly the effect size of 0.53 on text quality suggested a meaningful superiority of spelling over keyboarding students. Importantly, none of the intervention programs had a reliable effect on the average duration of long pauses.

Limpo and Alves (in press) examined whether transcription training would increase the effectiveness of a self-regulation intervention in Grade 2 (age 7-8). For that, they developed a self-regulation program and a transcription program, which were implemented in parallel. Students receiving the two programs (n = 43) were compared with students receiving the self-regulation program only (n = 37), and with students receiving the regular Portuguese language arts curriculum (n = 39). Notably, the self-regulation-only intervention improved text quality, but had no effects on burst length, short pauses duration, and long pauses duration. Moreover, findings revealed that combining self-regulation with transcription training produced an incremental effect on students' writing. Compared to students without transcription training, those receiving self-regulation and transcription training showed improvements not only in intervention-specific measures, such as handwriting and spelling, but also on burst length and writing fluency. There were, however, no effects on the average duration of either short or long pauses. The added value of transcription training was also observed for text quality, particularly among the poorest writers.

Taken together, these studies increased our understanding of children's text production by showing that bursts of written language are also present in beginning writing, and that the length of these segments is influenced by writers' transcription skills. As the text production model proposed by Hayes and Chenoweth (2001, 2003) was not designed to account for children's writing, such an association between transcription and bursts was absent. Here, we aim to fill in that gap, by showing that along with the translator, the transcriber can also constrain burst length, writing fluency, and text quality.

When non-automatic, transcription may not only impede writers to keep the pace with the speed at which the translator converts ideas into text, but also drain resources that are diverted from keeping a linguistic segment temporarily active (Alves et al., 2012; Alves & Limpo, 2015b; Alves et al., 2016). The more often this occurs, the greater the likelihood of interfering with the fluency of writing as well as with the quality of the written text. For example, poor transcription skills may lead writers to forget already generated language resulting in several interruptions to recover the message, or they may impede writers to devote considerable attention to the most appropriate linguistic forms to accurately express an idea. Such a negative influence of transcription on the translating process is expected to be manifested in shorter bursts and longer pauses, which in turn may contribute to a slower production process and a poorer written text. Despite prior evidence supporting that bursts and pauses may be likely candidates to mediate the relationship between transcription and writing as reviewed, such a mediating effect has not been explicitly tested before, in particular using powerful statistical techniques and comparing alternative hypotheses. This was the main aim of the present research.

Present Study

Aims and Hypotheses

The current study aimed to examine the mediating role of bursts and pauses in the relationship between transcription skills and writing performance in Grade 2. Initial primary grades seem particularly suitable to study this relationship because these children's transcription skills are

not automatic and impose heavy constraints on their ability to write. As discussed before, lack of automaticity in transcription seems a relevant condition for this process to influence burst length. In here, we used path analyses to test a mediation model predicting writing fluency and another mediation model predicting text quality. Similar across the models, handwriting and spelling were specified to predict writing fluency or text quality both directly and indirectly via bursts and pauses (cf. Figure 1). In what follows, the multiple sources of evidence supporting each specified path in the models are summarized.

Since handwriting and spelling are closely intertwined and act together during the process of putting words into paper (Kandel, Hérault, Grosjacques, Lambert, & Fayol, 2009), we hypothesized that handwriting would be positively correlated with spelling. Furthermore, we predicted that higher handwriting and spelling skills would be directly associated with longer bursts and briefer short pauses, as well as directly associated with greater writing fluency and better texts. These hypotheses stem from experimental and correlational research showing that students' transcription skills impact burst length and short pauses duration (Alves et al., 2012; Alves, Leal, & Limpo, in press; Alves & Limpo, 2015b; Alves et al., 2016; Connelly et al., 2012; Limpo & Alves, in press) as well as writing fluency and text quality (Alves et al., 2016; Graham et al., 1997; Graham & Santangelo, 2014; Limpo & Alves, 2013; Santangelo & Graham, 2015). In line with previous evidence, transcription skills were not specified to influence long pauses duration (Alves & Limpo, 2015b; Alves et al., 2016; Connelly et al., 2012). Based on findings showing that writers producing longer bursts typically make shorter pauses (Alves & Limpo, 2015b; Alves et al., 2016; Connelly et al., 2012), we additionally hypothesized bursts to be negatively correlated with short and long pauses duration. Since these two types of pauses are thought to tap into different processes (Alves et al., 2008; Wengelin, 2006), no correlation was specified between them. Finally, we expected that longer bursts along with shorter short and long pauses would be associated with greater writing fluency and better texts. This hypothesis is grounded on prior studies that showed these associations, regardless of writers' age and across different modalities (Alves et al., 2012; Alves et al., in press;

Alves & Limpo, 2015b; Connelly et al., 2012; Lindgren, Sullivan, & Spelman Miller, 2008; Spelman Miller, Lindgren, & Sullivan, 2008).

It is worth mentioning that the proposed models tested the overall hypothesis that bursts and pauses explain part but not all of the variability in writing performance associated with transcription skills (i.e., partial mediation). This hypothesis is based on research showing that factors other than bursts and pauses (viz., planning, translating, and self-efficacy) mediated the link between transcription skills and writing (Limpo & Alves, 2013; Limpo et al., 2017). However, it could also be the case that, in beginning writers, bursts and pauses could fully explain the relationship between transcription skills and writing performance (i.e., full mediation). Thus, to examine whether the transcription-writing link would be partially or fully accounted for by bursts and pauses, we additionally compared the proposed partial-mediation models with alternate full-mediation models. To build these latter, the direct paths from handwriting and spelling either to writing fluency or text quality were removed.

Figure 1 about here

Theoretical, Empirical, and Educational Contributions

This study may move the field forward in three ways. First, it provides a robust test of the likely mediating role of bursts and pauses in the transcription-writing link. Besides there is research suggesting that transcription skills are associated with bursts and pauses, which, in turn, have been found to be associated with writing fluency and text quality, the possibility of a mediating effect might be at place has never been directly tested before. Findings may be particularly relevant to the conceptualization of the process of text production in children, particularly concerning the role of written language bursts on that process. Based on skilled writers text production processes, bursts were proposed as the external manifestation of the process of converting ideas into language (Hayes, 2009, 2012). Additionally, only factors affecting the capacity of the translator were considered to influence burst length (e.g., linguistic experience or working memory capacity). The current study

may contribute to extend this view by highlighting the role the transcriber seems to play in enabling or limiting the number of words a writer can put in the page (i.e., burst length). Second, results may contribute to better understand the constraints imposed by handwriting and spelling in beginning writing. Importantly, this study will not only focus on writing fluency and text quality as the majority of studies did, but also on the moment-to-moment production of a text. As evident from the previous literature review, only a handful of studies have examined how transcription skills influence children's written language bursts and pauses, in spite of their documented value to investigate early text production. Finally, by focusing on bursts and pauses, the current study also intends to highlight their importance to educational researchers and practitioners. Assessing children's bursts and pauses during writing may provide relevant information on children's efficiency with written language, which may assist in the identification of struggling writers and guide the design of interventions tailored to their needs.

Method

Participants

In this study participated 207 Portuguese native students in Grade 2. Based on the following criteria, 33 students were excluded from the analyses: special education needs (4 students), two or more retentions (4 students), no story writing (7 students), illegible handwriting (7 students), corrupted smartpen files (11 students). Subsequent analyses were thus based on the data from 174 students with a mean age of 7.3 years (*SD* = 0.4, age range = 5.9–9.6; 93 girls). Their socioeconomic status was assessed through the educational level of their mothers, which was as follows: 3% completed Grade 4 or less, 29% completed Grade 9 or less, 30% completed high school, 17% completed college, 14% completed some postgraduate study, and 7% was unknown. Students' school achievement was assessed through their previous marks for Portuguese Language, Mathematics, and Social Studies, which are given in a scale ranging from 1 (*lowest score*) to 5 (*highest score*). Respectively, average marks for these subjects were 4.0 (*SD* = 0.9), 3.9 (*SD* = 1.0) and 4.5 (*SD* = 0.7).

Instructional Setting

Students came from 9 classes integrated in a public cluster of schools located in Porto Metropolitan Area. In Portugal, basic education lasts 9 years and comprises three stages: Grades 1–4 (age 6–10), Grades 5–6 (age 10–12), and Grades 7–9 (age 12–15). Participants were thus attending the initial years of the first stage of basic education, in which they have a single teacher teaching all school subjects, including writing. The initial years of primary education are greatly oriented to the instruction and training of transcription skills (Reis et al., 2009). Handwriting instruction mainly occurs in Grade 1, in which students are introduced to the cursive letters and practice them with cursive letter models and sample words and sentences. There is also a focus on fine motor skills and capitalization rules, usually trained through letter writing and text copying with a "careful calligraphy". Spelling is a main focus of Portuguese curriculum from Grade 1 onward. It involves explicit instruction of orthographic rules and rote memorization, trained through dictations and error-finding activities. In general, the production of written texts initiates in Grade 2. The curriculum suggests teachers to adopt a process-oriented approach, addressing students' planning, translating, and revising skills. Still, few guidelines are provided on how to implement it. Usually, teachers guide students in writing stories, invitations, and descriptions following age-appropriate models.

Procedure

Data was collected in classroom groups with about 20-25 students in a 60-min session at the beginning of the academic year. Students did several tasks, which formed the pretest assessments conducted within a research intervention project, but only those relevant to the present study are described next. In the alphabet task, students wrote the lowercase letters of the alphabet during 60 s, as quickly as possible and legibly (Berninger, Mizokawa, & Bragg, 1991). In the writing task, students wrote a story to the prompt "Tell a story about a child who broke his/her brother's toy". They were given 10 min to write the text and they were notified 5 and 2 min before the end of the time limit. If a student stopped writing he or she was encouraged once to continue. Students were

not provided with any guidance to write the story, including in how to correctly spell words. The study was conducted under the ethical standards for research involving human subjects of the authors' University, in compliance with the Declaration of Helsinki.

Material: HandSpy

To collect and analyze temporal handwriting data we used a new web-based system called *HandSpy* (Alves et al., in press). To write their texts, each student was provided with a digital pen and a paper sheet. The digital pen was a LiveScribe Pulse, which is similar to a regular pen, but hosts an infrared camera at its nib and runs 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. This data is then uploaded to the *HandSpy* web application for real-time analyses.

Measures

Except text quality and measures calculated with software (i.e., average duration of pauses and writing fluency), the alphabet and story-writing tasks of one third of the students were rescored by a second judge. Interrater reliability was calculated using the Intraclass Correlation Coefficient (ICC).

Handwriting. Students' handwriting was measured by counting the number of correct letters written in the alphabet task (ICC = .99). A letter was considered correct when it was legible out-of-context and in the right alphabetical order.

Spelling. Spelling was assessed within writing by calculating the percentage of words spelled correctly in the stories (ICC = .98).

Burst length. In line with past research into child and adult writers (Alves & Limpo; Chenoweth and Hayes 2001; Connelly et al., 2012; Kaufer et al., 1986), a burst was defined as graphomotor activity between two consecutive pauses longer than 2 s, in which at least one word was written. This one-word criterion was used to assure a semantically-based operationalization of bursts, so to reflect their theoretical conceptualization as an external representation of the process of

converting ideas into linguistically meaningful strings (Hayes, 2009, 2012). Any time a word was split in two bursts (i.e., existence of a 2-s pause within a word), the full word was included in the burst where the greater part of the word was written. Burst length was calculated by averaging the number of words per burst (ICC = .98).

Pauses duration. A pause was defined as a period of transcription interruption above a given threshold. Periods of transcription interruption between 30 ms and 2 s were considered short pauses, and those above 2 s were considered long pauses. The average duration of pauses was provided by *HandSpy*.

Writing fluency. Writing fluency was measured by the number of words written per minute (wpm), which was calculated by dividing text length by composing time. Text length was calculated with the Computerized Language Analysis software (MacWhinney, 2000), while composing time was recorded by *HandSpy*.

Text quality. Two research assistants, blind to study purposes, assessed text 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 = .91).

Results

Preliminary Data Analysis

Table 1 displays descriptive statistics for all measures. Students wrote an average of 15.45 letters in the alphabet task and correctly spelled an average of 78.50% of the words in their texts. During story writing, students produced bursts with an average length of 1.45 words and the mean duration of their short and long pauses was, respectively, 610.83 ms and 8.15 s. Texts were produced with an average fluency was of 4.32 words per minute and rated with an average quality

of 2.62. Table 1 also presents bivariate correlations between all study's variables. Overall, we found that handwriting and burst length were correlated with all variables, except with long pauses duration, which was only related to writing fluency and text quality. Importantly, all variables were correlated with writing fluency and text quality, though stronger correlations were found between bursts and pauses and writing fluency.

Table 1 about here

Data-Analytic Strategy

Path analyses were conducted with the R system for statistical computing (R Development Core Team, 2005). Since data collection occurred in classroom groups, we used the lavaan.survey package, which allows structural equation modeling analyses of clustered data (Oberski, 2014). The method of estimation was maximum-likelihood with robust standard errors, which takes into account not only the non-independence of the observations but also any effects of non-normality. To evaluate models fit we used the chi-square statistic (χ^2), the confirmatory fit index (CFI), and the root-mean-square error of approximation (RMSEA). CFI values greater than .95 and .90, and RMSEA values less than .06 and .10 are considered good and adequate fits, respectively (Hu & Bentler, 1999). The fit of the partial- and full-mediation models was compared with a chi-square difference test.

Effects on Writing Fluency

Partial- vs. Full-Mediation Models. The partial-mediation model fitted the data extremely well, $\chi^2(3, N = 174) = 4.351$, $p = .2260$, CFI = .994, RMSEA = .051, 90% CI [.000, .145], $P(\text{rmsea} \leq .05) = .397$. This model was then compared with a full-mediation model in which the direct paths from handwriting and spelling to writing fluency were deleted. The fit of this alternative model was also extremely good, $\chi^2(5, N = 174) = 5.718$, $p = .335$, CFI = .997, RMSEA = .029, 90% CI [.000, .108], $P(\text{rmsea} \leq .05) = .578$, and did not differ from the fit of the partial-mediation model, $\Delta\chi^2(2) = 1.823$, $p = .177$. However, an examination of the partial-mediation

model revealed that the direct paths from handwriting and spelling to writing fluency did not reach statistical significant, B = -0.00, SE = 0.01, β = -.00, p = .99; and B = 0.01, SE = 0.01, β = .05, p = .22, respectively. Based on the results, showing that the two models fitted the data equally well, we decided to accept the alternate full-mediation model (cf. Figure 2) because it was the most parsimonious one.

Figure 2 about here

Direct and indirect effects. As detailed in Table 2, handwriting and spelling were correlated with each other (r = .28), as well as burst length and short pauses duration (r = -.34). Both handwriting and spelling were associated with burst length (β = .31 and β = .13. respectively), but only handwriting was associated with short pauses duration (β = -.15). Burst length (β = .64), short pauses duration (β = -.12), and long pauses duration (β = -.56) were all related to writing fluency. Regarding indirect effects, handwriting and spelling were found to be associated with writing fluency via burst length (β = .20 and β = .09. respectively). A small indirect effect of handwriting fluency on writing fluency via short pauses duration was also found (β = .02). Overall, the full-mediation model explained 80% of the variability in writing fluency.

Table 2 about here

Effects on Text Quality

Partial- vs. Full-Mediation Models. The partial-mediation model fitted the data extremely well, $\chi^2(3, N = 174) = 4.351$, p = .226, CFI = .990, RMSEA = .05, 90% CI [.000, .145], P(rmsea≤.05) = .397. This model was then compared with a full-mediation model, in which the direct paths from handwriting and spelling to text quality were deleted. The fit of this alternative model was acceptable, $\chi^2(5, N = 174) = 18.876$, p = .002, CFI = .894, RMSEA = .126, 90% CI [.065, .194], P(rmsea≤.05) = .023. A chi-square difference test showed that this full-mediation model was significantly worse than the proposed partial-mediation model, $\Delta\chi^2(2) = 14.525$, p

= .001. Based on the results, we decided to keep the proposed partial-mediation model (cf. Figure 3), as it was significantly better than the full-mediation model.

Figure 3 about here

Direct and indirect effects. As detailed in Table 3, handwriting and spelling were correlated with each other (r = .28), as well as burst length and short pauses duration (r = -.34). Both handwriting and spelling were related to burst length (β = .31 and β = .13. respectively), but only handwriting was related to short pauses duration (β = -.15). Additionally, handwriting (β = .15), burst length (β = .51), and long pauses duration (β = -.24) were associated with text quality. There was however no effect of short pauses duration on text quality, and that of spelling was marginally significant (β = .12, p = .08). Concerning indirect effects, handwriting and spelling were found to be associated with text quality via burst length (β = .16 and β = .07. respectively), but not via short pauses duration. Overall, the partial-mediation model explained 46% of the variability in text quality.

Table 3 about here

Discussion

The current study used path analyses to investigate the effects of transcription skills on writing fluency or text quality via bursts and pauses in beginning writers (Grade 2, age 7-8). Results indicated that both writing fluency and text quality models were excellent descriptions of the data. Transcription skills (i.e., handwriting and spelling) along with bursts and pauses explained 80% of the variability in writing fluency, and 46% of the variability in text quality. The comparison between models testing partial against full mediation showed that whereas the effects of transcription skills on writing fluency were fully mediated by bursts and short pauses, the effects of transcription skills on text quality were partially mediated by bursts.

Correlations between transcription variables as well as between burst length and average pause duration partially supported our hypotheses. As expected, we found that handwriting and spelling were correlated with each other. This result agrees well with extant research suggesting that the act of putting words onto paper requires the close integration of the orthographic letter codes and written spellings with the sequential finger movements required by the writing tool (Abbott & Berninger, 1993; Christensen, 2004; Kandel et al., 2009). We additionally confirmed that burst length was negatively correlated with short pauses duration, suggesting that writers who are able to put more words into language bursts produced briefer short pauses (between 30 ms and 2 s) within those bursts. However, burst length was not associated with the duration of long pauses (above 2 s). This finding is contrary to those of Connelly et al. (2012) and Alves and Limpo (2015b), showing negative and significant correlations between burst length and long pauses duration in narrative texts. Yet, no association was found by Alves and Limpo (2015) in opinion essays. More research is warranted to ascertain the nature of the relationship between bursts and long pauses, including likely moderating factors (e.g., genre, age, etc.).

In line with our hypotheses, transcription skills were associated with burst length and short pauses duration. We showed that higher handwriting and spelling skills resulted in longer bursts. This finding joins a growing body of research showing that transcription skills limit the number of words that writers are able to write before pausing for 2 s or more (Alves et al., 2012; Alves & Limpo, 2015b; Alves et al., 2016; Connelly et al., 2012; Limpo & Alves, in press). Results are also aligned with prior findings showing that, even though both handwriting and spelling contributed to burst length in beginning writers, the effects of handwriting were higher than that of spelling (Alves & Limpo, 2015b). Furthermore, we found that handwriting, but not spelling, was negatively associated with the average duration of short pauses, which are presumably devoted to transcription processes (Wengelin, 2006). As expected, students with higher handwriting skill produced briefer short pauses. This result replicates past findings from an intervention study, showing that, compared to spelling and keyboarding training, handwriting training resulted in briefer short pauses during

story writing (Alves et al., 2016). Taken together, these results confirm our initial predictions that fast and accurate transcription – particularly handwriting – facilitates the process of putting words onto paper. Higher transcription skills may lessen the effort required to fully capture the language segment temporarily held in mind, thereby increasing the speed and ease at which it is transformed in written language. It is worthy to reiterate that transcription variables were not specified to have influence the duration of long pauses (i.e. above 2 s). As reviewed in the Introduction, the lack of an association between transcription and long pauses has been consistently reported in prior research across grades and genres (Alves & Limpo, 2015b; Connelly et al., 2012), and it was observed in the present study as well (cf. correlation analysis on Table 1).

Agreeing with prior studies using real-time writing analyses, (Alves et al., 2012; Alves et al., in press; Alves & Limpo, 2015b; Connelly et al., 2012; Lindgren et al., 2008; Spelman Miller et al., 2008), the anticipated effects of bursts and pauses on writing performance were also observed. Burst length, short pauses duration, and long pauses duration were all found to be associated with writing fluency. Students producing longer bursts as well as making briefer short and long pauses were able to produce their stories at a higher rate of words per minute. Compared to the effect of short pauses duration, those of burst length and long pauses duration were clearly higher. Aligned with Alves and Limpo (2015) claim, these results suggest that the number of words per burst and the average duration of pauses above 2 s are fine-grained measures of writing fluency, conveying useful information about writers' efficiency in writing. Regarding text quality, three main findings may be highlighted: short pauses duration did not influence text quality; longer bursts and briefer long pauses resulted in better texts; and the contribution of bursts to text quality was higher than that of long pauses. The unstandardized beta coefficient of the relationship between burst length and text quality is worthy of emphasis (B = 1.03): For each additional word put in a burst, there was a 1-point increase in text quality (measured with a 7-point scale). This is an educationally relevant finding. It means that writing instruction in the initial stages of learning to write should aim at increasing burst length, as this seems a major predictor of students' writing performance.

We found partial evidence for the hypothesized indirect effects between transcription skills and writing performance, via bursts and pauses. Concerning short pauses duration, we found that handwriting contributed to writing fluency via the average duration of short pauses. Nevertheless, this was a low magnitude effect, not replicated in the text quality model. Concerning burst length, we did find the anticipated mediating role of bursts in the transcription-writing link. The results were straightforward: Both handwriting and spelling were found to be associated with writing fluency and text quality via burst length. It seems that higher handwriting and spelling skills allowed students to write more words without pausing, which, in turn, resulted in a higher production rate as well as in a higher text quality. Importantly, burst length (and to a lesser extent short pauses duration) fully accounted for the relationship between transcription skills and writing fluency. This was not observed for the text quality model, in which burst length was found to partially mediate the relationship between transcription skills and text quality. This means that burst length explained some, but not all, variability in text quality associated to transcription skills. Likely factors additionally mediating this relationship are higher order cognitive writing processes. Indeed, in older students, the transcription-writing link was already found to be mediated by planning skills, sentence-related abilities, and self-efficacy beliefs (Limpo & Alves, 2013; Limpo et al., 2017).

Theoretical Implications

The findings from this study allow extending the text production model of Hayes and Chenoweth (2001, 2003) to encompass early writers' attempts at producing text. Specifically, they highlight the bottleneck role that transcriber seems to play when it is not automatized. Supported by the findings from this and other studies (Alves et al., 2012; Alves et al., in press; Alves & Limpo, 2015; Connelly et al., 2012; Lindgren et al., 2008; Spelman Miller et al., 2008), it is our suggestion that when transcription skills are not fully automatized, the transcriber constrains the ability of the writer to engage other writing processes. There are at least three ways through which an inefficient transcriber can hamper text production and more broadly the development of expertise in writing.

First, limited handwriting and spelling skills hinder the ability of the transcriber to keep pace with the translator. When starting to compose texts, children have typically gained some mastery over spoken language, thus the pace at which they are able to produce speech is considerably faster than the pace at which they can record it. This is well exemplified by the seminal finding that in beginning writers spoken texts are of better quality than written texts (Graham, 1990; Scardamalia & Bereiter, 1983). Initially, the transcriber is too slow to keep pace with the fast translator and is not knowledgeable about the spellings of the few thousand words the child is able to utter. This means that virtually all beginning writers struggle with the huge asymmetry of production rates between spoken and written languages. Such disparity, reflected in the common complaint that "slow hands do not progress at the same speed as fast thought", can easily hamper early text productions.

Second, if not automatic, the transcriber requires full attentional resources (Olive & Kellogg, 2002), which are known to be conspicuously limited (Baddeley, 2007). Attention devoted to transcription means no attention allocated to other important writing processes, such as those exemplified by the homunculi in the text production model of Chenoweth and Hayes (2003). Specifically, by limiting the ability of other cognitive processes to be enacted concurrently with transcription, a resource-demanding transcriber may constrain recursiveness (Hayes & Flower, 1986) and interactivity (McCutchen, 1988) among writing cognitive processes typical of expert writing, which may ultimately hamper text quality (Graham & Harris, 2000).

Lastly, the demanding and effortful nature that characterizes early transcription, coupled with poor instruction (Graham & Santangelo, 2014; Santangelo & Graham, 2015) and unsupportive writing environment (Alves & Limpo, 2015a; Camacho & Alves, 2017), may turn writing a text into a difficult, strenuous, and even painful activity. As a consequence, children may lose interest and enjoyment in writing, thus facing a potentially downward spiral conducing to low writing achievement, writing avoidance, and arrested writing skill (Graham & Harris, 2000). Altogether,

these findings point to a conception of the transcriber as a pivotal player not only in text production but also in developing writing.

Limitations and Future Directions

Interpretation of current findings is qualified by at least five limitations, which may provide indications for future research. First, because data were obtained at a single time point and because this study is correlational in nature, causality inferences should be avoided. Further research is needed to replicate reported results, particularly, through experimental tests of the causal mechanisms through which transcription skills influence writing. Second, as evident from the data-analytic strategy adopted, all variables were measured through single indicators, similarly to what is traditionally done in regression-based analyses. Although the measures used have proved validity and reliability evidence (Alves et al., in press; Alves & Limpo, 2015b; Graham et al., 1997; Limpo & Alves, 2013), it is advisable to cross-validate the proposed model using a multiple-indicator approach. Third, the spelling measure was derived from text production. Based on findings showing that poor spelling influenced written vocabulary in children with learning disabilities (Sumner, Connelly, & Barnett, 2016), it could be argued that students in the current study might have avoided using words they did not know how to spell. It is, however, worth mentioning that writers in this study did not have learning disabilities. Additionally, similar in-text spelling measures have been extensively used in prior research with sound validity evidence (Graham et al., 1997; Limpo & Alves, 2013; Nelson & van Meter, 2007; Wagner et al., 2011). Moreover, moderate correlations between in-text spelling measures and spelling-to-dictation measures have also been reported (Alves et al., in press; Graham et al., 1997; Limpo & Alves, 2013). Finally, it should be noted that, in agreement with prior studies with adults (Chenoweth & Hayes, 2001; Kaufer et al., 1986; Strömqvist, Holmqvist, Johansson, Karlsson, & Wengelin, 2006) and children (Alves & Limpo, 2015; Alves et al., 2016; Connelly et al., 2012; Limpo & Alves, in press), the threshold for long pauses and burst definition was set in 2 s. However, as transcription skills typically vary across child writers (Alves & Limpo, 2015), future research can consider setting individual thresholds for

each writer rather than using a common threshold for all writers (for a similar suggestion, see Baaijen, Galbraith, & de Glopper, 2012; Wengelin, 2006). Even if direct comparison with previous studies is lost, the accommodation of individual differences in pause analysis may provide further insights into the meaning of these handwriting interruptions and underlying writing processes, as well as into their association with writing fluency and text quality. Finally, it should be mentioned that Chenoweth and Hayes (2001) have reported that in adult writers some bursts are stopped by pauses and others interrupted by revision. Accordingly, they labeled the former as P-bursts and the latter as R-bursts. This distinction was subsequently fine-grained by Baaijen et al. (2012). In the current study, we were unable to use this distinction as R-bursts were virtually absent from the collected protocols. This is not surprising considering that our writers were second graders and early writers are known for barely using revision (Berninger & Swanson, 1994).

Educational Implications

Findings of the current study highlight the important role of transcription skills in beginning writing. Therefore, as a building block of writing development, transcription skills may need to be taught and practiced until a proficient level is achieved. There is now plenty of evidence on the effectiveness of interventions aimed at promoting either handwriting or spelling skills in primary grades (for meta-analyses, see Graham & Santangelo, 2014; Santangelo & Graham, 2015). Teachers can provide their students not only with explicit instruction and guided practice in writing letters and words fluently and accurately, but also with frequent composing opportunities to enact transcription skills in the context of authentic writing (Graham, 2009). This kind of in-context instruction might be particularly relevant to support efficiency in writing, behaviorally manifested in longer bursts and shorter pauses. Such efficiency seems critical to produce written texts fluently and of high-quality, at least in young writers.

It is worth cautioning that the effects of handwriting and spelling on writing performance do not mean that transcription instruction is sufficient for students to develop other key writing processes. While we would contend that good transcription instruction is necessary to leverage

writing skill, the very independence of cognitive writing processes would disavow such sufficiency claim. Indeed, an intervention comprising 20 hours of handwriting training, including repeated composing opportunities, enhanced the overall quality of the stories produced by second graders, but it did not produce any effect on fine-grained composing measures, such as stories completeness, syntactic complexity, or vocabulary diversity (Alves et al., 2016). Together, these findings clearly signal the need to provide students with systematic and explicit instruction coupling transcription together with high-level writing processes such as planning (for an example of an intervention coupling transcription and planning training, see Limpo & Alves, in press). To devise such evidence-based multicomponent interventions is particularly important. If we want children to master writing and use it effectively in literate societies, key writing cognitive processes need to be strengthened alongside each other.

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Table 1

Descriptive Statistics for and Correlations between All Study Measures

	Descriptive Statistics						Correlations					
Measures	*M*	*SD*	*Sk*	*Ku*	*Min*	*Max*	1	2	3	4	5	6
1. Handwriting	15.45	7.07	0.67	0.08	2.00	37.00						
2. Spelling	78.50	12.81	-0.57	-0.34	41.67	100.00	.28***					
3. Burst length	1.45	0.50	1.96	5.39	1.00	4.04	.35***	.23**				
4. Short pauses duration	610.83	136.06	0.64	0.07	340.69	1001.96	-.17*	-.12	-.38***			
5. Long pauses duration	8.15	3.35	1.42	2.38	3.32	22.28	-.13	-.13	-.07	.004		
6. Writing fluency	4.32	1.79	0.62	0.14	1.04	10.08	.32***	.27***	.71***	-.36***	-.59***	
7. Text quality	2.62	1.04	0.56	0.57	1.00	6.00	.39***	.30***	.61***	-.26***	-.30***	.65***

**$p < .01$. ***$p < .001$.

Table 2

Parameter Estimates for the Full-Mediation Model Testing the Relationship between Transcription Skills, Bursts and Pauses, and Writing Fluency

Effects	*B*	*SE*	β	*p*
Direct Effects				
Handwriting → Burst Length	0.02	0.01	.31	< .001
Handwriting → Short pauses duration	-2.81	1.02	-.15	.01
Spelling → Burst Length	0.01	0.002	.13	.03
Spelling → Short pauses duration	-0.83	0.83	-.08	.32
Burst length → Writing fluency	2.23	0.12	.64	< .001
Short pauses duration → Writing fluency	-0.002	0.001	-.12	.01
Long pauses duration → Writing fluency	-0.29	0.03	-.56	< .001
Indirect Effects				
Handwriting → Burst length → Writing fluency	0.05	0.01	.20	< .001
Handwriting → Short pauses duration → Writing fluency	0.004	0.002	.02	.02
Spelling → Burst length → Writing fluency	0.01	0.01	.09	.02
Spelling → Short pauses duration → Writing fluency	0.001	0.001	.01	.39
Covariances				
Handwriting ↔ Spelling	25.31	5.84	.28	< .001
Burst length ↔ Short pauses duration	-21.02	4.70	-.34	< .001
Burst length ↔ Long pauses duration	-0.04	0.14	-.03	.78

Table 3

Parameter Estimates for the Partial-Mediating Model Testing the Relationship between Transcription Skills, Bursts and Pauses, and Text Quality

Effects	*B*	*SE*	β	*p*
Direct Effects				
Handwriting → Burst Length	0.02	0.01	.31	< .001
Handwriting → Short pauses duration	-2.81	1.02	-.15	.01
Handwriting → Texts quality	0.02	0.01	.15	.002
Spelling → Burst Length	0.01	0.002	.13	.03
Spelling → Short pauses duration	-0.83	0.83	-.08	.32
Spelling → Texts quality	0.01	0.01	.12	.08
Burst length → Text quality	1.03	0.11	.51	< .001
Short pauses duration → Text quality	-0.00	0.00	-.03	.64
Long pauses duration → Text quality	-0.07	0.03	-.24	.01
Indirect Effects				
Handwriting → Burst length → Text quality	0.02	0.01	.16	.001
Handwriting → Short pauses duration → Text quality	0.001	0.001	.004	.66
Spelling → Burst length → Text quality	0.01	0.003	.07	.05
Spelling → Short pauses duration → Text quality	0.00	0.00	0.002	.63
Covariances				
Handwriting ↔ Spelling	25.31	5.84	.28	< .001
Burst length ↔ Short pauses duration	-21.02	4.70	-.34	< .001
Burst length ↔ Long pauses duration	-0.04	0.14	-.03	.78

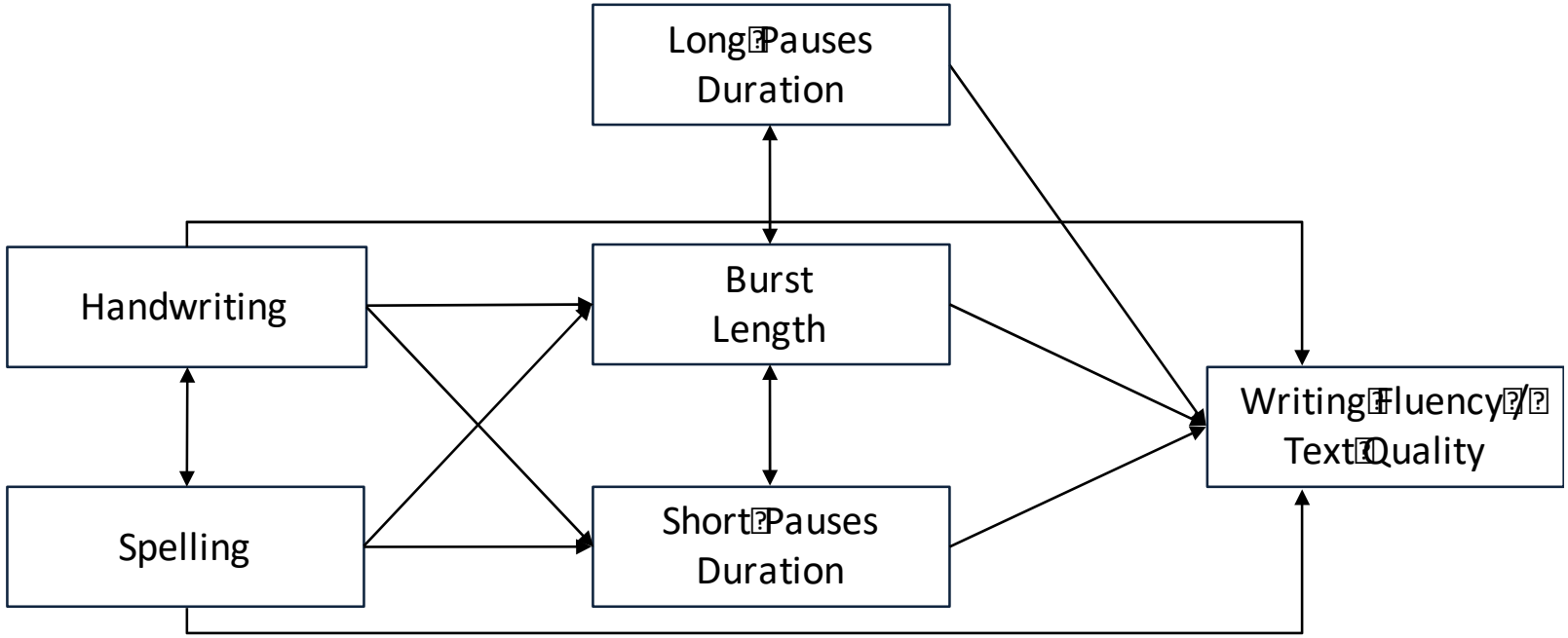

Figure 1. Partial-mediation model tested to examine the effects of transcription skills via bursts and pauses on writing fluency as well as on text quality. This model was compared with a full-mediation model, in which the direct paths from handwriting and spelling to writing fluency or text quality were deleted.

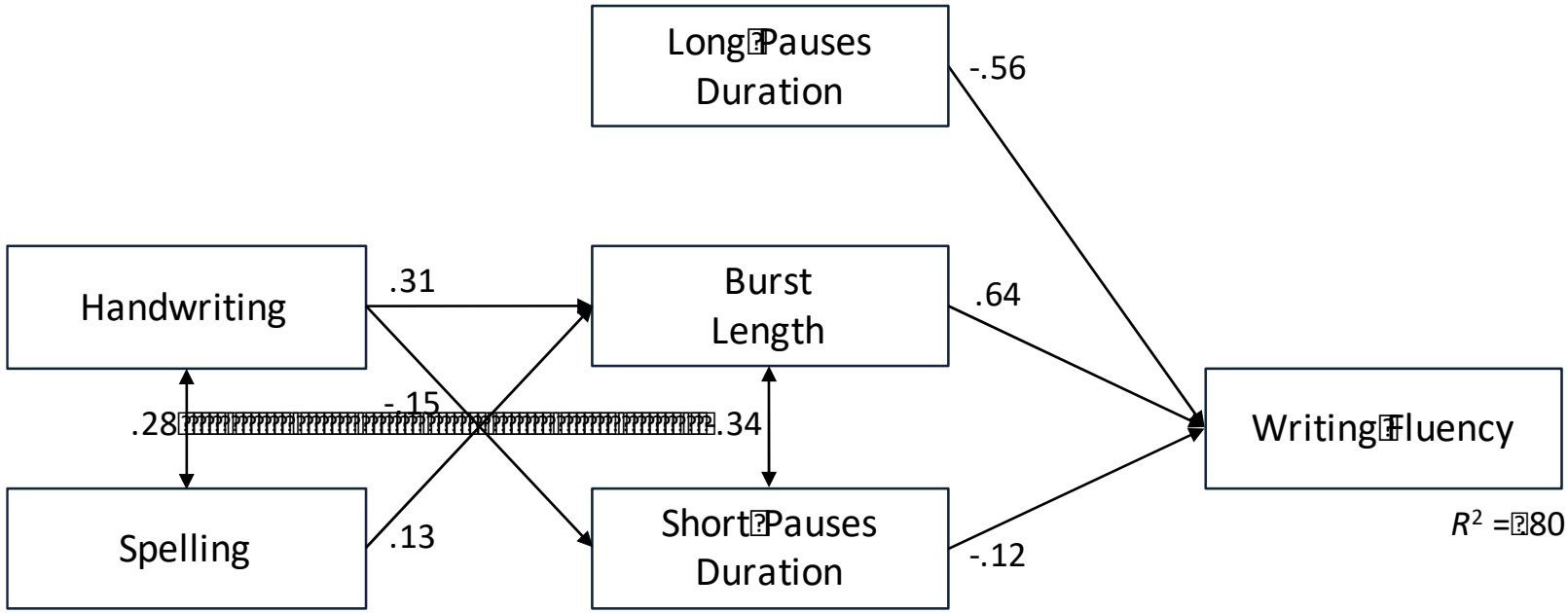

Figure 2. Accepted full-mediation model depicting the effects of transcription skills via bursts and pauses on writing fluency, with standardized betas for significant paths.

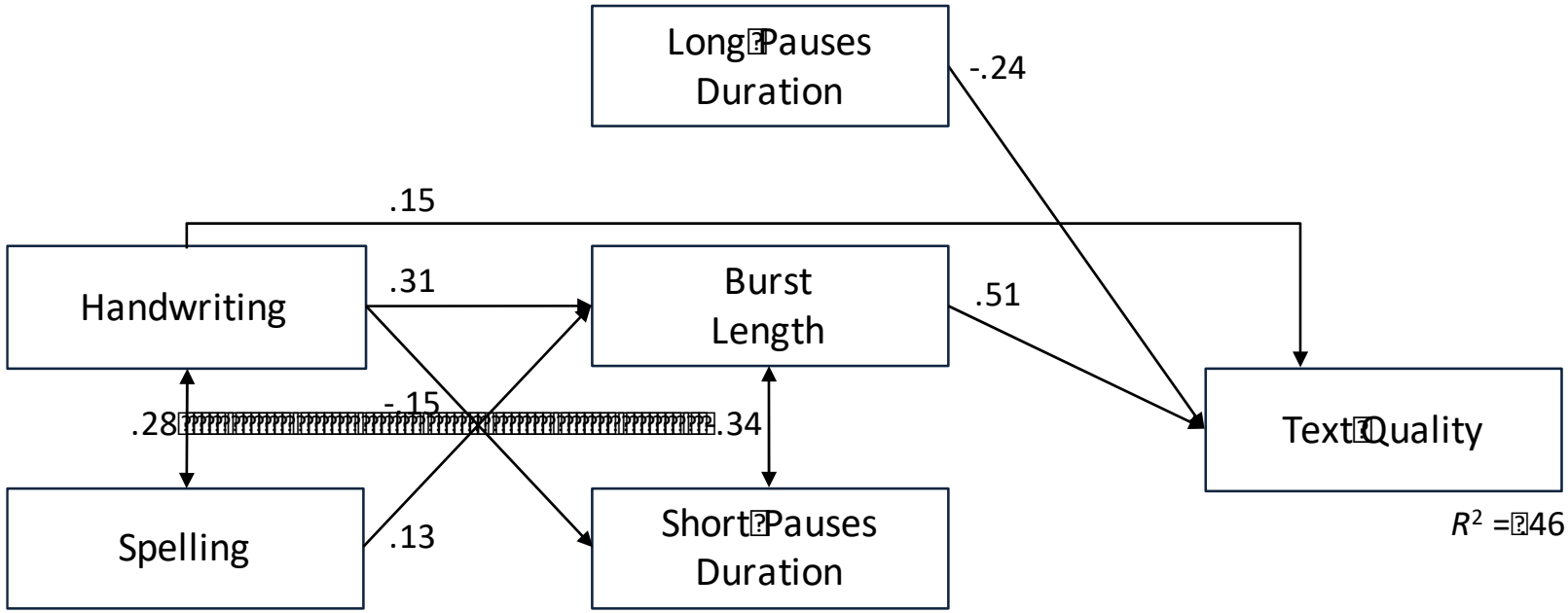

Figure 3. Accepted partial-mediation model depicting the effects of transcription skills via bursts and pauses on text quality, with standardized betas for significant paths.