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Do executive functions contribute to writing quality in beginning writers? A longitudinal study with second graders

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Abstract
Writing is an important activity that involves many demanding processes. Given the complexity and goal-directed nature of writing, this activity is heavily dependent on executive functions (EFs). This study aimed to examine the longitudinal contribution of EFs (i.e., inhibitory control, working memory, cognitive flexibility, and planning) to text quality in Grade 2. One hundred and sixteen Portuguese native speakers in Grade 2 ($M_{age}=7.26$ years; $SD=0.29$) participated in two measurement occasions with a 6-month interval (viz., Fall and Spring). In the Fall measurement, students completed EFs and writing tasks, while in the Spring measurement, students completed writing tasks only. We conducted a set of hierarchical regression analyses to examine the contribution of EFs measured in the Fall to story quality measured both in the Fall and in the Spring. Results showed that working memory and planning at the beginning of the school year had a significant and unique contribution to text quality 6 months later, above and beyond the effects of gender, reasoning, and transcription skills. These findings provide evidence of the key role of working memory and planning in children's writing. From an applied side, this study also indicates that teachers should aim to promote EFs in order to support writing in young learners.

Keywords Executive functions · Writing quality · Longitudinal study · Children

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Introduction

Composing a text is a highly complex and demanding task. Writing requires the activation and management of several processes that must be well orchestrated to achieve a high-quality text (Kellogg, 1994). In the early stages of writing, composing a text can be especially challenging, since beginning writers have not yet mastered the knowledge, skills, and processes needed to complete the task effectively and efficiently (Graham, Harris, & Adkins, 2018).

The complexity of writing is well illustrated in the Hayes's model (Hayes, 1996; Hayes & Flower, 1980). This model proposes that writing involves two main dimensions: the task, which includes social and physical components; and the individual, which includes motivation, long-term memory, and cognitive processes. There is general agreement that there are three main cognitive processes that are crucial to writing, namely, planning (i.e., generation and organization of ideas), translating (i.e., transformation of ideas into linguistic forms), and revising (i.e., reading and editing text). However, despite the importance of this model, it was solely based on adult writers. Consequently, it failed to consider transcription, a fundamental process to be acquired by beginning writers (Berninger, Cartwright, Yates, Swanson, & Abbott, 1994; Berninger & Swanson, 1994). In order to account for the specificities of writing in early stages of development, Berninger and colleagues proposed the Not-So-Simple View of Writing (Berninger & Chanquoy, 2012; Berninger & Winn, 2006). According to this model, text generation (i.e., translation of ideas into linguistic representations at the diverse levels of written language) requires the interaction between transcription and executive functions (EFs). This model has become a useful framework for the understanding of writing development. However, although the contribution of transcription to writing is well documented (Graham & Harris, 2000; Graham & Santangelo, 2014; Santangelo & Graham, 2016), the role of EFs in children's writing is poorly understood. Based on this, we conducted the present study, in which we examined the concurrent and longitudinal contribution of EFs to text quality in Grade 2, above and beyond the effects of transcription and other variables known to influence text quality, namely, gender and reasoning.

Transcription skills

Transcription can be defined as the externalization of language through the integration of the orthographic codes of letters and written spellings with the sequential finger and hand movements required by a particular writing tool, such as a pencil or a keyboard (Abbott & Berninger, 1993). Simply put, transcription includes spelling and handwriting, which are critical components in writing acquisition (Berninger & Swanson, 1994; Berninger et al., 1992).

The contribution of transcription skills to text quality in children is well established (Graham & Harris, 2000). Text quality is a product-based writing measure, typically assessed with holistic scales tapping different key aspects of a text, such as creativity, coherence, syntax, and vocabulary (Cooper, 1977). Jones and Christensen (1999) showed that, in Grade 1, handwriting fluency explained 57% of the variance of text quality. Also, these authors demonstrated that improvements in handwriting fluency through systematic training resulted in better texts. This finding has been replicated by several authors (Alves et al., 2016; Graham & Santangelo, 2014; Limpo & Alves, 2017; Santangelo & Graham, 2016). In another study focusing both on handwriting and spelling, Berninger et al. (1992) showed that, in Grades 1–3, transcription placed considerable constraints on written composition. Moreover, it was observed that if a child showed some difficulties in these skills, he or she could also struggle in translating the generated ideas into written language. Additionally, Graham, Berninger, Abbott, Abbott, and Whitaker (1997) demonstrated that handwriting and spelling explained 25–42% of the variance in the quality of texts produced by students from Grades 1 to 6. The contribution of handwriting and spelling to writing seemed to be higher in primary than intermediate grades, supporting the claim that transcription skills are a crucial component in beginning writing. Extending the findings from Graham and co-workers, Limpo and Alves (2013a) showed that, in two developmental points, Grades 4–6 and 7–9, transcription skills, together with self-regulation and self-efficacy, contributed to text quality. The authors found that these variables explained 76% and 82% of the variance in text quality in younger and older students, respectively. However, transcription skills were only found to constrain text quality directly in younger students (Grades 4–6). In older writers, the effect of transcription on text quality was indirect, via planning and self-efficacy. Students with higher transcription skills exhibited higher levels of planning and self-efficacy, which in turn were associated with better texts. This mediation effect was replicated in a subsequent study with seventh and eighth graders by Limpo, Alves, and Connelly (2017), who found that transcription had an indirect effect on writing performance, through planning and translating. Together, these findings provide evidence that transcription plays a key role in writing, mainly in beginning writers, where transcription skills have a direct and significant contribution to text quality.

Executive functions

In contrast to the evidence supporting the relationship between transcription and text quality, the relationship between EFs and text quality has received less attention. EFs are an umbrella term used to define the capabilities that enable an individual to successfully engage in independent, purposeful, self-directed, and self-serving behaviour (Lezak, Howieson, Biegler, & Tranel, 2012). According to Diamond (2013), EFs include several top-down mental processes that coordinate cognitive, behavioural, and emotional functions. These executive processes act in situations where a person has to concentrate and pay attention to the task, as well as in situations where going on automatic or relying on instinct/intuition would be ill-advised, insufficient, or impossible. There is general agreement that there are three core EFs, namely: inhibitory control, that is, the ability to control attention, behaviour, thoughts and/or emotions in order to ignore internal and external stimuli; working memory, that is, the ability to keep in mind information and to manipulate it mentally; and cognitive flexibility, that is, the ability to change the perspective or approach to a problem, and flexibly adjust to new requirements, rules or priorities. These core EFs are critical for writing in several ways. For example, when composing a text, children should use inhibitory control to ignore external stimulus that might diverge their attention from the task in hand, or to ignore irrelevant ideas to the main topic of the text. Working memory is also fundamental to produce a good text by supporting writers in building and storing a text representation (Olive, 2004, 2012, 2014). During text production, writers also need to constantly update the information present in working memory to align what they are writing with the stored representations (St Clair-Thompson & Gathercole, 2006). Finally, cognitive flexibility also plays a key role in writing. This cognitive function is crucial for writers to assume different perspectives, which might be relevant, for example, when a story has different characters. Moreover, it may also support the effective articulation of different writing processes, for instance, the shift between revising what is already written and continue to write the text.

Inhibitory control, working memory, and cognitive flexibility set the basis for other higher-order functions, which seem to require the activation of more than one core EF (Collins & Koechlin, 2012; Lunt et al., 2012), which together contribute to perform a writing task (Kellogg, Whiteford, Turner, Cahill, & Mertens, 2013). In writing, a particularly important higher-order EF is planning, that is, the ability to conceive a plan of action according to an objective, to play the selected strategies, and to monitor the implementation of that plan (Allain et al., 2005; Hill, 2004). This EF involves decision-making, judgements, and evaluation of one's own and others' behaviours (Das & Heemsbergen, 1983). During writing this function allows writers not only to create a "map" about the text they will compose, but also to express their intentions and their characters' intentions.

Despite the theoretical proposal of the Not-So-Simple View of Writing on the key role of EFs in writing (Berninger & Chanquoy, 2012; Berninger & Winn, 2006), this claim lacks sound empirical evidence, particularly in beginning writing. Indeed, only a handful of studies has focused on the role of EFs in primary children' writing. In a study with first and second graders, Hooper et al. (2011) showed that a latent factor representing EFs—which combined measures of inhibitory control, attention, planning, verbal fluency, working memory, and long-term retrieval—had a significant contribution to spelling and written expression, controlling for language and fine-motor skills. Also, the contribution of EFs remained stable across school grades. In a sample of older students from Grades 3 to 5, Altemeier, Abbott, and Berninger (2008) showed that inhibitory control and cognitive flexibility were unique contributors to word fluency and sentence-combining skills. In Grade 4, Drijbooms, Groen, and Verhoeven (2015) showed that EFs explained 8% of text length in narratives. Specifically, inhibitory control and working memory (respectively labeled by authors as inhibition and updating) contributed directly to text length, over and above transcription and language skills. Authors also found an indirect effect of EFs on text length, syntactic complexity, and story content, via handwriting fluency. These children in Grade 4 were then followed to Grade 6 (Drijbooms, Groen, & Verhoeven, 2017). This longitudinal study revealed that oral grammar, inhibition, and planning in Grade 4 contributed to syntactic complexity in Grade 6. More recently, in Grades 3–7, Rodríguez, Torrance, Betts, Cerezo, and García (2017) examined the differences in writing quality between students with Attention-Deficit/Hyperactivity

Disorder (ADHD) and age- and gender-matched controls. Authors observed that students with ADHD wrote texts with lower quality than control students. This lower performance of ADHD students was attributed to deficits on working memory and sustained attention that characterize this neurodevelopmental disorder. It should however be noted that comparisons across these studies are difficult given the variability of measures used to evaluate EFs.

Present study

EFs are important to deal with the demands involved in writing, by allowing writers to adopt self-regulation strategies to guide and monitor their cognitive and affective processes during writing (Drijbooms et al., 2015). Though it is typically assumed that EFs predicts writing quality concurrently (Drijbooms et al., 2015, 2017; Hooper et al., 2011; Hooper, Swartz, Wakely, de Kruif, & Montgomery, 2002), little is known about the longitudinal contribution of EFs at the earlier stages of learning to write. The main goal of the current study was therefore to examine the longitudinal contribution of EFs (viz., inhibitory control, working memory, cognitive flexibility, and planning) measured at the beginning of Grade 2 (Fall) to text quality, which was measured both at the beginning of Grade 2 (Fall) and 6 months later (Spring). Hooper et al. (2011) conducted a similar study with students from Grades 1 and 2. However, they considered EFs as a latent trait, which does not allow the analysis of the contribution of specific EFs to writing. In here, we conducted two hierarchical regression analyses to assess the contribution of EFs to text quality concurrently ($EFs_{Fall} \rightarrow Quality_{Fall}$) and longitudinally ($EFs_{Fall} \rightarrow Quality_{Spring}$), after controlling for gender, reasoning, and transcription skills (viz., handwriting fluency and spelling). These controls allowed us to isolate the contribution of EFs to text quality by co-varying out their effects on writing, which have been reported in the literature.

There is considerable evidence regarding gender differences in written composition. Girls outperformed boys on several measures of writing, across different instruments, testing settings, and age groups (Camarata & Woodcock, 2006; Hajovsky, Villeneuve, Mason, & De Jong, 2018; Halpern, 2004; Scheiber, Reynolds, Hajovsky, & Kaufman, 2015). For example, Berninger and Fuller (1992), with a sample of students from Grades 1 to 3, showed that girls achieved higher levels of handwriting fluency than boys. In another study, Allred (1990) found that girls, in Grades 1–6, had a higher performance than boys in spelling tasks. Recently, with a sample of students from Grades 4 to 9, Cordeiro, Castro, and Limpo (2018) consistently found that girls had a better performance than boys in handwriting, spelling, text length, and text quality. Another important variable to consider when studying writing is reasoning, which can be defined as a higher-order EF that depends upon the three core EF. Reasoning corresponds to the ability to infer patterns or relations among items (Diamond, 2013; Ferrer, Shaywitz, Holahan, Marchione, & Shaywitz, 2010). Research suggests that this variable has a contribution to the way children reflect upon and produce written language, being consistently used as a control variable in studies that examine writing (Abbott & Berninger, 1993; Abbott, Berninger, & Fayol, 2010; Berninger et al., 1992, 1994; Hayes, 1996; Stanovich, Cunningham, &

Freeman, 1984). As mentioned earlier, transcription skills also have a crucial contribution to text quality in beginning writers. Students who struggle to write fluently and accurately tend to produce written texts that are judged of poorer quality (Graham et al., 1997; Graham & Harris, 2000; Graham & Perin, 2007). Considering these findings that demonstrated a significant contribution of gender, reasoning, and transcription skills to text quality we studied the unique contribution of EFs to writing quality, after controlling for these variables.

In the present study, we used data from 116 Portuguese-speaking students from Grade 2, who performed a set of EFs tasks, two handwriting fluency tasks (viz., alphabet and copy), a spelling task (viz., dictation of isolated words), and story writing tasks. Based on our goal to examine the relationship between EFs and writing, the following research questions were put forward: To which extent do EFs predict text quality in beginning writers? Is this relationship concurrent and/or longitudinal? Stemming from the research previously surveyed, and considering our study design, we hypothesized that EFs would have a unique and independent contribution to text quality above and beyond gender, reasoning, and transcription skills.

Method

Participants

Participants were 127 Portuguese native speakers in Grade 2. Students came from seven classes integrated in a public cluster of schools located in an urban district in Porto, Portugal. Parental consent was obtained for each child participating in the study. Eleven students were excluded from analysis based on one or more of the following criteria: missing tasks or noncompliance with task instructions (7), presence of special education needs (2), and grade retention (2). The data-analytic sample included 116 students in Grade 2 (63 girls, 53 boys) with an average of 7.26 years ($SD=0.29$; range 6.82–7.82 years). The sample's socioeconomic status was measured through mother's education level and it was as follows: 13.9% completed Grade 4 or below, 47.8% completed Grade 9 or below, 24.3% completed high school, and 13.9% completed college or above (data of one participant was unknown). To measure children's school achievement, we used their final marks for Portuguese, Mathematics, and Sciences at the end of Grade 1. Using a scale between 1 *(lowest score)* and 5 (*highest score*), average marks were 4.20 ($SD=0.81$) for Portuguese; 4.16 ($SD=0.81$) for Mathematics; and 4.49 ($SD=0.63$) for Sciences.

Procedure

All students were evaluated in two measurement occasions with a 6-month interval. The first measurement occurred in the Fall, which corresponded to the first academic period (October–November 2017), and it included two 20-min group sessions and one 45-min individual session. The second measurement occasion occurred in the Spring, which corresponded to the third academic period

(May 2018), and it included two 20-min group sessions. Students were asked to write a story in each of the four group sessions, which were implemented in the classroom. At both measurement points, students were asked to do handwriting and spelling tasks at the end of the first session. The individual sessions were conducted only in the Fall and took place in a quiet room provided by schools, where students were asked to perform the EFs tasks. Within each session, the order of tasks was held constant. Between the two measurement points, students received the regular lessons about the contents presented on curricula. The tasks performed in each occasion are described next.

Measures

Control variables

As control variables we considered gender, reasoning, and transcription skills (viz., handwriting fluency and spelling).

Gender Gender was coded in a dichotomous way, with 0 being "boy" and 1 being "girl".

Reasoning We used the Raven's Colored Progressive Matrices (Raven, Raven, & Court, 2004; Simões, 2000). This test is constituted by three sets, each with 12 items. Children were asked to identify the missing element that completed the corresponding pattern. One point was assigned for each correct answer. The final score was the sum of correct answers in each set, with higher scores corresponding to better ability. This task presents a good internal consistency ($.65 < \alpha > .88$; Simões, 2000).

Transcription skills To assess handwriting fluency, we used the alphabet and copy tasks, and to assess spelling we used a dictation task. In the alphabet task, students were asked to write the alphabet in lowercase as quickly as possible, without making mistakes, during 15 s. The final score of this task was the number of correct letters written. A letter was counted when it was legible out of context and in the right alphabetic order. In the copy task, students were asked to copy a 9-word sentence as quickly as possible, without making mistakes, during 90 s. The sentence was displayed at the top of a page of primary-lined paper, and students had to copy the sentence directly below the display. The final score of this task was the number of words copied accurately. A word was considered correct when its letters were copied without any mistakes. Both tasks have well-established validity (Berninger et al., 1992; Limpo et al., 2017), with higher scores indicating greater handwriting fluency.

To asses spelling, we used a dictation task composed of 56 isolated words. These words were organized into seven categories, representing the following complexities of the Portuguese spelling system: complex graphemes, silent letter *h,* contextual effect, position effect, inconsistency, consonantal group, and stress marks (Alves & Limpo, 2015). The final score of this task was the number of spelling errors, with higher scores indicating poorer spelling skills.

Executive functions

Based on the framework of Diamond (2013), we measured inhibitory control, working memory, cognitive flexibility, and planning.

Inhibitory control We used the Big-Small Stroop-like task (adapted from Ikeda, Okuzumi, & Kokubun, 2014). This is a computerized task with congruent and incongruent blocks. In the congruent block, when a big ball appears on the screen, children should press the button with a symbol of a big ball as quickly as possible, and, when a small ball appears on the screen, children should press the button with a symbol of a small ball. In the incongruent block, children should press the big-ball button when a small ball appears on the screen, and vice-versa. Before each block, there were four examples. Reaction time was also recorded. The final score was an index of interference, which corresponds to the difference between mean reaction time in the incongruent block and mean reaction time in the congruent block. Higher scores represent lower inhibitory control.

Working memory We used the Digit Span subtest from the Wechsler Intelligence Scale for Children-III (WISC-III; Simões, Rocha, & Ferreira, 2003). In this subtest, children were asked to recall sequences of numbers with increasing length in forward and backward order. For each sequence correctly recalled, one point was assigned. The total scores were number of sequences completed in forward order and number of sequences completed in backward order. These tasks have good stability coefficient, $r = .71$ for 7 years old and $r = .80$ for 8 years old (Simões et al., 2003). Higher scores correspond to higher working memory. It should be noted that there is a theoretical distinction between the forward task, which can be used to measure short-term memory capacity, and the backward task, tapping more directly executive processing within working memory (Diamond, 2013). However, to facilitate the comparison of the present' study results with those from prior research (e.g., Drijbooms et al., 2015, 2017), we opted to include these two measures separately.

Cognitive flexibility We used the semantic fluency task from the Coimbra Neuropsychological Assessment Battery (BANC) (Simões et al., 2016). This task is comprised of three categories: animals, names, and food. For each category, children were asked to produce the maximum number of examples during 60 s. In each category, the examiner gave two examples of possible words. Each correct answer received one point. Incorrect answers included words not matching the category, meaningless words, words that had been given as examples, and repeated words. The final score was the sum of correct words in the three categories. This task presents good psychometric qualities ($\alpha = .70$, and stability coefficient between .74 and .79 for children between 6 and 8 years old; Simões et al., 2016), with higher scores indicating better cognitive flexibility. It is noteworthy that, as the majority of EFs tasks, this task does not purely measure cognitive flexibility, since this EF is built on the other two core EFs (Diamond, 2013).

Planning We used the Tower task from BANC (Simões et al., 2016). This task is composed of a tray with three pins with different heights and three colorful balls. In this task, children had to reproduce the models that were presented to them on cards. The models were progressively more demanding, both in terms of required strategies and capacity for anticipation. Before starting the task, there was a demonstration trial. There was no time limit to solve the models. The final score used was the number of models correctly completed at the first trial. This task presents a moderate stability coefficient through test-retest, $r = .33$ (Simões et al., 2016). A higher number of successful trials is used as an index of better planning skills.

Text quality

Each student was asked to write two narratives, with a 1-week interval, on each measurement occasion (total of four texts). In order to avoid interference from prompt format and topic, both in the Fall and Spring assessments, there were two writing topics provided in two formats (viz., sentence or set of images). Fall topics were "Tell a story about a child who lost his or her pet" and "Tell a story about a child who broke his or her brother's toy", and Spring topics were "Tell a story about a child who lost his or her balloon" and "Tell a story about a child who ripped his or her sister's book". Half of the students started with one prompt provided in a sentence, and the other half started with another prompt provided in a set of images. Thus, on each measurement occasion, story writing was counterbalanced for both prompt topic and format. Before writing the story, children were given 1 min for thinking about what they wanted to write. Afterwards, they were given 10 min to write the texts.

Text quality was assessed by two graduate students, blind to study purposes. In order to avoid biased judgements, all texts were previously typed, removing all identifying information, and corrected for spelling, punctuation, and capitalization errors (Berninger & Swanson, 1994; Graham, Harris, & Hebert, 2011). Text quality was assessed through a holistic scale ranging from 1 *(low quality)* to 7 *(high quality).* Raters were asked to read each text attentively, but not laboriously, in order to obtain a general impression of overall quality. When forming a judgement about quality, raters were told to consider and give the same weight to the following factors: ideas quality (i.e., originality and relevance), organization (i.e., coherence and organization of the text), sentence structure (i.e., syntactic correctness and diversity of sentences), and vocabulary (i.e., diversity, richness, and proper use of words). To guide the scoring procedure, raters were provided with anchor points for a score of 1, 4, and 7, which were selected from another sample. For each text, the quality scores were the average of the two judges. In the Fall assessment, text quality for sentence prompt was 2.15 ($SD = 1.16$) and for image prompt was 2.44 ($SD = 1.32$). In the Spring assessment, text quality for sentence prompt was 3.20 ($SD = 1.51$) and for image prompt was 3.66 ($SD = 1.59$). To obtain a more valid and reliable measure of text quality, we created a composite measure for text quality in the Fall and another for text quality in the Spring, by computing the average score across the two texts written by each child ($r = .48$ for texts written in the Fall; and $r = .52$ for texts written in the Spring).

Measures' reliability

A second judge rescored the handwriting fluency and spelling measures for 20% of the students. Interrater reliability, as measured by the intraclass correlation coefficient (ICC), was above .998 for all three measures of transcription in the Fall and Spring assessments. Concerning the evaluation of text quality, all texts were rated by two judges. In the Fall assessment, the ICC for texts elicited by a sentence was .94 and for texts elicited by a set of images was .95. In the Spring assessment, the ICC for texts elicited by a sentence was .97 and for texts elicited by a set of images was .97.

Data analysis

In order to test the unique contribution of EFs to text quality both concurrently ($EF_{Fall} \rightarrow Quality_{Fall}$) and longitudinally ($EF_{Fall} \rightarrow Quality_{Spring}$), we conducted two hierarchical regression analyses. In the first one, we analyzed the contribution of EFs measured in the Fall to text quality measured in the Fall, after controlling for gender and reasoning, as well as transcription skills in the Fall. In the second analysis, we examined the contribution of EFs measured in the Fall to text quality measured in the Spring, after controlling for gender and reasoning, transcription skills in the Spring, and prior writing performance (i.e., text quality in the Fall).

Results

Table 1 displays descriptive statistics for the observed variables. Skewness and kurtosis values were below |3| and |10|, respectively, suggesting no severe deviations from the normal distribution, and therefore, the appropriateness of using parametric

Table 1 Descriptive statistics for all observed variables

	Mean	SD	Skewness	Kurtosis
Fall assessment				
Reasoning	19.72	4.63	−0.04	−0.61
Handwriting fluency—alphabet	9.08	4.49	1.06	2.48
Handwriting fluency—copy	11.11	3.77	0.26	−0.40
Spelling	35.65	11.14	0.14	−0.93
Inhibitory control	318.27	275.85	−0.05	3.24
Working memory—forward	5.91	1.24	0.97	4.08
Working memory—backward	2.96	0.97	0.09	−0.24
Cognitive flexibility	26.78	7.95	0.20	−0.35
Planning	6.59	7.95	0.20	−0.35
Text quality	2.30	1.07	0.68	−0.29
Spring assessment				
Handwriting fluency—alphabet	14.86	6.32	0.35	−0.66
Handwriting fluency—copy	17.08	5.33	0.88	3.42
Spelling	27.63	9.09	0.58	−0.08
Text quality	3.43	1.35	0.21	0.23

procedures. The inspection of the correlation matrix presented in Table 2 showed that most of the variables were moderately-to-strongly correlated with each other.

After these preliminary analyses, we tested the unique contribution of EFs to text quality both concurrently ($EF_{Fall} \rightarrow Quality_{Fall}$) and longitudinally ($EF_{Fall} \rightarrow Quality_{Spring}$). For that, we conducted two hierarchical regression analyses. The results of each regression analysis are presented next by steps. In both analyses, the inspection of the Variance Inflation Factor (VIF) showed no evidence of multicollinearity, since all values were below 2.09.

Concurrent contribution of EFs (Fall) to text quality (Fall)

This analysis included three steps (see Table 3 for full results). On Step 1, we introduced gender (0 = boy; 1 = girl) and reasoning. On Step 2, we added handwriting fluency and spelling measures. On Step 3, we introduced inhibitory control, working memory, cognitive flexibility, and planning. All measures were collected in the Fall.

Step 1 This step was statistically significant, $R^2 = .06$, $F(2, 115) = 3.80$, $p = .025$. Reasoning, but not gender, was a significant predictor of text quality ($\beta = .10$, $p = .009$).

Step 2 When transcription skills were entered on Step 2, the model remained significant, $R^2 = .46$, $F(5, 115) = 19.07$, $p < .001$, and there was a large increase in the variance explained $\Delta R^2 = .40$, $F_{change}(3, 110) = 27.48$, $p < .001$. On this step, spelling was the unique significant predictor of text quality ($\beta = -.59$, $p < .001$).

Step 3 Finally, EFs were entered on Step 3. Although this model remained significant, $R^2 = .49$, $F(10, 115) = 10.5$, $p < .001$, there was no significant change from Step 2, $\Delta R^2 = .03$, $F_{change}(5, 105) = 1.01$, $p = .415$. In this final model, spelling remained the unique significant predictor of text quality ($\beta = -.59$, $p < .001$). None of the tested EFs were shown to predict text quality in the Fall, above and beyond control variables.

Longitudinal contribution of EFs (Fall) to text quality (Spring)

This analysis included four steps (see Table 4 for full results). On Step 1, we entered gender (0 = boy; 1 = girl) and reasoning. On Step 2, we introduced handwriting fluency and spelling measured in the Spring. On Step 3, we added text quality measured in the Fall. On Step 4, we introduced inhibitory control, working memory, cognitive flexibility, and planning.

Step 1 This step was statistically significant, $R^2 = .06$, $F(2, 115) = 3.43$, $p = .036$. As before, reasoning, but not gender, was a significant predictor of text quality in the Spring ($\beta = .23$, $p = .014$).

Step 2 When transcription skills were entered on Step 2, the model remained significant $R^2 = .46$, $F(5, 115) = 18.41$, $p < .001$, and there was a large increase in the amount of variance explained, $\Delta R^2 = .40$, $F_{change}(3, 110) = 26.82$, $p < .001$. Handwriting fluency, measured through the copy task ($\beta = .25$, $p = .003$), and spelling accuracy ($\beta = -.49$, $p < .001$) were significant predictors of text quality.

Table 2 Correlations between all measures

Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Gender		−.13	−.12	−.12	.08	.08	0.0	−.01	.01	−.09	.06	.10	.18	.16	.07
Fall assessment															
2. Reasoning			0.21*	.03	−.45*	.14	.17	.20*	.24*	.11	.23	.05	.13	−.39*	.23*
3. Handwriting fluency—alphabet				.58*	−.50*	−.03	.33*	.20*	.27*	−.01	.45*	.50*	.31*	−49*	.39*
4. Handwriting fluency—copy					−.42*	−.22*	.19*	.09	.08	−.09	.36*	.45*	.37*	−.34	.32*
5. Spelling						−.04	−.37*	−.20*	−.25*	.19*	−.65*	−.34*	−.30*	.86*	−.57*
6. Inhibitory control							−.14	.05	−.04	.07	−.004	−.03	−.10	−.03	.88
7. Working memory—forward								.23*	.37*	−.02	.31*	.18	.23*	−.34	.40*
8. Working memory—backward									.11	.10	.18	.02	.10	−.29*	.22*
9. Cognitive flexibility										.03	.32*	.18	.15	−.20*	.17
10. Planning											−.09	−.11	−.07	.13	.03
11. Text quality												.27*	.37*	−.56*	.59*
Spring assessment															
12. Handwriting fluency—alphabet													.49*	−.36*	.43*
13. Handwriting fluency—copy														−.23*	.44*
14. Spelling															−.58*
15. Text quality															

*$p < .045$

Table 3 Regression model predicting text quality in fall assessment

Predictor	*B*	*SE*	*β*	*t*
Step 1				
Gender	0.20	0.20	.10	1.04
Reasoning	0.06	0.02	.25	2.67*
Step 2				
Gender	0.28	0.15	.13	1.92
Reasoning	−0.01	0.02	−.05	−0.59
Handwriting fluency—alphabet (Fall)	0.04	0.02	.16	1.78
Handwriting fluency—copy (Fall)	0.01	0.03	.03	0.35
Spelling (Fall)	0.06	0.01	.59	−6.45*
Step 3				
Gender	0.27	0.15	.13	1.76
Reasoning	−0.02	0.02	−.09	−1.02
Handwriting fluency—alphabet (Fall)	0.03	0.02	.11	1.20
Handwriting fluency—copy (Fall)	0.01	0.03	.05	0.52
Spelling (Fall)	−0.06	0.01	−.59	−5.98*
Inhibitory control	−4.03E−5	0.00	−.01	−0.14
Working memory—forward	−0.01	0.07	−.01	−0.13
Working memory—backward	0.05	0.08	.05	0.65
Cognitive flexibility	0.02	0.01	.15	1.98
Planning	0.02	0.04	.04	0.51

*$p < .001$

Step 3 Prior writing performance, indexed by text quality in the Fall, was then introduced in the model on Step 3. The model remained significant, $R^2 = .51$, $F(6, 115) = 19.03$, $p < .001$, and there was an increase in the amount of variance explained, $\Delta R^2 = .06$, $F_{change}(1, 109) = 12.53$, $p = .001$. Besides the contribution of copy and spelling measures, text quality in the Fall was a significant predictor of text quality in the Spring ($\beta = .30$, $p = .001$).

Step 4 When EFs was entered on Step 4, the model remained significant, $R^2 = .56$, $F(11, 115) = 12.05$, $p < .001$, and we found a unique contribution of EFs above and beyond the other predictors, $\Delta R^2 = .05$, $F_{change}(5, 104) = 2.30$, $p = .05$. In this final model, all transcription measures were significant predictors of text quality ($\beta_{\text{alphabet}} = .16$, $p = .050$, $\beta_{\text{copy}} = .16$, $p = .050$, $\beta_{\text{spelling}} = -.30$, $p = .002$), as well as text quality in the Fall ($\beta = .31$, $p < .001$). Moreover, working memory in forward order ($\beta = .18$, $p = .016$), and planning ($\beta = .14$, $p = .050$) were also significant predictors of text quality in the Spring.

Table 4 Regression model predicting text quality in spring assessment

Predictor	*B*	*SE*	*β*	*t*
Step 1				
Gender	0.28	0.25	.10	1.11
Reasoning	0.07	0.03	.23	2.50*
Step 2				
Gender	0.26	0.20	.10	1.28
Reasoning	0.00	0.79	.00	−0.01
Handwriting fluency—alphabet (Spring)	0.03	0.02	.12	1.44
Handwriting fluency—copy (Spring)	0.06	0.02	.25	3.06*
Spelling (Spring)	−0.07	0.01	−.49	−5.86*
Step 3				
Gender	0.16	0.19	.06	0.85
Reasoning	−0.001	0.02	−.003	−0.05
Handwriting fluency—alphabet (Spring)	0.03	0.02	.14	1.72
Handwriting fluency—copy (Spring)	0.05	0.02	.18	2.18*
Spelling (Spring)	−0.05	0.01	−.33	−3.60*
Text quality (Fall)	0.39	0.11	.31	3.63*
Step 4				
Gender	0.18	0.19	.07	0.95
Reasoning	−0.01	0.02	−.02	−0.30
Handwriting fluency—alphabet (Spring)	0.03	0.02	.16	1.98*
Handwriting fluency—copy (Spring)	0.04	0.02	.16	1.98*
Spelling (Spring)	−0.05	0.01	−.30	−3.18*
Text quality (Fall)	0.39	0.11	.31	3.63*
Inhibitory control	0.00	0.00	.04	0.57
Working memory—forward	0.20	0.08	.18	2.44*
Working memory—backward	0.03	0.10	.02	0.34
Cognitive flexibility	−0.02	0.01	−.11	−1.44
Planning	0.09	0.05	.14	1.99*

*$p < .003$

Discussion

This study examined the contribution of EFs (viz., inhibitory control, working memory, cognitive flexibility, and planning) to text quality measured at the beginning of Grade 2 (Fall) and 6 months later (Spring). We examined this contribution after controlling for gender, reasoning, and transcription skills (viz., handwriting fluency and spelling). Findings indicated that EFs have a longitudinal contribution to text quality in Grade 2. Specifically, working memory and planning in the Fall explained further additional variance in the quality of texts produced in the Spring, above and beyond the effects of gender, reasoning, and transcription.

These two EFs, measured at the beginning of the school year, seem to play a key role in text quality measured 6 months later.

Contrary to our expectations, gender was not a significant predictor of writing quality, neither in the Fall assessment nor in the Spring assessment. This finding contrasts with previous research showing that girls outperformed boys on several writing measures and across different age groups (Cordeiro et al., 2018; Kim, Al Otaiba, Wanzenk, & Gatlin, 2014). Reasoning was a significant predictor of text quality both in the Fall and Spring assessments. In line with prior findings, student's ability to infer patterns or relations among items (Diamond, 2013; Ferrer et al., 2010) seem to be an important factor to the quality of stories produced in Grade 2. Moreover, reasoning as an indicator of non-verbal intelligence is crucial to solve a problem-solving task as writing, since it implies that students are able to perceive the similarities and differences among different pieces of information.

As expected, transcription skills were a significant predictor of text quality across the school year, confirming the importance of these skills in the performance of beginning writers. These findings are in accordance with previous research, consistently showing the association between transcription and text quality in children (Alves & Limpo, 2015; Alves et al., 2016; Limpo & Alves, 2013a, 2017, 2018; Limpo et al., 2017). It seems that, in the beginning of writing development, transcription skills are so effortful and demand such a high amount of cognitive resources, that few attention is left for other processes crucial to good writing, such as ideas generation or language formulation (Graham & Harris, 2000; Olive & Kellogg, 2002). It should however be noted that our analyses revealed that the two components of transcription (i.e., handwriting and spelling) contributed differently to writing throughout the school year. On the one hand, spelling was found to contribute to text quality in both the Fall and Spring assessments. This result replicated previous findings, showing that the ability to spell words correctly is essential to produce high-quality texts in Grade 2 (Graham & Santangelo, 2014). On the other hand, handwriting fluency was found to contribute to text quality only in the Spring assessment. The emergence of an association between handwriting and text quality at the end of Grade 2 could be due to the daily practice promoted by teachers to write letters on alphabetic order throughout the year. Contrary to Grade 1, in which there is a large focus on spelling, Grade 2 teachers may place a greater focus on handwriting, promoting several types of exercises, such as writing the alphabet and copying texts.

A major finding of this study was that, above and beyond the contribution of reasoning, transcription, and, notably, prior writing performance, EFs in the Fall were found to have a unique and independent contribution to text quality in the Spring. This result joins to an emerging body of research showing concurrent and longitudinal relations between EFs and writing in children (Drijbooms et al., 2015, 2017; Hooper et al., 2002, 2011; Rodríguez et al., 2017). Findings are also aligned with the Not-So-Simple View of Writing (Berninger & Chanquoy, 2012; Berninger & Winn, 2006), highlighting the key role of EFs in writing development. Specifically, we found that working memory (forward digit span) and planning in the beginning of Grade 2 were the only EFs significantly contributing to text quality, 6 months later. Children who had higher working memory capacity and higher planning skills were more likely to produce stories with higher quality, than those children who had a lower performance on those executive tasks. The role of working memory and planning in writing is defended by several authors (Drijbooms et al., 2015, 2017; Olive, 2012). From a cognitive perspective, the task of composing a text can be seen as a problem-solving activity (Hayes, 2012). Therefore, children need to create a plan to achieve success in that activity. For example, they need to plan the topics they want to include in their texts and how to organize them in a coherent manner. Moreover, while composing the text, children need to keep in mind that plan and manipulate the information contained on it. This updating of contents in working memory according to the text written so far is a key process to achieve a high-quality text (Olive, 2004, 2012). Greater working memory resources may also be associated with better texts by allowing writers to engage in other processes during writing, such as revising (Olive, 2014).

As described before, only a handful of studies focused on the relationship between EFs and writing in children. Even though findings are generally aligned (i.e., showing a link between EF and writing), there is less consistency concerning the specific EF contributing to writing. Drijbooms et al. (2015) showed that, in Grade 4, there is evidence for a concurrent relationship between inhibition and working memory to text length. Also, they showed a longitudinal contribution of inhibition (Grade 4) to syntactic complexity (Grade 6), but there were no effects of EFs on narrative content. In another study, Hooper et al. (2011) showed an effect of an EF latent trait on spelling and written expression. The differences between our findings and those of these studies can be explained by the different methods used. Indeed, there is a large variability in the measures used to assess both EF and writing. It should, however, be highlighted that this is the first study showing the contribution of working memory and planning to text quality in Grade 2, after controlling for non-verbal intelligence, handwriting and spelling abilities and, critically, prior writing performance.

Limitations and future research directions

When interpreting these findings, there are at least four limitations that need to be taken into consideration. First, despite our sample size was appropriate to the analyses conducted, with approximately 10 cases per each predictor in the step with more predictors, the number of participants precluded the analysis of more complex relationships between EFs and text quality. In the future, the relationship between EFs and text quality should be examined in larger samples. This would allow researchers not only to conduct complex analyses taking into account measurement error (e.g., structural equation modeling), but also to test mediation and moderation models, thereby providing informative hints about the mechanisms through which EFs may impact text quality.

Second, the contribution of EFs to text quality was only examined for story writing. Although we asked children to write two texts using different prompt formats (sentence vs. set of pictures) in each measurement occasion to reduce variability, both texts relied on the narrative scheme. Therefore, our findings cannot be generalized to other genres. Current findings were obtained through asking children to produce narratives, which is a genre widely used and practiced, especially in the early years of schooling. It seems necessary to test whether these results can be replicated across other genres, such as opinion essay, which may pose higher constraints on children's writing and, therefore, rely on other EFs.

A third limitation of this study is that it focused on more decontextualized and abstract measures of EFs. Writing involves not only these cognitive processes, but also social and affective ones. These latter are activated when individuals have to solve problems demanding high-affective involvement and motivation, or to make decisions with emotionally significant consequences (Kerr & Zelazo, 2004). Despite their relevance to writing (Hayes, 1996), the social and affective dimensions of EFs were not considered here. Future studies should include measures that focus more on this "hot" dimension of EFs, for example, through delay of gratification tasks.

A fourth limitation of the present study is that there was only a single measurement of EFs at the beginning of school year. For practical reasons associated with the school management, we were not able to collect EFs twice. Although there is some research showing longitudinal stability of EFs in preschoolers (Gooch, Thompson, Nash, Snowling, & Hulme, 2016), we do not know whether in the 6-month interval between the Fall and Spring measurements there was an increase in EFs, associated with the findings here reported. Future research should aim to not only follow children during a longer period of time but also collect both EFs and writing measures on all measurement occasions.

Educational implications

The results of the current study are important to understand the relationship between cognitive processes such as EFs and an essential academic skill such as writing. Findings can be used to design interventions entailing specific strategies to improve writing by targeting key EFs in beginning writers. Currently, school instruction focuses on curricular-specific skills, such as handwriting and spelling. The benefits of promoting the transcription skills in children with or without writing disabilities are already well-established in the literature (Alves et al., 2016; Graham et al., 2018; Limpo & Alves, 2018). In addition to promoting these skills, teachers could also aim to implement exercises to promote working memory and planning, which may foster text quality in beginning writers. Although research examining the role of working memory in children's writing is scarce, there is evidence that higher working memory capacity is associated with better texts in school aged children (McCutchen, Covill, Hoyne, & Mildes, 1994; Swanson & Berninger, 1994). Despite this evidence, programs intended to promote working memory had demonstrated little to none near-transfer effects to several academic skills (Melby-Lervag & Hulme, 2013). These disappointing effects might be due to the training of a single EF, through isolated and decontextualized exercises (e.g., letter span tasks or static visuospatial tasks). There is a clear need to develop and test training programs tapping several EFs together (Diamond, 2013). A combination of exercises to improve working memory and planning in primary grades could be particularly effective to foster writing.

Another way to promote EFs, and consequently writing, could be through teaching self-regulation strategies, which have been shown to have a positive impact on text quality (Altemeier et al., 2008; Graham & Harris, 2000; Limpo & Alves, 2018). A particularly effective instructional model to teach self-regulation strategies and foster the executive management of writing processes is the Self-Regulated Strategy Development model (SRSD) (Harris & Graham, 2009). This model targets skills related to goal setting, self-monitoring, and self-instructions, and has been shown to strongly increased text quality in Grades 2–12 (Graham, McKeown, Kiuhara, & Harris, 2012; Limpo & Alves, 2013b, 2018). These strategies seem to support EFs that are related to decision-making, attentional control, and flexible adaptation (Harris, Graham, Mason, McKeown, & Olinghouse, 2018), alleviating the cognitive load of orchestrating the several processes necessary to achieve success in writing. Overall, the SRSD seems a promising tool to promote key EFs with tandem in writing.

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