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The role of transcription and executive functions in writing: a longitudinal study in the transition from primary to intermediate Grades

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Abstract
Learning to write is one of the great challenges children face in primary grades, requiring both transcription skills (handwriting and spelling) and executive functions (EFs; working memory, inhibitory control, and cognitive flexibility). Although this claim is widely accepted, the field suffers from some limitations, including few longitudinal studies examining the joint role of transcription and EFs in the writing of school-age children. The current study aimed to fill in this gap with a twofold goal: to examine the development of transcription and EFs in Portuguese children transitioning from primary (Grade 4) to intermediate school (Grade 5); and to evaluate the longitudinal and concurrent links between transcription and EFs to text quality. The sample included 222 Portuguese students in Grade 4, who were reassessed one year later, in Grade 5. Results showed significant improvements from Grade 4 to 5 in handwriting and spelling as well as in verbal working memory and cognitive flexibility. Moreover, though spelling and cognitive flexibility in Grade 4 had longitudinally predicted text quality in Grade 5, these links disappeared when Grade 5 predictors were considered. In the final model, only transcription skills along with cognitive flexibility and inhibitory control in Grade 5 were significant predictors of text quality in Grade 5. These findings show that transcription and EFs play a role in writing and suggest that this role might be more concurrent than longitudinal.

Keywords Transcription skills · Executive functions · Transition Grade 4 to 5 · Text quality

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Writing is a powerful communication tool that plays an important role in school learning (Graham & Perin, 2007). It is a very demanding activity, that takes writers more than two decades to achieve expertise on (Kellogg, 2008). Therefore, the development of this competence is one of the great challenges that children face throughout schooling. According to Writer(s)-Within-Community (WWC) model (Graham, 2018a, b), writing is a complex neuromotor skill involving socio-cultural and cognitive dimensions. From a socio-cultural perspective, writing is a social activity within specific writing communities, including the social, historical, and cultural influences that shape it. From a cognitive perspective, the act of writing requires the simultaneous use of various mental processes that involve a large amount of attentional resources. Two critical cognitive processes that young writers have to develop are transcription (i.e., handwriting speed and spelling accuracy) and executive functions (EFs; e.g., working memory, inhibitory control, and cognitive flexibility) (Berninger, 1999). Respectively subsumed under production and control processes in the WWC model, transcription and EFs have been acknowledged as key processes to produce good writing in other theoretical models, such as the Not-So-Simple View of Writing (Berninger & Winn, 2006).

Despite these theoretical propositions, there is a need for more research examining the link between transcription and EFs in children given several limitations in the field: lack of studies examining transcription skills beyond primary years; mixed results in studies examining the role of EFs in writing; and separate study of transcription and EFs in writing, using cross-sectional designs. Here, we aimed to overcome these gaps. First, we examined the development of transcription (viz., handwriting speed and spelling accuracy) and three core EFs domains (viz., verbal working memory, inhibitory control, and cognitive flexibility) of Portuguese children who are in the transition from primary (Grade 4) to intermediate school (Grade 5). Then, we assessed the longitudinal (in adjacent grades) and concurrent (in the same grade) relationships between transcription and EFs measured in Grade 4 and 5 and text quality measured in Grade 5.

Transcription skills

Transcription is the transformation of oral language into written text (Berninger, 1999; Graham et al., 1997). This process integrates two sub-processes: spelling, which involves retrieving, recognizing, and representing orthographic symbols, and handwriting, which involves the fine motor movements required to produce these symbols by hand (Abbott & Berninger, 1993). A substantial amount of experimental and correlational research shows that both spelling and handwriting skills are key ingredients for good writing in beginning writers (for meta-analyses, see Graham & Santangelo, 2014; Santangelo & Graham, 2016). Several studies showed that systematic training of transcription skills increases text quality in primary students (Alves & Limpo, 2015; Hurschler Lichtsteiner et al., 2018; Limpo et al., 2020) and in intermediate students with poor transcription skills (Limpo et al., 2017). Moreover, Graham et al., (1997) showed that handwriting and spelling accounted for a sizable proportion of the variance in text quality for primary (1–3) and intermediate grades (4–6)

(25% and 42%, respectively). Another study with students from Grades 4–6 and 7–9 also analyzed the contribution of transcription along with planning, revision, and self-efficacy to text quality (Limpo & Alves, 2013). Authors found that transcription skills influenced text quality directly in younger students (Grades 4–6), but in older ones (Grades 7–9), the association of transcription with text quality was indirect, via planning and self-efficacy (see also Limpo et al., 2017).

These findings support the claim that transcription skills are a crucial writing component in primary and intermediate grades. Consistently, students who produced fewer spelling errors and wrote faster also produced better texts. The degree to which students write fast without misspellings is considered an indicator of transcription automaticity (Graham & Santangelo, 2014; Limpo & Alves, 2013). It is assumed that when transcription becomes automatic, spelling and handwriting stop requiring conscious control, that is, students do not need to devote attentional resources to spelling words or write letters (Graham et al., 1997). Thus, they can use the spare attentional resources for other writing processes, which are fundamental to produce good writing, such as idea generation or language formulation (Olive & Kellogg, 2002).

Although the importance of transcription skills in the early years of schooling is well established in the literature, most of the research supporting this claim is cross-sectional. Moreover, few studies examined the role of these skills at the end of the primary grades and afterwards, and even less studies explored the role of transcription together with EFs as predictors of writing quality (Cordeiro et al., 2020; Drijbooms et al., 2015, 2017). Here, we intend to fill in these gaps.

Executive functions

EFs are cognitive control mechanisms that direct and coordinate human behavior in an adaptive manner, allowing for rapid and flexible changes in response to the demands of the environment (Diamond, 2013). Among the several theoretical conceptualizations about EFs in children (for a review see Best & Miller, 2010), this study was based on the one proposed by Diamond (2013). In addition to being an up-to-date, widely used, and empirically based approach (Willoughby & Hudson, 2021), it is aligned with the WWC model (Graham, 2021), used to frame the current study.

According to Diamond (2013), there are three core EFs: (a) working memory, which allows individuals to keep in mind verbal or non-verbal (visuospatial) information while performing other mental operations; (b) inhibitory control, which is the ability to control attention, behavior, thoughts, or emotions; and (c) cognitive flexibility, which involves the ability to change the perspective or approach to a problem and flexibly adjust to new challenges (Diamond & Ling, 2016). Since the eighties all cognitive approaches to writing have been recognizing the fundamental role of EFs in writing (cf. Limpo & Olive, 2021). Despite one can find empirical evidence supporting the association of verbal working memory, inhibitory control, and cognitive flexibility with writing performance, a closer look at the findings reveals a mixed pattern of findings.

Among all EFs, the relationship between working memory and writing is the most explored, especially in school-age children (Hooper et al., 2021). Several studies

showed that working memory is a significant predictor of text quality throughout schooling, at least from Grade 2 (Berninger et al., 2010; Cordeiro et al., 2020). However, a cross-sectional study, comparing the links between EFs and text length (a good indicator of writing quality), found supporting evidence for the predictive role of working memory in Grade 2 and 8, but not in Grade 4 (Salas & Silvente, 2020). These findings revealed that the link between working memory and writing may not be as consistent across development as assumed in theoretical models of writing. Inhibitory control has also been linked with writing performance. This EF measured in Grade 4 was found to contribute to text length in Grade 4 (Drijbooms et al., 2015) and syntactic complexity in Grade 6 (Drijbooms et al., 2017) Salas and Silvente (2020) also reported that inhibition was directly and/or indirectly (via transcription) related to text length in Grade 2, 4, and 8. Nevertheless, Cordeiro et al., (2020) did not find this link in Grade 2. Hooper et al., (2002) showed that inhibition did neither differ between good and poor fourth and fifth grade writers, nor predicted written expression. Perhaps the less consistent link between EFs and writing involves cognitive flexibility. Altemeier et al., (2008) showed that cognitive flexibility (along with inhibitory control) predicted word fluency and sentence combining skills in Grades 3 to 5. Similarly, Balioussis et al., (2012) found all core EFs, including cognitive flexibility, to predict syntactic complexity in persuasive but not narrative writing in Grades 3 and 5. Despite this evidence, many of the studies reported above did not find this EF to predict writing (Cordeiro et al., 2020; Drijbooms et al., 2015, 2017).

All in all, although there is theoretical and empirical research supporting the involvement of working memory, inhibitory control, and cognitive flexibility in writing, there are also studies failing to replicate those links. Moreover, a recent longitudinal study using complex statistical modeling failed to find a developmental association between EFs and written expression throughout primary school (Costa et al., 2020). Clearly, despite the widespread theoretical assumptions about the role of EFs in writing, more research, mainly longitudinal, seems needed to examine the relationship between different components of EFs and writing, as proposed in the present study.

Transition from Grade 4 to 5

In Portugal, the educational system includes four stages: preschool, basic, secondary, and higher education (Ministério da Educação, 2007). Whereas preschool and higher education are facultative, basic and secondary stages are mandatory. Basic education is composed of three cycles: Grades 1–4 (primary), Grades 5–6 (intermediate) and Grades 7–9 (upper intermediate). Secondary education (Grades 10–12) offers three study programmes: Scientific-Humanistic, Technologic and Professional and Specialized Art. During their academic life, a crucial moment faced by students is, therefore, the transition from primary to intermediate grades, that is, from Grade 4 to 5.

This transition is an important milestone, because children are confronted with an educational system completely different from their learning experiences so far (Mac Iver & Epstien, 1993). In the Portuguese system, this transition is characterized by contextual and personal changes. Students tend to go to a different school and

faced an increased workload and a new organization of the curriculum, now split into specific subjects. The curriculum becomes more demanding with the increase in the number of subjects and class hours. The number of teachers also increases, resulting in less centralized teacher-student relationships. However, if, on the one hand the teacher-student relationship becomes more distant, promoting students' autonomy, on the other hand, it can trigger an increase in stress levels, creating feelings of fear and insecurity (Choi, 2012). There is evidence in the literature (Gomes & Carvalho, 2007) confirming that school transitions can be associated with a decrease in academic grades and motivation as well as with an increase in socio-emotional difficulties, such as lower self-esteem and self-concept (Coelho & Romão, 2017).

In Portugal, unlike many countries (e.g., United Kingdom or Spain), the transition to intermediate grades occurs very early, usually when children have 9–10 years of age. This means that a transition that already encompasses a multiplicity of changes in the school context coincides with a period of development associated with significant personal changes in biological, socioemotional, and psychological domains (Coelho & Romão, 2017). Little is known about the role these changes can play in the development of writing and its underlying processes, namely, transcription and EFs.

In a cross-sectional study, Alves & Limpo (2015) demonstrated an increase in spelling accuracy from Grade 4 to 5, but the same was not found for handwriting speed. Graham et al., (1998) also found that, despite an overall growth throughout schooling, the rate of growth in handwriting seemed slower from Grade 4 to 5. It is not clear if this transition affects the development of EFs. These are known to develop progressively and asymmetrically, as each component has its own development trajectory (Diamond, 2013). Inhibitory control is the first EF to be developed, supporting all other EFs (Hooper, 2021). Between the ages of 4 and 5 children become progressively more able to inhibit initial reactions and act more thoughtfully. Despite emerging at an early age, the development of inhibition continues until adolescence, when it reaches the adult-equivalent level (Best & Miller, 2010). Similarly, working memory begins to manifest and become more functional around age 4, with its developmental trajectory being tracked into the early teenage years (Best & Miller, 2010). Cognitive flexibility, which builds on inhibitory control and working memory, comes later in development, between the ages of 5 to 7 (Best & Miller, 2010). Overall, in intermediate grades, students are expected to be able to respond to different tasks simultaneously, shift attention quickly between different tasks, and have greater working memory capacity (Guy et al., 2004). These findings are in accordance with Mizuno et al., (2011), which showed that the transition from Grade 4 to 5 brings gains in inhibitory control, working memory, adaptive problem solving, and planning. Altemeier et al., (2008) also found improvements in EFs from Grade 1 to 5. However, despite being steady for inhibition, these improvements slowed down for cognitive flexibility. Examining the longitudinal development of transcription and EFs in the transition from primary to intermediate school can be particularly useful to understand whether students need additional help to develop these fundamental skills. Given the additional writing demands imposed after primary school, entering intermediate grades with poor transcription skills and EFs can compromise the future development of writing.

The present study

The present study had a twofold goal: to examine the development of transcription skills (viz., handwriting speed and spelling accuracy) as well as three core EFs (viz., verbal working memory, inhibitory control, and cognitive flexibility) in Portuguese children transitioning from primary (Grade 4) to intermediate school (Grade 5); and to evaluate the longitudinal and concurrent relationships of transcription and EFs measured in Grades 4 and 5 with text quality measured in Grade 5. We asked the following research questions (RQs):

RQ1 Are there differences in transcription and EFs in the transition from Grade 4 to 5?

RQ2 Are transcription and EFs longitudinally and/or concurrently related to text quality in Grade 5?

Stemming from the research previously surveyed, we anticipated a progressive increase in transcription and EFs as children moved from primary to intermediate grades (Abbott et al., 2010; Alves & Limpo 2015; Drijbooms et al., 2017). Moreover, based on prior findings (e.g., Cordeiro et al., 2020; Drijbooms et al., 2015; Salas & Silvente, 2020), we expected that transcription and EFs in Grade 4 and 5 would have a unique and independent association with text quality in Grade 5, above and beyond previous school achievement and the presence of special education needs. These variables are known to be related with the quality of texts produced by children. Previous school achievement was controlled because there is consensus that students' previous knowledge constitutes a solid basis on which later learning is built (Almeida, 1996). This variable was also a predictor of student success throughout schooling, which can facilitate the transition to a new schooling cycle (Almeida, 1996). Regarding special education needs, several studies indicated that students with learning difficulties or other special educational needs have greater difficulties in writing texts, compared to students without difficulties (Graham et al., 2001). For this reason, it is common to exclude these students from data-analytic samples. Rather than doing that, to achieve a more representative sample we opted to statistically control this aspect.

Overall, this study will extend current knowledge in three ways. First, the present study examines the predictive role of transcription skills and EFs in children's writing quality. Despite the considerable amount of research focused on transcription (Graham & Santangelo, 2014; Santangelo & Graham, 2016), few studies explored the role of EFs in children's writing (Limpo & Olive, 2021) and even less simultaneously tested the role of transcription and EFs in the same research design (but see Cordeiro et al., 2020). Thus, this study will contribute to move the field forward by providing evidence on the relative contribution of key cognitive processes in writing, thereby testing central assumptions of past (Berninger & Winn, 2006) and recent writing models (Graham, 2018a, b). Second, the role of transcription and EFs in writing will be explored through a longitudinal design, which is the greatest asset of this study. Indeed, most of the prior studies focusing on this topic used cross-sectional methodologies, raising concerns about the nature of the relationships found and their

respective interpretation. The lack of longitudinal studies in writing is a major limitation in the field (Hooper et al., 2021), which our study intends to overcome. Third, our study focuses on a critical period in children's development, specifically, the transition from primary to intermediate grades. In addition to curriculum changes, this transition involves changes in different domains of children's lives, that may turn it into one of the most difficult moments in their academic path. By studying writing processes in this period, this study will generate relevant information concerning students' need of additional assistance to overcome the challenges of this transition and their possible detrimental effect in children's writing and underlying processes.

Method

Participants

Two hundred and twenty-two Portuguese students in Grade 4 (108 boys, 114 girls) with an average age of 9.75 years ($SD = 0.43$; range 9.09 to 11.25 years), who were reassessed one year later, in Grade 5, participated in this study. These students came from 16 fourth-grade classes in a set of public schools in the North of Portugal. Parental consent was obtained for each child participating in the study. Their socioeconomic status was measured through their mother's education level, which was as follows: 6.8% completed Grade 4, 32.9% completed Grade 5–6, 35.6% completed Grade 9, 21.6% completed high school, 1.8% completed college or above.

Procedure

All students were evaluated annually in the second term of each school grade. The tasks were administered in one group session of 10 min in Grade 4 and 30 min in Grade 5. In both grades, the group session occurred in-between two 45-minute individual sessions. Students were asked to do handwriting (viz., copy) and spelling tasks (viz., dictation of words) in the group sessions in Grades 4 and 5. In Grade 5 only, they were additionally asked to write an opinion essay. In the individual sessions, which took place in a quiet room provided by the school, students were asked to perform the EFs tasks, similarly in Grade 4 and 5. The order of the individual sessions was counterbalanced, but task order within sessions was held constant. Between the two measurement years, students received regular lessons about the contents presented in the curricula.

Measures

Control variables

We collected previous school achievement using Portuguese and Mathematics grades in the first term of Grade 4. These grades are assigned by teachers using a scale ranging from 1 (*lowest score*) to 5 (*highest score*). We also gathered information on the presence of special education needs. To have a sample as representative as possible,

all students were included and the presence of special educational needs ($n=7$) was statistically controlled.

Transcription Skills

To assess handwriting speed, we used a copy task and to assess spelling accuracy, a word dictation task. In the copy task, students were asked to copy a 9-word sentence as quickly as possible, without making mistakes, for 90 s (Limpo & Alves, 2018). The sentence was "O rouxinol azul fugiu do jardim porque chovia bastante" (The blue nightingale ran away from the garden because it rained a lot). The final score was the number of words accurately copied, with higher scores indicating greater handwriting speed. In the spelling task, we dictated a set of 16 words (cf. Appendix). These words were organized into four categories, representing the following complexities of the Portuguese spelling system: inconsistencies, consonant group, silent <h> and stress marks (a task validated by Magalhães et al., 2020). The final score was the number of correctly spelled words, thus higher scores indicating better spelling skills. For the copy and spelling tasks, 15% of the written responses were doubled scored. Inter-rater reliability was high, as indicated by the intraclass correlation coefficient for single measures (above 0.98 for both tasks in Grade 4 and 5).

Executive functions

Verbal working memory We assessed verbal working memory through the Digit Span subtest from the Wechsler Intelligence Scale for Children-III (WISC-III; Simões et al., 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. Total scores were the number of sequences completed in forward order and the number of sequences completed in backward order. Higher scores correspond to higher verbal working memory. It should be noted that the forward task measures short-term memory capacity (recall and immediate repetition) and the backward task taps more directly executive processing within verbal working memory (Diamond, 2013). Thus, we examined growth on these variables separately, but calculated their average to create a composite score, which was introduced in the regression analysis to reduce the number of predictors and increase power. Correlations between forward and backwards scores were 0.40 and 0.45 in Grade 4 and 5, respectively.

Inhibitory control We used the inhibition combined score of the Inhibition subtest of the Development Neuropsychological Assessment Battery II (Korkman et al., 2007). This test evaluates children's ability to quickly inhibit automatic responses in favor of adjusted responses. This task is organized into two parts. In the first part, participants receive a sheet with a series of circles and squares, and in the second part, they are presented with arrows pointing up or down. In both parts, children are asked to say the opposite shape (i.e., saying square when circle and vice-versa) or arrow direction (i.e., saying up when pointing down and vice-versa). The maximum duration of each

part is 240 s. The final score is a combination of the time used and errors committed, as described in the task manual (Korkman et al., 2007). A higher combined score indicates better inhibition skills. This task was shown to exhibit good test-retest reliability ($r=0.81$, Brooks et al., 2009) and excellent internal consistency (Cronbach's alpha = 0.92; Korkman et al., 2007).

Cognitive flexibility We used the flexibility combined score of the verbal fluency (Semantic and Phonemic) subtest of the Coimbra Neuropsychological Assessment Battery (BANC) (Simões et al., 2016). The semantic and phonetic fluency subtests evaluate children's ability to verbalize the largest number of words in different semantic categories during 60 s (viz., animals, names, and food) and of words beginning with a given sound (viz., P-M-R). After being presented with examples, participants are asked to verbalize their answers. Each correct answer receives one point. Incorrect answers include words that do not match the category/sound, meaningless or repeated words, and words that had been given as examples. The final score is the sum of correct words given in the semantic and phonemic fluency tasks. As with verbal working memory scores, though we examined progress separately by task, we averaged the two scores to create a composite score introduced in the regression analysis. Correlations between semantic and phonemic fluency scores were 0.59 and 0.54 in Grades 4 and 5, respectively.

Text quality

In Grade 5 only, each student was asked to write an opinion essay considering the following question "Do you think children should eat sweets whenever they want?". Students had 10 min to write the text, and they were notified 5 and 2 min before the end of the time limit. Anytime a student stopped writing, he or she was prompted once to continue. During the task, students were not helped in any aspect of text production (e.g., vocabulary, spelling).

The quality of the text was assessed by two research assistants, blind to study purposes, after removing all identifying information. Because there is evidence that texts' handwriting and spelling features influence their holistic quality assessments (Graham et al., 2011), all texts were typed and corrected for spelling and punctuation errors before being evaluated. This procedure, whose validity is well established in different genres and grades (e.g., Limpo & Alves, 2018; Limpo et al., 2020), allowed us to set apart transcription skills (measured with other tasks) from text quality. Raters were asked to read each text and, using a holistic scale ranging from 1 (*low quality*) to 7 (*high quality*), to rate each one with a single score, considering the following factors: creativity (originality and relevance of ideas), coherence (clarity and organization of the text), syntax (syntactic correctness and diversity of sentences) and vocabulary (diversity, interest and proper use of words). Several previous studies have demonstrated the validity of this procedure to assess writing quality in Portuguese school-age children (Limpo & Alves, 2013; Limpo et al., 2017; Cordeiro et al., 2020). 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 qual-

ity scores were the average of the two judges. The intraclass correlation coefficient for average measures was 0.94.

Results

Table 1 displays descriptive statistics for all variables for Grades 4 and 5. We tested if our data met the normality assumption of parametric procedures. Inspection of skewness (Sk) and kurtosis (Ku) revealed no distributional problems, as the absolute values of these indexes did not exceed 3.0 and 10.0, respectively (Kline, 2005). Inferential statistics were then conducted to answer our RQs, using an alpha level of 0.05. Though p-values equal or close to alpha were considered significant, they should be read carefully and interpreted together with effect sizes.

RQ1: Are There Differences in Transcription and EFs in the Transition from Grade 4 to 5

Paired sample t-tests were used to compare performance in transcription and EFs tasks between Grade 4 and 5. The results indicated significant differences in all measures examined except inhibitory control $t(221) = -0.80$, $p = 0.43$, $d = -0.08$ (see Table 1). Specifically, from Grade 4 to 5, we observed a large increase in handwriting speed ($d = 1.14$) and medium-size increases in spelling ($d = 0.67$), verbal working memory ($d = 0.51$), and cognitive flexibility ($d = -0.66$) (interpretation based on Cohen, 1988).

RQ2: Are Transcription and EFs Longitudinally and/or Concurrently Related to Text Quality in Grade 5?

To answer this RQ, we first examined correlations between all variables, which are in Table 2. Overall, the analyses indicated that transcription skills were moderately correlated between and within grades. Similar findings were found for EFs.

To examine whether transcription and EFs in Grades 4 and 5 predicted text quality in Grade 5, we conducted a hierarchical regression analysis. A stepwise procedure was used to test five models (see complete results in Table 3). On Step 1, we introduced special education needs (0 = no special education needs; 1 = presence of special education needs) and children's grades in Portuguese and Mathematics. On Step 2, we added transcription skills, namely, handwriting speed, and spelling accuracy in Grade 4. On Step 3, we introduced EFs assessed in Grade 4. On Step 4, we added transcription in Grade 5. Finally, on Step 5, we introduced EFs in Grade 5. Before conducting the analysis, we confirmed that there was no evidence of multicollinearity between independent variables, as tolerance and variance inflation factor were, respectively, above 0.36 and below 3 (Kline, 2005). Following the guidelines provided by Tabachnick & Fidell (2007), the visual examination of the residual scatter plot indicated no evidence of heteroscedasticity.

Step 1 was statistically significant, adjusted $R^2 = 0.16$, $F(3, 218) = 15.46$, $p < 0.001$. When Grade 4 transcription was entered, the model remained significant, adjusted $R^2 = 0.19$, $F(5, 216) = 11.66$, $p < 0.001$, with an increase in the amount of variance

Table 1 Means, standard deviations and T-Tests for all variables observed by Grade

		Grade 4				Grade 5				Grade 4 vs. 5		
Measures		*M*	*SD*	Sk	Ku	*M*	*SD*	Sk	Ku	*t*	*p*	*d*
Previous academic performance												
	Portuguese grades	3.64	0.75	0.11	−0.46							
	Mathematics grade	3.60	0.88	−0.06	−0.70							
Transcription												
	Handwriting speed	21.43	5.22	−0.19	0.71	25.75	4.80	−0.22	0.11	12.02	< 0.001	1.14
	Spelling accuracy	8.59	2.63	−0.72	0.43	9.46	2.46	−0.87	1.49	6.97	< 0.001	0.67
EFs—Verbal Working memory (composite)		5.75	1.24	1.00	1.62	6.19	1.47	1.07	2.69	5.23	< 0.001	0.51
	Digits forward	7.14	1.58	1.14	2.77	7.64	1.73	0.68	1.04	4.80	< 0.001	0.46
	Digits backward	4.36	1.40	0.56	0.48	4.73	1.72	1.50	5.77	3.13	0.002	0.30
EFs—Inhibitory control		9.93	3.48	0.11	−0.31	9.74	3.51	0.14	−0.35	−0.80	0.43	−0.08
EFs—Cognitive flexibility (composite)		29.43	7.65	0.43	0.32	32.35	7.87	0.17	−0.47	6.87	< 0.001	0.66
	Semantic fluency	43.67	10.86	0.45	0.33	45.47	10.61	0.16	−0.58	3.01	0.003	0.28
	Phonemic fluency	15.19	6.13	0.42	0.08	19.23	7.22	0.40	0.05	9.58	< 0.001	0.92
Text quality						3.53	1.37	0.35	−0.47			

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Grade 4																					
1. Portuguese grades	-	.73**	.15*	.51**	.39**	.31**	.35**	.39**	.37**	.34**	.32**	.17**	.48**	.42**	.31**	.41**	.31**	.32**	.28**	.29**	.40**
2. Mathemathics grades		-	.04	.43**	.36**	.22**	.39**	.32**	.30**	.28**	.27**	.14*	.39**	.39**	.29**	.38**	.34**	.29**	.23**	.31**	.25**
3. Handwriting speed			-	.25**	.18**	.25**	.03	.12	.11	.08	.12	.43**	.27**	.11	.15*	.03	.04	.08	.10	.02	.20**
4. Spelling accuracy				-	.32**	.25**	.29**	.29**	.26**	.23**	.24**	.24**	.74**	.30**	.26**	.26**	.21**	.22**	.12	.29**	.37**
5. Verbal working memory - composite					-	.86**	.81**	.28**	.27**	.23**	.27**	.10	.29**	.59**	.55**	.46**	.28**	.29**	.22**	.30**	.15*
6. Verbal working memory - digits forward						-	.40**	.19**	.18**	.15*	.18**	.12	.24**	.55**	.56**	.39**	.19**	.24**	.19**	.22**	.13
7. Verbal working memory - digits backward							-	.29**	.28**	.25**	.27**	.04	.25**	.44**	.36**	.39**	.29**	.25**	.18**	.29**	.13
8. Inhibitory control								-	.34**	.30**	.32**	.14*	.24**	.23**	.17*	.22**	.51**	.25**	.20**	.24**	.20**
9. Cognitive flexibility – composite									-	.95**	.82**	.15*	.29**	.32**	.31**	.23**	.29**	.67**	.65**	.49**	.38**
10. Cognitive flexibility - semantic fluency										-	.59**	.16*	.29**	.29**	.28**	.21**	.25**	.61**	.65**	.37**	.36**
11. Cognitive flexibility - phonemic fluency											-	.09	.23**	.29**	.29**	.20**	.29**	.58**	.47**	.57**	.30**
Grade 5																					
12. Handwriting speed												-	.22**	.09	.08	.08	.09	.12	.14*	.05	.27**
13. Spelling accuracy													-	.27**	.24**	.23**	.18**	.23**	.18**	.23**	.39**
14. Verbal working memory- composite														-	.85**	.85**	.34**	.34**	.32**	.27**	.19**
15. Verbal working memory - digits forward															-	.46**	.32**	.35**	.33**	.28**	.19**
16. Verbal working memory - digits backward																-	.26**	.23**	.22**	.18**	.14*
17. Inhibitory control																	-	.33**	.28**	.31**	.27**
18. Cognitive flexibility - composite																		-	.92**	.82**	.36**
19. Cognitive flexibility - semantic fluency																			-	.54**	.33**
20. Cognitive flexibility - phonemic fluency																				-	.31**
21. Text quality																					-

*$p < .05$; **$p < .01$

Table 2 Pearson's Correlations between all Measures by Grade

explained in text quality in Grade 5, $\Delta R^2 = 0.03$, F_{change} (2, 216) = 5.09, $p < 0.001$. When Grade 4 EFs were entered on Step 3 the model remained significant, adjusted $R^2 = 0.24$, $F(8, 213) = 9.85$, $p < 0.001$. There was an increase in the amount of explained variance, $\Delta R^2 = 0.05$, F_{change} (3, 213) = 5.59, $p < 0.001$. In Step 4, we introduced Grade 5 transcription. The model was significant, adjusted $R^2 = 0.26$, $F(10, 211) = 8.94$, $p < 0.001$, and there was an increase in the explained variance in text quality in Grade. 5, $\Delta R^2 = 0.02$, F_{change} (2, 211) = 4.15, $p = .01$. The last model, including Grade 5 EFs, was also significant, adjusted $R^2 = 0.29$, $F(13, 208) = 7.85$, $p < 0.001$., and there was an increase in the amount of variance explained in text quality, $\Delta R^2 = 0.02$, F_{change} (3, 208) = 3.26, $p = 0.02$. We found that handwriting speed (β = 0.14, $p = 0.03$), spelling accuracy (β = 0.19, $p = 0.04$) cognitive flexibility (β = 0.15, $p = 0.05$) and inhibitory control (β = 0.15, $p = 0.04$), all measured in Grade 5, were predictors of text quality also measured in Grade 5.

Discussion

This study aimed to answer two RQs. In the first one, we examined the development of transcription and EFs from Grade 4 to 5. In the second one, we evaluated the longitudinal and concurrent links between transcription and EFs to text quality in Grade 5. Findings are discussed below in line with these questions.

RQ1: Are there differences in transcription and EFs in the transition from Grade 4 to 5?

In general, results confirmed our hypothesis that transcription and EFs would increase from Grade 4 to 5. Concerning transcription skills, results showed significant improvements both in handwriting speed and spelling accuracy. Specifically, from Grade 4 to 5, we found an increase of four words in the copy task and one correctly spelled word in the dictation task. These results are in line with previous cross-sectional

Table 3 Regression analysis: Predictors of text quality in Grade 5

Measures	*B*	β	*t*	*p*
Step 1				
Portuguese grades	0.86	0.47	5.27	< 0.001
Mathematics grades	− 0. 16	− 0.10	− 1.15	0.25
Special education needs (0 = no, 1 = yes)	− 0.83	− 0.11	− 1.72	0.09
Step 2				
Portuguese grades	0.66	0.36	3.79	< 0.001
Mathematics grades	− 0.16	− 0.10	− 1.13	0.26
Special education needs	− 0.23	− 0.03	− 0.45	− 0.66
Grade 4 Handwriting speed	0.03	0.10	1.60	0.11
Grade 4 Spelling accuracy	0.10	0.19	2.45	0.01
Step 3				
Portuguese grades	0.57	0.31	3.27	< 0.001
Mathematics grades	− 0.17	− 0.11	− 1.21	0.22
Special education needs	− 0.25	0.03	− 0.50	0.62
Grade 4 Handwriting speed	0.03	0.10	1.60	0.11
Grade 4 Spelling accuracy	0.09	0.18	2.35	0.02
Grade 4 Verbal working memory (composite)	− 0.09	− 0.08	− 1.16	0.25
Grade 4 Inhibitory control	− 0.01	− 0.01	− 0.20	0.84
Grade 4 Cognitive flexibility (composite)	0.05	0.26	3.98	< 0.001
Step 4				
Portuguese grades	0.52	0.29	3.01	< 0.001
Mathematics grades	− 0.19	− 0.12	− 1.35	0.18
Special education needs	0.08	0.01	0.15	0.88
Grade 4 Handwriting speed	0.01	0.03	0.45	0.65
Grade 4 Spelling accuracy	0.03	0.06	0.70	0.49
Grade 4 Verbal working memory (composite)	− 0.08	− 0.07	− 1.04	0.30
Grade 4 Inhibitory control	− 0.01	− 0.02	− 0.28	0.79
Grade 4 Cognitive flexibility (composite)	0.04	0.24	3.65	< 0.001
Grade 5 Handwriting speed	0.04	0.14	2.16	0.03
Grade 5 Spelling accuracy	0.10	0.18	1.97	0.05
Step 5				
Portuguese grades	0.53	0.29	3.10	< 0.001
Mathematics grades	− 0.23	− 0.15	− 1.74	0.08
Special education needs	0.13	0.02	0.26	0.80
Grade 4 Handwriting speed	0.01	0.04	0.58	0.56
Grade 4 Spelling accuracy	0.03	0.07	0.73	0.47
Grade 4 Verbal working memory (composite)	− 0.10	− 0.09	− 1.17	0.24
Grade 4 Inhibitory control	− 0.03	− 0.08	− 1.10	0.27
Grade 4 Cognitive flexibility (composite)	0.02	0.13	1.63	0.11
Grade 5 Handwriting speed	0.04	0.14	2.13	0.03
Grade 5 Spelling accuracy	0.10	0.19	2.09	0.04
Grade 5 Verbal working memory (composite)	− 0.02	− 0.02	− 0.34	0.74
Grade 5 Inhibitory control	0.06	0.15	2.11	0.04
Grade 5 Cognitive flexibility (composite)	0.03	0.15	1.94	0.05

findings showing that Portuguese students acquire greater automaticity in transcrip-

tion skills throughout schooling (Alves & Limpo, 2015). Similar evidence has been found in other countries, such as Spain (Salas & Silvente, 2020), which has a similar teaching approach to writing (Fernández-Rufete Navarro, 2015). This approach is characterized by explicit instruction and extensive practice in transcription only in primary grades (Limpo et al., 2020). However, as shown here, these basic skills continue to develop after these years, even without explicit attention from teachers. This means that greater improvements would be achieved if these skills were worked out explicitly. Considering the association between transcription and writing quality at all levels of education (e.g., Limpo & Alves 2013; Abbott et al., 2010; Salas & Silvente, 2020), the explicit instruction and practice of handwriting and spelling beyond primary grades may be bring additional benefits to writing development.

Regarding EFs, we found a relevant growth in verbal working memory and cognitive flexibility from Grade 4 to 5. Previous research had already shown a progressive development in these skills (Correia, 2017; Gathercole, 1999). In the transition from primary to intermediate school, children increased their capacity to retain, manipulate, and monitor information in mind, as well as to switch between tasks. This is a relevant attainment as these processes may set the basis for success in school and play an important role in everyday life (Diamond, 2013). However, a similar growth was not observed for inhibitory control, which was stable from Grade 4 to 5. This result may indicate that inhibitory control, which is fundamental for the development of other EFs (Diamond, 2013), may be characterized by a longer developmental progression. This has already been suggested by Altemeier et al., (2008), who found similar results. Likewise, Brocki & Bohlin (2004) concluded that despite being the first EF to develop, in the 3–4 years age range, inhibitory control continues to mature during adolescence. Together, these findings strengthen the importance of implementing supplementary practices to boost the development of children's ability to control their attention and ignore internal or external stimuli (Diamond, 2013).

It should be highlighted that the growth in transcription and EFs observed here occurred in a critical moment for children, that of transitioning from primary to intermediate school. This transition entails new challenges for children because of associated contextual changes (school, teachers, subjects) and expectations regarding school performance (Gomes & Carvalho, 2007). Given these challenges, it is encouraging that this transition is nevertheless attended with improvements in basic transcription skills and fundamental cognitive processes. This may represent solid foundations to deal with the heightened demands of intermediate school.

RQ2: Are transcription and EFs longitudinally and/or concurrently related to text quality in Grade 5?

To answer this RQ, we conducted a 5-step hierarchical regression analysis. In what follows, we discuss findings concerning the predictive role of control variables, transcription, and EFs.

In the first step of the analysis, we included Portuguese and Mathematics grades along with special education needs as predictors. Previous grades in Portuguese, but not in Mathematics, were significant predictors of text quality in Grade 5. In the Portuguese subject, children develop core literacy-related competencies in their native

language, such as oral expression, written expression, understanding of orality, reading and linguistic awareness. Writing is therefore a fundamental competence targeted in this subject (Ministério da Educação, 2007; Niza et al., 2011). Thus, it is not surprising that those who previously achieved better grades in Portuguese were capable of producing better texts. Although there is evidence that special educational needs may be an obstacle to learning (Graham et al., 2001), this variable was not a statistically significant predictor of text quality in the current study. This can be related to the reduced number of students with special educational needs as well as to the inclusion of different disorders, without considering the varying difficulties inherent to them. However, these results should be read carefully as the presence of special education needs was not the main focus of our work.

Results showed that Grade 4 transcription skills had a longitudinal relationship with text quality in Grade 5, above and beyond previous Portuguese grades. Specifically, spelling was a predictor of text quality, confirming the key role that spelling plays in the production of good texts (Graham et al., 1997; Abbott et al., 2010; Limpo & Alves, 2013). This result is consistent with the longitudinal study of Abbott et al., (2010), which demonstrated that spelling skills were the most stable predictor of text quality throughout schooling. However, in the current study, the relationship between Grade 4 spelling to Grade 5 text quality disappeared when Grade 5 spelling was introduced into the model. The concurrent link of spelling and text quality in Grade 5 is in line with prior cross-sectional findings, showing that spelling constrains text quality, mainly at the end of primary grades and afterwards (Graham et al., 1997; Abbott et al., 2010; Limpo & Alves, 2013). Our findings extend these results by showing that this link exists even when previous spelling skills are controlled. It seems that current spelling abilities are more relevant to text writing than previous ones.

Our findings also showed that handwriting speed in Grade 4 did not predict text quality in Grade 5. Similar results have already been reported in the longitudinal study of Abbott et al. (2010), indicating a lack of a longitudinal association between handwriting and text quality. However, when we added handwriting speed in Grade 5 to the model, this variable proved to be a significant predictor. This result aligns with evidence from cross-sectional studies showing that higher handwriting speed predicts better text quality, with a more prominent role than spelling (Salas & Silvente, 2020). Together, these findings suggest that there is a concurrent but not longitudinal relationship between handwriting speed and text quality.

Overall, in the final model, both handwriting speed and spelling accuracy in Grade 5 were significant predictors of text quality in Grade 5. These concurrent, but not longitudinal links, support the importance of explicit instruction and systematic practice in transcription to be sustained over time (Graham & Santangelo, 2014; Limpo & Alves, 2018). Indeed, after primary school, children's abilities to copy written words fast (Limpo et al., 2017) and to accurately write dictated words (Magalhães et al., 2020) predicted the quality of their texts. Thus, if teachers promote the automatization of transcription, they will be contributing to enhance text quality by freeing up attentional resources that can be devoted to high-level writing processes (Berninger & Winn, 2006).

When Grade 4 EFs were introduced in the regression model predicting Grade 5 text quality, cognitive flexibility was found to be a significant predictor. However,

when Grade 5 cognitive flexibility was added to the model, this longitudinal link was replaced by a concurrent one. Together, both cognitive flexibility and inhibitory control in Grade 5 were significant predictors of text quality in Grade 5, as also found by Altemeier et al. (2008) with students from Grades 3 to 5. These EFs may help writing in different ways. For example, during the process of translating ideas into written language, it is through cognitive flexibility that children can switch between lower (e.g., identifying each letter in individual words) and higher levels of processing (e.g., maintaining the superficial form of the planned phrase) (St. Claire-Thompson & Gathercole, 2006). Inhibitory control may also be essential. For example, when transcribing their ideas, children must focus and keep their attention to the task at hand while ignoring outside distractions and inhibiting impulses to change the idea until the sentence is finished and they can see what it looks like in print (Graham, 2021).

Contrary to our expectations, verbal working memory, both in Grade 4 and 5, was not a significant predictor of text quality. This finding contrasts with other longitudinal and cross-sectional studies associating children's working memory and text quality Cordeiro et al., 2020; Salas & Silvente, 2020; St Clair-Thompson & Gathercole, 2006). However, other studies with fourth graders also failed to report an association between working memory and writing performance, measured via syntactic complexity or the content of the story (Drijbooms et al., 2015) or via text length (Salas & Silvente, 2020). Our findings join to this body of research suggesting that this relationship may not be as robust as expected. These mixed findings can be related to methodological characteristics of the studies, such as participants' age, measures used to assess working memory and text quality, and also the statistical approach used to inspect this link.

In sum, our findings showed that both transcription and EFs play a role in the production of written texts, which is aligned with the propositions of the WWC model (Graham, 2018a, b). Additionally, our results suggested that transcription and EFs showed progress in one year and that current rather than past performance seems a more relevant predictor of text quality. Some results are however in need of additional tests and should be read carefully. Given the low beta coefficients and p-values close or equal to 0.05, the predictive role of spelling, cognitive flexibility, and inhibition requires further replication.

Limitations and indications for future research

When interpreting the results of the present study, six limitations should be considered. First, we only examined the role of three core domains of EFs, inhibitory control, verbal working memory and cognitive flexibility. However, in addition to these lower-level EFs, Diamond (2013) proposed a conceptualization including higher-level EFs (viz., planning, reasoning, problem solving and decision making). Though not addressed here, there is evidence suggesting that these EFs may also be relevant in beginning writing (e.g., Cordeiro et al., 2020). Future studies should therefore aim for a broader and comprehensive measurement of EFs, to ascertain the differential association between low and high-level EFs with writing.

Second, we did not measure motivational factors, which play a key role in writing (Graham, 2018b). As these factors seem related to transcription (Limpo & Alves, 2013; Limpo et al., 2020) and text quality (Rocha et al., 2019), we cannot know whether including them in our model would change the pattern of relationships observed. Further studies testing comprehensive models, targeting both cognitive and motivational processes in writing, are needed. These studies should also consider tapping this affective dimension in EFs, typically known has "hot EFs" (Kerr & Zelazo, 2004), which were not measured in the present study, only focused on "cold EFs". Recently, Georgiou (2021) provided relevant insights on how to develop measures to bridge the gap between hot and cold EFs to understand their role in writing, which are worthy of consideration as a follow-up of this study.

Third, the assessment of text quality in this study was restricted to opinion essay writing, which may limit the generalization of findings to other genres. A relevant path for future research would be to consider other genres, such as narratives or descriptions. This would allow us to understand whether the association of transcription and EFs with text quality here observed is genre-specific or universal.

Fourth, handwriting speed was assessed with a pen-and-paper copy task, providing us only product information about number of copied words in 90 s. Still, this task is limited as it does not give any insight about the processes underlying that result, which could help to understand the role of handwriting in writing. Currently, there are several logging tools (Rosenblum et al., 2003) that allow researchers to combine product and process data. A particularly useful one is the Eye and Pen (Alamargot et al., 2010), which collects a large range of process data (e.g., pauses and bursts) including eye movements. Future research should replicate the reported results using technology-based tools to collect not only product but also process information as a means to achieve fine-grained assessments of students' handwriting abilities (for an example on how this can be done see Limpo & Alves, 2017).

Fifth, our research questions were answered with statistical approaches that do not account for measurement error nor control for students' clustering within classes. Moreover, the regression analyses did not provide information about the potential mediating or moderating effects of transcription and EFs. In the future, it would be important to examine these links in larger samples. This would allow the modeling of these relationships through complex statistical approaches, such as structural equation modeling (for an example see Costa et al., 2020). By accounting for measurement error and allowing the testing of models with direct and indirect associations as well as interactions between variables, those approaches can provide insightful findings concerning the role of transcription and EFs in writing.

Finally, this study focused on a particular period in Portuguese students' academic life, namely, the transition from Grade 4 to 5. This was a thoughtful decision, as we wanted to examine whether transcription and EFs would progress in this challenging period. Yet, targeting this transition limits the generalization of our findings to other educational contexts, in which an analogous transition does not happen in this age range (e.g., United Kingdom or Spain). Cross-cultural comparisons targeting 9–10-year-olds' writing skills would be particularly insightful to understand the impact of stage vs. age transitions in writing.

Educational implications

The present study highlighted the importance of transcription and EFs in developing writers. It is now well-established that the daily practice of transcription skills, mostly through copy and spelling tasks, is essential to produce high-quality texts (Berninger et al., 2002; Limpo & Alves, 2018; Santangelo & Graham, 2016). Given the importance of these skills to writing beyond primary school, that kind of practice should be kept until a sufficient level of automatization is achieved. Despite accumulating evidence on the relevance of EFs in writing (for a recent review, see Limpo & Olive 2021), these skills are overlooked in curricular goals (Ministério da Educação, 2018). Thus, there is a need to introduce complementary curricular programs to stimulate these skills. For example, these programs can focus on self-regulation in the classroom (such as the "Sarilhos do Amarelo" program developed by Rosário et al., 2012, for the Portuguese context) or target mindfulness skills, which have been found to be associated with enhanced EFs and literacy-related skills (Bakosh et al., 2015), including in Portuguese children (Cordeiro et al., 2021). Overall, in spite of the transcription and EFs progress observed here, there is ample room for improvement through additional instructional programs. These are likely to bring benefits to writing development and, ultimately, success in school.

Appendix 1

16 Words List used in the Spelling-to-Dictation Test.

Words	Complexity category
Teclado	**Consonant cluster**: refers to consecutive consonants at the onset of a syllable (CCV syllable). In this category, the second consonant of the cluster was /ɾ/ or /l/.
Drama	
Sagrado	
Dupla	
Júri	**Stress marks**: indicate whether the vowel is open or closed through a rule-based placement of diacritics to indicate lexical stress.
Fértil	
Último	
Pêndulo	
Gema	**Inconsistency**: occurs when a phoneme-grapheme mapping is not predictable on the basis of contextual rules. For example, the phoneme /ʒ/ can be represented by ‹g› or ‹j› (e.g., ‹**g**ema› *yolk* /ˈʒɛ.mɐ/).
Tigela	
Lojista	
Anexo	
Hino	**Silent ‹h›**: the letter ‹h› as a single grapheme is used in word initial position and has no phonemic value. For example, ‹hera› *ivy* and ‹era› *was/era* are both pronounced /ˈɛ.ɾɐ/.
Hípico	
Haste	
Humana	

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Declarations

Interest Conflicts No potential conflict of interest was reported by the author(s).

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