

# The contributions of executive functioning to handwritten and keyboarded compositions in Year 2 children

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## ABSTRACT

Writing is a multifaceted skill, recruiting varied cognitive processes that involve working memory, attention shifting and inhibition, also known as executive functioning (EF). Despite emerging research examining associations between EF and handwritten composition, the mediating role of transcription skills on the relation between EF and text composition remains underexplored. Even less is understood about the nature of these potential mediation mechanisms in keyboard-based text composing, a writing modality that is becoming pervasive during the first years of schooling. This study investigated whether the automaticity of inscription skills (handwriting and keyboarding) and spelling mediate the relation between children's EF and text composition across two modes (paper and keyboard-based text composing) on a sample of 544 Year 2 Australian children. Assessments of EF, inscription skills, spelling, and text composition were measured concurrently. Indirect pathways were tested via structural equation modelling. Findings indicated that across text composition modes, handwriting automaticity, keyboarding automaticity and spelling mediated the relationship between children's EF and writing composition (i.e., compositional fluency and quality). The findings of this study extend current understanding of associations between cognitive processes and text composition in the junior years by examining keyboard-based text composing.

## 1. Introduction

Over the past decades, researchers have turned their attention to the educational implications of executive functioning (EF) in early childhood. EF is an umbrella term used to describe higher-order cognitive processes related to intentional goal-directed behaviour (Brydges et al., 2012). EF in the early years is fundamental to academic achievement, namely literacy and mathematics (Ahmet et al., 2019; Best et al., 2009; Blair & Razza, 2007; Fuhs et al., 2014; Gathercole et al., 2004). Some researchers have confirmed a linear relation between EF and academic outcomes, more specifically, children with higher levels of EF tend to perform better academically and vice versa (Hooper et al., 2021).

A seminal definition of writing states that text composition is a goal-directed cognitive process, led by the writer's goals (Hayes & Flower, 1980). As a goal-directed activity, it is reasonable to assume that writing

may be underpinned and supported by EF (Drijbooms et al., 2015). Despite being widely accepted, the relationship between EF and writing is based more on theoretical claims and less on empirical research (Limpo & Olive, 2021). To date and to our knowledge, a few studies have investigated the relation between children's EF and handwritten composition (e.g., Drijbooms et al., 2015; Puranik et al., 2019; Rocha et al., 2022; Salas & Silvente, 2020; Valcan et al., 2020), with no studies examining relationships between children's EF and keyboarded composition.

The present study examined concurrent associations between EF and text composition, as indicated by compositional fluency (total number of words) and compositional quality, via both handwriting and keyboarding in a cohort of Year 2 Australian children. In Australia, both handwriting and keyboarding are sub-elements of the National Literacy Learning Progression (Australian Curriculum, Assessment and Reporting

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Authority [ACARA, 2021b]), with handwriting being replaced by keyboarding in high-stakes testing of students' literacy as early as in Year 3 (ACARA, 2021a). Concerns about students' writing skills have been reported across continents (e.g., Malpique et al., 2022; Banales et al., 2020; Cutler & Graham, 2008; Veiga-Simao et al., 2016). In Australia, results from the National Assessment Program-Literacy and Numeracy (NAPLAN) exams have shown a significant decline in students' writing performance in the nine years of the test (ACARA, 2021a; Thomas, 2020). The most recent NAPLAN results showed 22 % of Year 3, 32 % of Year 5, 36 % of Year 7, and 40 % of Year 9 students receiving scores below grade-level standards (ACARA, 2023). Therefore, investigating the contribution of EF to text composition via both handwriting and keyboarding has implications for schools and educators that aim to improve children's writing performance.

### 1.1. Executive functioning

Based on Miyake et al.'s (2000) seminal work, researchers have recurrently examined three key executive functions namely (a) working memory, the ability to retain and manipulate incoming information; (b) inhibition, the ability to withhold automatic and dominant responses in favour of more adaptive ones; and (c) shifting, the ability to switch flexibly between different tasks and mental processes (Miyake et al., 2000; Valcan et al., 2020). EF emerges in the early years and continues to develop into adolescence (Best et al., 2011), developing first as a unitary construct (3 to 8 years; Brydges et al., 2012) and progressively differentiating into three related, yet separable, components (Miyake et al., 2000).

### 1.2. Text composition and executive functioning

As a cognitively demanding process, writing requires the development of a wide range of skills, including lower-level skills, like handwriting, keyboarding and spelling, as well as higher-order skills involved in crafting texts, such as ideation, planning, and revision (Berninger et al., 1997). Writing requires children to manage multiple processes simultaneously (Kim et al., 2013), making it reliant on EF. For example, "to successfully write their ABCs, a child needs to retain the sequence of letters written so far while producing new ones (working memory), to keep in mind the goal of the task while inhibiting distractions from the environment (inhibition), and for every new letter, redirect their attention to a new set of subprocesses (attention shifting)", (Valcan et al., 2020, p. 3).

In Berninger and Winn's (2006) "not-so-simple-view" of writing model, adopted in the present study, EF is conceptualised as crucial for text composition and hypothesised to increase its significance as individuals develop and are presented with more cognitively demanding writing tasks. The model proposes three critical components of writing, including transcription, executive function, and text generation, with the first two conceptualised as foundational processes that support the latter (p. 97). As mentioned earlier, some researchers have confirmed a linear relation between EF and academic outcomes, including text composition (Hooper et al., 2021; Puranik et al., 2019; Valcan et al., 2020). More specifically, lower levels of EF tend to lead to poorer text composition while higher levels of EF skills tend to lead to better text composition (Hooper et al., 2021). It is hypothesised that higher levels of EF free mental capacity to allow children to benefit from writing instruction, favouring increased efficiency and coordination of EF as the complexity of writing tasks grows. This, in turn, "may contribute to individuals having more cognitive resources to devote during the writing process, whereas EF inefficiencies likely require more cognitive resources, leaving fewer resources to devote to the demands of the writing task" (Hooper et al., 2021, p. 150). Unfortunately, most research investigating associations between EF and text composition have focused, thus far, on older populations (e.g., Hoskyn & Swanson, 2003; Vanderberg & Lee Swanson, 2007).

### 1.3. The role of automaticity of transcription skills

Automaticity is a steppingstone to proficiency in text composition, with the "not-so-simple-view" of writing (Berninger & Winn, 2006) arguing that automatised frees up working-memory capacity, allowing writers to focus on higher-levels of compositional skills (e.g., goal setting and monitoring). Handwriting and keyboarding are two inscription skills, considered to be peripheral-motor facets of writing, involving the coordination and development of a range of skills, including phonological, orthographic, visual, and motor skills. However, differences between handwriting and keyboarding exist, potentially impacting text composition (Alamargot & Morin, 2015; Berninger & Richard, 2002). Keyboarding involves the coordination of both hands and therefore the coordination of two contralateral cerebral hemispheres. Early writers might find this coordination hard to attain (Berninger & Richard, 2002; Berninger et al., 2009). In addition, whilst handwriting allows early writers to simultaneously focus on letter formation and its textual context, keyboarding requires the ability to switch flexibly between the keyboard and screen, consuming cognitive resources otherwise required for text composition (Alamargot & Morin, 2015). In contrast to later states of keyboarding attainment, when writers rely on kinaesthetic feedback, during the first stages of keyboarding attainment, children may find keyboarding for text composition quite challenging as they rely on visual feedback when searching for the right letter keys on the keyboard (Perminger et al., 2004).

Effective spelling is another transcription component of the "not-so-simple-view" of writing (Berninger & Winn, 2006). As with handwriting, it is postulated that as children's spelling skills develop, their working memory and attentional capacity become available to focus on ideation and composition of texts (Abbott & Berninger, 1993; Kim et al., 2011). Hence, spelling is seen as a lower-order skill, required to enable more complex composition processes, such as creating text content, planning text structure and revising text (Scardamalia et al., 1982). A meta-analysis investigating the relationship between transcription skills and text composition of K-12 students (Kent & Wanzek, 2016) reported that both handwriting automaticity and spelling accounted for approximately 25 % of the variance in students' handwritten compositional quality.

### 1.4. EF across writing modalities

Research suggests that young children depend significantly on cognitive processes, such as EF (Salas & Silvente, 2020) to automatise transcription skills (i.e., handwriting, keyboarding, and spelling). Such investment in lower-level skills limits the availability of executive resources required for higher-order text composition. A recent study by Drijbooms and colleagues (2015) provides support for this proposition. They investigated the contribution of EF to handwritten composition in Year 4. One-hundred and three Dutch children were assessed on a range of skills, including EF, transcription skills (e.g., handwriting automaticity) and handwritten composition. The results showed that EF contributed indirectly to handwritten composition via handwriting automaticity, potentially depicting the role of executive control in the coordination of multiple cognitive processes during paper-based writing (Berninger et al., 1997). Altmeier and colleagues (2008) also showed that in primary aged children (Years 3, 4, and 5), variance in spelling and handwritten composition was explained by EF. A recent cross-sectional study by Gosse and colleagues (2021) found a significant positive correlation between spelling and handwritten compositional quality. While research examining relationships between keyboarding automaticity and spelling is relatively limited, recent findings (Malpique et al., 2023a) showed a moderate correlation between keyboarding automaticity and spelling (0.45) as well as a high correlation between keyboarding quality and spelling (0.69) in a sample of Year 2 students. Collectively, these findings reinforce the importance of examining how individual differences in transcription skills may mediate associations

between EF and compositional quality across writing modalities.

To date, researchers have placed specific focus on examining associations between EF, handwriting automaticity, spelling, and paper-based text composing. In today’s fast paced digital world, however, the use of digital devices in classrooms has become widespread and children frequently compose texts via keyboarding (Drijbooms et al., 2015), urging the investigation of modality effects on writing development. As previously mentioned, in much the same way as in paper-based text composing, a lack of keyboarding automaticity and spelling proficiency may affect the quality of keyboard-based texts. A recurring limitation in the literature, however, is the lack of studies investigating these relationships (Drijbooms et al., 2015; Limpo & Olive, 2021). Hence, the present study expands knowledge on the relation between keyboarding automaticity, spelling, and text composition (i.e., compositional fluency and compositional quality), and explores the contribution of EF to both handwritten and keyboarded composition.

1.5. The present study

This study examines whether transcription skills (i.e., handwriting automaticity, keyboarding automaticity, and spelling) mediate associations between children’s EF and text composition (operationalised as compositional fluency and compositional quality, see Method), in two text composing modes (paper-based and keyboard-based). Please refer to Fig. 1 for proposed models.

We employed a cross-sectional design, with the predictor variable (EF), mediator (transcription skills) and the outcome variable (text composition, as indicated fluency and quality) obtained concurrently. The present study tested the indirect pathways via structural equation modelling (Kline, 2016), an approach that has been shown to have higher power, readily accommodating suppression effects and multiple mediators (MacKinnon et al., 2002). Since research has consistently reported gender differences across writing outcomes favouring females (e.g., Reilly et al., 2019; Thomas, 2019), including in keyboard-based text composing (Malpique et al., 2023b), gender was included as a

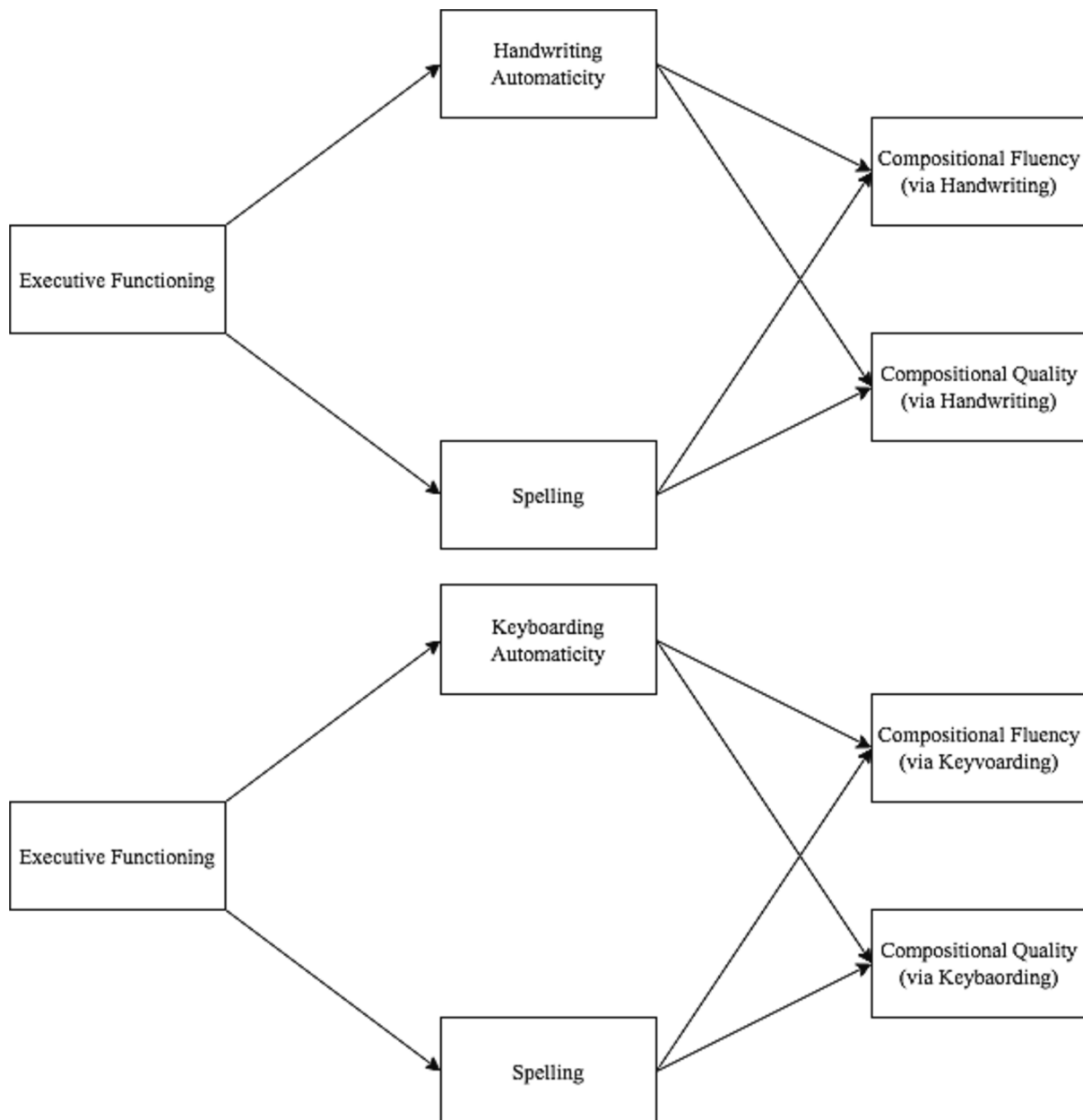


Fig. 1. Proposed theoretical models.

control variable in the SEM model.

As noted earlier, in Australia, where the current study took place, both handwriting and keyboarding are sub-elements of the National Literacy Learning Progression (ACARA, 2021), and children's literacy skills start being assessed via online national exams in Year 3 (ACARA, 2018). Given the lack of studies examining modality effects in the early years of schooling, we deliberately assessed text composition via both handwriting and keyboarding. The study addressed the following research questions:

1. Do transcription skills (i.e., handwriting automaticity and spelling) mediate the relationship between children's EF and paper-based text composing (i.e., fluency and quality)?
2. Do transcription skills (i.e., keyboarding automaticity and spelling) mediate the relationship between children's EF and keyboard-based text composing (i.e., fluency and quality)?
3. Do transcription skills moderate the relationship between children's executive functions (EF) and text composing differently in handwriting and keyboard-based composition modes?

## 2. Method

The data and analyses reported here are a component of a larger study examining Year 2's writing achievement and instruction (Malpique et al., 2023b). Before commencing the study, a pilot was conducted ( $n = 49$  children; Malpique et al., 2023a), to examine the suitability of assessment protocols and tasks, and the overall feasibility of the study.

### 2.1. Participants

Participants included 544 children (54.2 % female) with a mean age of 7 years ( $SD = 0.02$  years). The sample was recruited from 17 publicly funded primary schools in Western Australia (Perth Metropolitan Region). These primary schools were located in areas of varying socioeconomic affluence as indicated by the Index of Community Socio-Educational Advantage (ICSEA). The ICSEA is an index of Australian school's educational advantage that accounts for parental education and income, geographical location and proportion of Indigenous students (Australian Curriculum, Assessment and Reporting Authority [ACARA], 2012). The ICSEA average (1000) is used as a benchmark value. Of the 17 participating schools, six scored within the average range (950–1050), and 11 schools scored above average range ( $>1050$ ). National and state results on Year 3 students' writing performance collected in the Australian National Assessment Program, Literacy and Numeracy (NAPLAN, ACARA, 2019) were used to evaluate the representativeness of the participating schools. Year 3 results represent the earliest NAPLAN assessment, also repeated in Years 5, 7, and 9. The recruited sample included three schools below and 14 schools above the NAPLAN writing national average results (422.5) and two schools below and 15 schools above the state's NAPLAN writing average results (419.4). Enrolment of Indigenous students ranged from 0 to 12 % ( $M = 2.8$ ,  $SD = 2.9$ ) and the percentage of students with language backgrounds other than English ranged from 7 to 47 % ( $M = 18.3$ ,  $SD = 10.3$ ).

### 2.2. Procedure

All publicly funded primary schools in Perth, Western Australia, were emailed invitation letters, with 17 schools agreeing to participate. In each school, families of children in second grade (Year 2 in Australia) were invited to take part. Parent and child consent was sought before data collection. Children were assessed over two sessions, outside their classroom and on separate days. Session one (individual) assessed children's EF, handwriting and keyboarding automaticity, and spelling, taking approximately 45 min. Session two (group of three children) assessed text composition (fluency and quality, via handwriting and

keyboarding), taking approximately 30 min. To account for order effects, the presentation of handwriting and keyboarding tasks was counterbalanced. The first and second authors administered the tasks, along with three education and psychology graduate research assistants. Task administration was piloted (as indicated earlier) and was standardised among team members ensuring strict adherence to assessment protocols.

### 2.3. Measures

#### 2.3.1. Executive functioning

**Head-Toes-Knees-Shoulders (HTKS; Ponitz et al., 2008).** The HTKS integrates multiple EF components into a game-like measure appropriate for children aged 4 to 8 years, with the examiner relaying several behavioral rules to the child. The task asked participants to do the opposite of what they were instructed. The researcher asked children to touch their toes (or their head), with children expected to do the opposite and touch their head (or their toes). A minimum of four (out of ten) correct responses to head/toes commands were needed to proceed to a more advanced trial including knees and shoulder commands. If participants succeeded in the advanced trial (four or more correct attempts), they proceeded to the final part of the task, where rules were changed (e.g., when instructed to touch their head, children had to touch their knees). Incorrect responses (or not passing a trial) scored 0; self-corrected responses scored one; and correct responses were assigned a score of two. The sum of scores (0–60) was taken as the indicator of EF. The HTKS task has been conceptualized by Ponitz et al. (2009) as a measure of working memory (recalling and modifying tasks rules), inhibition (refraining the tendency to follow researcher's instruction), and attention shifting (switching between changing task rules). The HTKS task was originally developed in the context of self-regulation (which includes aspects of EF as well as other aspects of regulation including emotions and behaviour, McClelland et al., 2021), a direct assessment of children's behavioural self-regulation that requires the above-mentioned EF components. In this study, like many others, the HTKS task refer to the use of EF skills (i.e., working memory, inhibition, and task shifting) in different situations (McClelland et al., 2021), such as "remembering to raise one's hand and waiting to be called upon instead of shouting out an answer in class" (McClelland et al., 2021, p. 2). The HTKS correlates with other reputable EF assessments and is a strong indicator in latent variable models of EF (Allan & Lonigan, 2011; Schmitt et al., 2017; Valcan et al., 2020). It has good inter-rater reliability ( $k = 0.90$ ; Ponitz et al., 2009; McClelland & Cameron, 2012) and strong predictive and concurrent validity (McClelland et al., 2007, 2014; Ponitz et al., 2009; Cameron et al., 2019).

#### 2.3.2. Spelling

**Wechsler Individual Achievement Test (WIAT-III, Wechsler, 2016).** Spelling was assessed using the Spelling sub-test of the WIAT-III (A&NZ), a standardised and normed measure of academic strengths (ages 4–85) in reading, mathematics, oral language, and written expression. The Spelling sub-test assesses written spelling of single sounds and words from dictation. Research confirms the validity of the WIAT-III (Pelling & Burton, 2017).

(e.g., content, construct, and criterion-related) and that its composites and subtests adequately measure each intended construct.

#### 2.3.3. Handwriting and keyboarding automaticity

**Alphabet Writing Task (Berninger & Rutberg, 1992; Berninger et al., 2009).** The Alphabet Writing Task asked children to write (via pencil) and type (via keyboard), in alphabetical order, all the letters (lower-case) of the alphabet, as correctly and quickly as possible. This task assessed the ability to access, retrieve, and write (or type) letters automatically and accurately. A score of one was given for each correctly formed (handwriting task) and sequenced letter (handwriting and keyboarding task). The indicator of handwriting automaticity was

the number of letters correctly written at 15 s (range 0–26). Similarly, the indicator of keyboarding automaticity was the number of letters correctly typed at 15 s (range 0–26). Inter-rater reliability (random 20 % of data) was calculated to assess the degree of agreement between two researchers. Intraclass correlation coefficients (ICCs) yielded a score of 0.99 and 0.99 for handwriting and keyboarding, respectively.

#### 2.3.4. Text composition

Children's text composition (i.e., fluency and quality) was assessed via a written composition task. Children were required to write a text following a story prompt ("On my way home from school, I found a robot") by hand on a A4 lined paper; and by keyboard ("On my way home from school, I found a spaceship") on a laptop running a Microsoft Windows operating system with both spelling and grammar checks turned off. Children were given 10 min to carry out the task by hand and the same amount of time to finish the task by keyboard. To control for students' knowledge and motivation, the written prompts were similar in both written modalities (see Berninger et al., 2009, for similar procedures).

Children's compositional fluency via handwriting and keyboarding was assessed via the total number of words (TNW), a widely used measure strongly predicting compositional quality in prior studies (e.g., Graham et al., 2016). A score of one was given for every word that represented a spoken word, regardless of spelling. The indicator of text length was the TNW. Inter-rater reliability (random 20 % of data) via intraclass correlation coefficients (ICCs) was calculated to assess the degree of agreement between two researchers who scored the TNW, yielding an inter-rater reliability of 0.99 for handwriting and 0.97 for keyboarding.

Children's handwritten and keyboarded compositional quality were assessed using an analytical scoring system. This system was adapted from the Australian National Assessment Program, Literacy and Numeracy (NAPLAN) narrative writing marking (ACARA, 2016) and from the 6 + 1 Trait® Writing rubric for Primary Grades (NREL, 2011) since these measures are consistent with judging standards for writing and creating texts set in the Western Australia curriculum (School Curriculum and Standards Authority [SCSA], 2020). Children's written compositions were scored from 1 (low quality) to 5 (high quality) on 10 criteria: audience (e.g., capacity to orient and affect the reader); ideas (e.g., development of main idea); text structure (e.g., beginning, middle, and end); character and setting (e.g., capacity to portray and develop characters and/or time and atmosphere); vocabulary (e.g., interesting and specific words to convey meaning); cohesion (e.g., use of grammatical elements to link parts of the text); paragraphing (e.g., segmenting of text into paragraphs); sentence structure (e.g., sentence-level grammar and flow); punctuation and capitalization; and spelling (e.g., spelling of grade-level words) (see Appendix A for a detailed description). The final score of compositional quality was the sum of the 10 assessment criterion score (range 0–50). Inter-rater reliability (random 20 % of data) via intraclass correlation coefficients (ICCs) was calculated to assess the degree of agreement between two researchers who scored the writing composition tasks (i.e., the sum of the 10-assessment criterion score), yielding an inter-rater reliability of 0.90 for handwriting and 0.84 for keyboarding.

#### 2.4. Data analysis strategy

In this study, children were nested within classrooms ( $k = 47$ ), and classrooms were nested within schools ( $k = 17$ ). The number of classrooms per school varied from one to five ( $Md = 3$ ). Children's N per classroom ranged between two and 23 ( $Md = 12$ ). Given that our questions addressed individual-level variables, the following approach (as per our earlier study, Valcan et al., 2020) was taken to account for classroom or school effects on individual scores (i.e., children). For each of the tasks, we used Hierarchical Linear Modelling (HLM) 8.2 (Raudenbush et al., 2019) to build an unconditional 3-level hierarchical

model where we partitioned the variance into its components at each level (refer Table 1). Following this, we used the child-level residuals on each task in the remaining analyses, therefore controlling for any between-classroom and between-school differences (Woltman et al., 2012).

Mediation analysis via structural equation modelling (SEM) using AMOS (Arbuckle, 2019) was the primary data analysis conducted. SEM, via the Maximum Likelihood (ML), was used to model the direct and indirect relations between EF, transcription skills (i.e., handwriting and keyboarding automaticity, and spelling fluency) and text composition (fluency and quality), with separate models constructed for handwritten composition and keyboarded composition. Indirect effects were tested via the Hayes' (2013) bootstrapping procedure, generating bias-corrected confidence intervals (Cis) for all indirect effects. An indirect (i.e., mediated) effect is considered significant if the value of zero does not fall within the bias-corrected bootstrapped (BCB) 95 % CI.

Four fit indices were used to evaluate model fit for all analyses namely: 1) the chi-square test ( $\chi^2$ ); 2) the root mean square error of approximation (RMSEA); 3) the comparative fit index (CFI); and 4) Tucker-Lewis index (TLI). The chi-square test is a measure of discrepancy between the current and saturated model. Thus, the chi-square value should be as low as possible, with a p value as high as possible (Blunch, 2009). According to Hu and Bentler (1998), RMSEA values below 0.08, CFI and TLI values equal to or greater than 0.95 indicate an excellent model fit. According to Kline, 2016, CFI and TLI values greater than (or close to) 0.90 are indicate an acceptable model fit. To ensure that the SEM model did not exclude any important paths, modification indices were checked and if theoretically plausible paths were added (Kline, 2016).

In order to investigate whether the strength of associations among variables differed between handwriting and keyboarding composition modes, a multi-group structural equation modelling (MG-SEM) analysis was conducted. This approach allowed for the comparison of structural weights (path coefficients) between the two composition modes.

Initially, an unconstrained model was estimated, allowing the structural weights (path coefficients) to vary freely between handwriting and keyboarding modes. This provided a baseline understanding of the relationships among variables within each composition mode. Subsequently, the structural weights were constrained to be equal across both composition modes. This constrained model facilitated direct comparison between handwriting and keyboarding modes. Model fit statistics, including chi-square ( $\chi^2$ ), comparative fit index (CFI), Tucker-Lewis index (TLI), and root mean square error of approximation (RMSEA), were then examined for both the constrained and unconstrained models. Furthermore, a chi-square difference test was employed to assess whether the coefficients were significantly different between handwriting and keyboarding composition modes.

**Table 1**

Proportion of variance in each task occurring at child level, classroom level, and school level.

Task	Child-Level	Classroom-Level	School-Level
HW Automaticity	0.93	0.01	0.06
HW Compositional Fluency	0.82	0.17	0.01
HW Compositional Quality	0.85	0.09	0.06
KB Automaticity	0.93	0.04	0.03
KB Compositional Fluency	0.84	0.13	0.03
KB Compositional Quality	0.88	0.09	0.03
Spelling	0.89	0.02	0.09
Executive Functioning	0.83	0.03	0.14

Note. HW = handwriting, KB = keyboarding.

## 4. Results

### 4.1. Descriptive statistics

Table 2 presents descriptive statistics for individual measures and Table 3 bivariate correlations among all variables. All normality tests, including tests of skewness and kurtosis, fell within acceptable ranges across all tasks except for Text Length via Keyboarding. Normality deviation was due to outliers; therefore, a trimming procedure was performed (as recommended by Ramsey & Ramsey, 2007). Only 1.7 % of cases were affected. Univariate outliers were represented by values greater than three *SDs* from the mean and replaced with a value equal to three *SDs* from the mean. Following this, the task Text Length via Keyboarding fell within acceptable levels of normality.

### 4.2. Structural equation modelling: Mediation analysis

#### 4.2.1. Handwriting and executive functioning

The mediation model predicting handwritten composition (i.e., fluency and quality) from EF (Fig. 2) exhibited excellent fit ( $\chi^2 = 2.24$ ,  $p = .14$ ,  $df = 1$ ; CFI = 0.998, TLI = 0.972, RMSEA = 0.048). SEM supported an indirect effect, with EF predicting handwriting automaticity (path a = 0.12,  $p < .01$ ) and spelling (path b = 0.28,  $p < 0.001$ ), which in turn predicted compositional fluency (path c = 0.21,  $p < 0.001$ , path d = 0.23,  $p < 0.001$ , respectively) and compositional quality (path e = 0.21,  $p < .001$ , path f = 0.50,  $p < 0.001$ , respectively). The overall indirect effect linking EF to compositional fluency via handwriting automaticity and spelling was significant (path ac = 0.03, BCB [0.022, 0.212]; path bd = 0.06, BCB [0.157, 0.402], respectively). The overall indirect effect linking EF to compositional quality via handwriting automaticity and spelling was also significant (path ae = 0.03, BCB [0.004, 0.034]; path bf = 0.14, BCB [0.063, 0.125], respectively). Controlling for gender (see Table 3 for significant associations between gender and all writing outcomes), the overall model explained 13 % and 36 % of the variance in compositional fluency and compositional quality, respectively.

#### 4.2.2. Keyboarding and executive functioning

Similarly, the mediation model predicting keyboarded composition (i.e., fluency and quality) from EF (Fig. 3) exhibited excellent fit ( $\chi^2 = 2.24$ ,  $p = .14$ ,  $df = 1$ ; CFI = 0.999, TLI = 0.978, RMSEA = 0.048). SEM supported an indirect effect, with EF predicting keyboarding automaticity (path a = 0.15,  $p < .01$ ) and spelling (path b = 0.28,  $p < 0.001$ ), which in turn predicted compositional fluency (path c = 0.41,  $p < 0.001$ , path d = 0.19,  $p < 0.001$ , respectively) and compositional quality (path e = 0.32,  $p < .001$ , path f = 0.37,  $p < 0.001$ , respectively). The overall indirect effect linking EF to compositional fluency via keyboarding automaticity and spelling was significant (path ac = 0.06, BCB [0.099, 0.339]; path bd = 0.05, BCB [0.105, 0.274], respectively). The overall indirect effect linking EF to compositional quality via keyboarding automaticity and spelling was also significant (path ae = 0.05, BCB [0.017, 0.056]; path bf = 0.10, BCB [0.047, 0.104], respectively). Controlling for gender (see Table 3), the overall model explained 28 %

**Table 2**  
Descriptive Statistics.

	<i>M</i>	<i>SD</i>	<i>Min</i>	<i>Max</i>
HW Automaticity	7.19	3.02	0	17
HW Compositional Fluency	71.39	33.66	4	190
HW Compositional Quality	27.85	5.26	10	47
KB Automaticity	8.89	4.39	0	24
KB Compositional Fluency	39.90	28.22	0	211
KB Compositional Quality	21.69	5.47	0	41
Spelling	99.99	14.17	49	158
Executive Functioning	51.41	7.83	0	60

Note. HW = handwriting, KB = keyboarding.

and 35 % of the variance in compositional fluency and compositional quality, respectively.

### 4.2.3. Multi-Group model comparison

In order to examine whether the strength of the associations among variables was the same for handwriting and keyboarding composition modes, we conducted multi-group SEM. To scrutinise the statistical significance of differences, structural weights (path coefficients) were constrained to be equal in both modes. Even though there appear to be variations in the coefficients (as shown in Figs. 1 and 2), model comparison between the constrained ( $\chi^2 = 11.04$ ,  $p = .35$ ,  $df = 10$ ; CFI = 0.999, TLI = 0.998, RMSEA = 0.010) and unconstrained model ( $\chi^2 = 4.48$ ,  $p = .11$ ,  $df = 2$ ; CFI = 0.998, TLI = 0.976, RMSEA = 0.034) didn't reveal significant differences ( $\Delta\chi^2 = 6.56$ ,  $p = .58$ ,  $df = 8$ ) in the coefficients between the handwriting and keyboarding composition modes. This finding suggests that the relationships among the variables under consideration remain consistent across both modes of composition.

## 5. Discussion

This study examined relationships between children's EF and text composition, via both handwriting and keyboarding, accounting for classroom and school-level effects and gender. A mediation analysis via SEM was conducted to determine whether children's transcription skills mediated the relationship between children's EF and text composition. Overall, our results demonstrate that transcription skills mediate the relationship between children's EF and writing performance in both writing modalities (i.e., handwriting and keyboarding), with the multi-group SEM results indicating no significant differences in the coefficients between the handwriting and keyboarding models.

### 5.1. EF and handwriting

As anticipated, handwriting automaticity and spelling mediated the relationship between children's EF and handwritten composition (i.e., fluency and quality). Our findings are aligned with other studies conducted with primary aged children both younger and older than our target sample (Drijbooms et al., 2015; Valcan et al., 2020). While Drijboom and colleagues (2015) examined mediation effects in a population of Dutch 4th graders, Valcan et al. (2020) previously used a longitudinal design to examine the mediating effects of transcription skills on EF-writing performance associations in Australian children as they transitioned from Kindergarten to Year 1. Consistency in findings across year groups suggests potential stability in these mediating effects as children navigate the first years of primary education, hinting its developmental significance. The findings of our study serve to further confirm the role of executive processes in facilitating transcriptions skills, which in turn free cognitive resources to produce higher quality texts. In line with Drijboom et al's (2015) rationale, we argue that EFs such as working memory, attention shifting, and inhibition may be central to the coordination of perceptual, motor and cognitive processes, key for the accurate and efficient retrieval and production of letters and words leading to higher automaticity and correct spelling. We also argue that, as these transcription processes become automatic, cognitive resources can be deployed towards the creation of more extended and richer texts, which is supported by intervention studies which signal that support on transcription processes leads to improvements in text composition (Graham et al., 2000, 2023).

### 5.2. EF and keyboarding

Our findings extend current literature by showing that, as in the case of paper-based text composing, keyboarding automaticity and spelling mediated the relationship between children's EF and keyboard-based text composing (i.e., fluency and quality). To our knowledge, this is

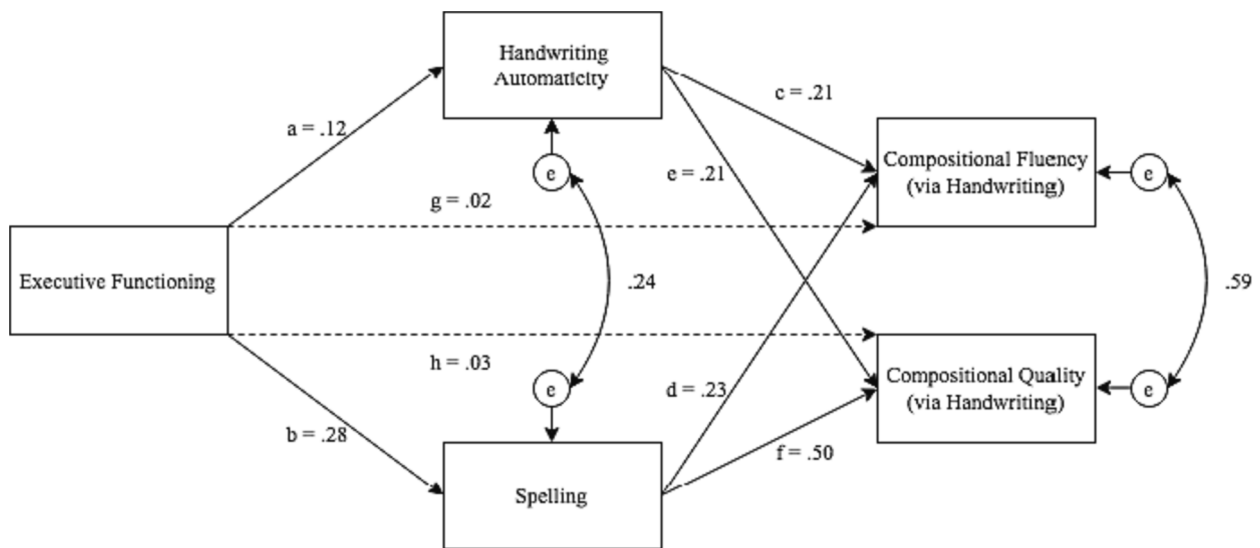
**Table 3**  
Correlations for all Study Variables.

	1	2	3	4	5	6	7	8	9
HW Automaticity	1								
HW Compositional Fluency	0.30**	1							
HW Compositional Quality	0.38**	0.67**	1						
KB Automaticity	0.42**	0.30**	0.44**	1					
KB Compositional Fluency	0.31**	0.50**	0.48**	0.53**	1				
KB Compositional Quality	0.31**	0.44**	0.53**	0.50**	0.71**	1			
Spelling	0.30**	0.33**	0.61**	0.47**	0.40**	0.51**	1		
Executive Functioning	0.15**	0.07	0.23**	0.18**	0.13**	0.15**	0.32**	1	
Gender	0.12**	0.27**	0.18**	0.11*	0.14**	0.11*	0.02	0.08	1

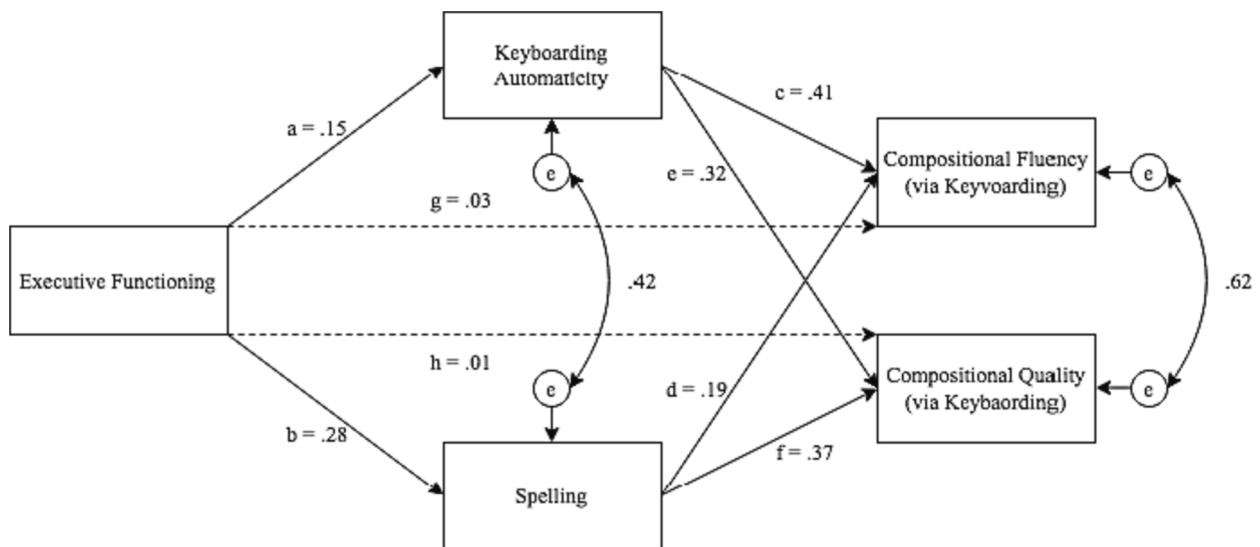
Note. HW = handwriting, KB = keyboarding.

\* p < .05.

\*\* p < .01.



**Fig. 2.** Structural equation modelling with standardised regression coefficients for handwritten composition. Note. For simplicity of presentation, the control variable, gender, is not shown. Solid lines signify statistically significant path coefficients.



**Fig. 3.** Structural equation modelling with standardised regression coefficients for keyboarded composition. Note. For simplicity of presentation, the control variable, gender, is not shown. Solid lines signify statistically significant path coefficients.

the first study to compare these mediation mechanisms across text composition modes, so findings must be treated with caution. This caveat, however, should not undermine the significance of these results as they stress the critical role of executive processes in developmental aspects of writing across modalities. In fact, a recent *meta*-analytic study by Feng and colleagues (2019) examining writing performance across text composition modes (handwriting and keyboarding) in primary aged children revealed that performance on automaticity of handwriting and keyboarding were associated specifically in terms of automaticity. As argued by Feng and colleagues, like handwriting “keyboarding also carries the responsibility of producing letters promptly and accurately” (p.36) signalling that, despite differences in perceptual and motor processes connected with these two modes, similar cognitive processes such as EF may underlie their effectiveness.

Notably, the multi-group SEM outcomes indicated that there were no significant differences in the coefficients between the handwriting and keyboard modes. The lack of significant differences in coefficients further reinforces the idea that the selected variables, despite the differing modalities of composition, exhibit consistent associations. This finding lends support to the notion that the underlying cognitive and linguistic processes involved in both handwriting and keyboard composition maintain a similar structure when considering the variables examined in this study. By revealing this consistency in relationships, our study adds a substantial dimension to the understanding of handwriting and keyboarding composition.

### 5.3. Limitations of the present study and future study directions

Notwithstanding the contributions of the current study, limitations should be acknowledged. First, the present study adopted a correlational design, precluding us from drawing casual inferences. Nevertheless, the use of a directional cross-sectional design allows us to make a stronger case than one derived from concurrent correlations alone. While cross-sectional mediation uses a single point in time for measurement, it still assumes cause and effect (Cain et al., 2018). However, cause and effect occur within that point in time (Cain et al., 2018). A recent study evaluated the ability of mediation models to detect a significant mediation effect when using limited data, comparing cross-sectional mediation models with longitudinal mediation models (Cain et al., 2018). The results of the study suggest the use of cross-sectional mediation when longitudinal mediation analysis is not possible or prudent. However, experimental studies, via target interventions, would be needed to investigate causal links.

Second, we used only one global measure of EF. While the decision was based on the developmental appropriateness of a play-based task able to capture EF as a unitary construct (McClelland et al., 2021), other studies have shown that associations between EF and writing may differ contingent on the component of EF (i.e., working memory, inhibition, and shifting). For example, Drijbooms and colleagues (2015) revealed that working memory and inhibition contributed directly to text length and indirectly, through handwriting automaticity, to text length and text composition in Year 4 (i.e., syntactic complexity and story content). Having established that EF may predict writing, future studies could examine whether the associations identified in this research are consistent across individual components of EF. This nuanced understanding would provide valuable information to target educational support or interventions to students with differing EF profiles. Relatedly, further research, with higher statistical power, is needed to determine the predictive ability of EF to different levels of text composition (e.g., audience, text structure, ideas).

Lastly, the present study examined the relation between EF and writing across Year 2 children. Children in Year 2 are expected to have acquired some degree of automaticity and spelling, allowing the examination of how individual differences in transcription processes may mediate associations between EF and compositional quality. More longitudinal studies are required to investigate how the contribution of EF

to writing changes (or develops) as students mature and progress in their educational journeys. As transcription skills become more automatic with age and have less impact on cognitive load (Beringer & Winn, 2006), EF may play a stronger and direct role in compositional quality. Moreover, computer-based testing has been incorporated in summative and formative methods of assessment in several educational contexts worldwide (e.g., Common Core State Standards [CCSS], 2016; Wollschheid et al., 2016). As previously noted, keyboarding has been replacing handwriting in Australian national exams, with students' literacy skills being assessed via keyboarding in the first semester of Year 3 (ACARA, 2018). Hence, it becomes critical to expand knowledge about student-level factors, including EF, contributing to the development of handwriting and keyboarding skills in the early years of schooling.

### 5.4. Implications and conclusion

The results of the present study offer a possible pathway via which EF may predict paper-based and keyboard-based text composing. Developing insight and perspective of the possible pathways between EF and text composition can tell us more about how to intervene at this age. Our findings indicate that automaticity of handwriting and keyboarding and spelling mediates the relations between EF and text composition, offering several pathways for potential educational intervention. For instance, identifying students with poor EF and developing curriculum that enhances opportunities for practicing EF may support children's developing transcription skills, presumably impacting positively on composition quality.

Additionally, EF demands could be reduced by providing opportunities for the automatization of transcription skills (Diamond & Lee, 2011), freeing the necessary cognitive resources for the planning and revision required for the production of high-quality texts. The positive effect of the practice of transcription skills on composition quality is well supported by previous research (Graham et al., 2000, 2023) and may be critical, particularly for young students who find the handwriting and keyboarding of letters and words an effortful task. Research also supports the idea that the quality of texts can be enhanced via the explicit instruction of strategic approaches that support higher order writing skills (Graham et al., 2012; 2023). Our findings therefore highlight the potential significance of interventions that encourage transcription skills and strategic approaches to text composing, with additional support on lower-level processes and EF for struggling students.

Despite the above-mentioned implications, much is yet to be understood, particularly when it comes to identifying which writing modalities (i.e., handwriting or keyboarding) should be introduced first in children's education. Large scale and long-term longitudinal studies are much needed to understand developmental pathways in response to writing instruction. Notwithstanding, our study contributes to the existing literature by highlighting the role of EF on writing performance and providing evidential support to previously argued theoretical connections between higher cognitive processes and writing. Our findings advance existing knowledge in the field by being one of the first studies examining mediation effects in keyboarding, an activity that is becoming part and parcel of schooling and that still requires significant examination.

### CRediT authorship contribution statement

**Debora Similieana Valcan:** Conceptualization, Writing – original draft, Writing – review & editing, Visualization, Investigation, Validation, Formal analysis, Methodology, Project administration. **Anabela Malpique:** Funding acquisition, Writing – original draft, Writing – review & editing, Investigation, Methodology, Resources, Project administration. **Deborah Pino-Pasternak:** Writing – original draft, Writing – review & editing. **Mustafa Asil:** Formal analysis, Writing – original draft, Writing – review & editing. **Timothy Teo:** Writing – review & editing.



**Declaration of competing interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Data availability**

The data that has been used is confidential.

**Appendix A. – Analytical scoring scale for compositional Quality**

<b>Audience</b>				
1- Low Quality Response to audience needs is limited; may be a title only OR meaning is difficult to access OR copied prompt topic.	2- Below Average Quality The writer's awareness of audience is not clear; may include simple narrative markers (formulaic story opening; reader may need to fill gaps in information).	3- Average Quality Awareness of audience is present in a general way; the writer's feelings about the topic are expressed (e.g. "fun", underlining, use of exclamation points); the writers show some signs of individual expression.	4 – Above Average Quality The writing shows an awareness of audience; the writer's feelings about the subject are identifiable; a sense of the writer's individuality emerges from the text.	5- High Quality Exhibits expectational audience awareness and is compelling to read; Supports and engages the reader through deliberate choice of language and use of narrative devices (fantasy, humour, suspense).
<b>Text Structure</b>				
1- Low Quality Has no obvious structure or organisation. Has no sense of beginning, middle, or end; inappropriate genre (e.g., recipe, argument); title only.	2- Below Average Quality Minimal evidence of narrative structure. Shows a beginning sense of structure in writing, but sequencing is not present or is confusing; may be just description.	3- Average Quality A structure is present, despite being basic or confusing in places. Begins developing a structure through organisation but may still be hard to follow; experiments with a beginning (e.g., "Once upon a time") and/or a middle; includes no clear ending except possibly "The End".	4 – Above Average Quality The structure is easy to follow; includes transitions in the structure. Includes a beginning, middle, and end; uses logical sequencing that can be followed by reader.	5- High Quality Complete and controlled story. Has a beginning, middle, and end that work together to communicate consistently; includes lead and concluding sentences; puts writing in an order that clarifies meaning.
<b>Ideas</b>				
1- Low Quality Does not communicate an idea through writing (uses scribbles or shapes that imitate letters/words; may write letters/words randomly).	2- Below Average Quality Attempts to present the idea, but it is vague. Drawing (if present) may be present but is not related to writing.	3- Average Quality Ideas show some development or elaboration; ideas relate coherently but may contain unnecessary elaboration (waffle). Tries to convey a simple experience or information about a topic using words.	4 – Above Average Quality Presents a simple idea (e.g., a story) with some details in writing. Conveys a clear idea.	5- High Quality Conveys a rich, clear main idea (e.g., tells a story) using multiple sentences with supporting details. Conveys a focused main idea.
<b>Characters and Setting</b>				
1- Low Quality No evidence or insufficient evidence	2- Below Average Quality Only names characters or gives their roles (e.g., <i>father, the teacher, my friend, dinosaur, we, Jim</i> ) AND/OR Only names the setting (e.g., <i>school, the place we were at</i> ) Setting is vague or confused.	3- Average Quality Suggestion of characterisation through brief descriptions or speech or feelings AND/OR Suggestion of setting through very brief and superficial descriptions of place and/or time.	4 – Above Average Quality Characterisation emerges through descriptions, actions, speech or the attribution of thoughts and feelings to a character AND/OR Setting emerges through description of place, time, and atmosphere.	5- High Quality Effective characterisation: details are selected to create distinct characters AND/OR Maintains a sense of setting throughout. Details are selected to create a sense of place and atmosphere.
<b>NOTE:</b>	<p>Characterisation and setting are essential components of effective narrative writing. The inclusion of AND/OR recognises that different types of stories may focus on only one aspect.</p> <ul style="list-style-type: none"> <li>– Some stories may be character-driven and the setting may be very sketchy or undeveloped.</li> <li>– Other stories, which attempt to build atmosphere and suspense, may focus on setting the scene (e.g., the wild west genre) with little character detail.</li> <li>– Many stories will have a balance of these two components.</li> </ul>			
<b>Vocabulary</b>				
1- Low Quality Makes inconsistent letter shapes; includes imitative writing or does not write at all (symbols or drawings)	2- Below Average Quality Includes a few words, but mostly simple verbs, adverbs, adjectives, or nouns; short script.	3- Average Quality Vocabulary is limited to known, safe words and may be repetitious. Relies on slang, safe, or simple words; includes general or ordinary words, sometimes incorrectly. May attempt new or challenging words but they may not fit the message.	4 – Above Average Quality Uses words that stand on their own to convey message; uses basic vocabulary correctly. May attempt a few creative word choices; uses favourite and/or safe words correctly; experiments with more sophisticated words with some success.	5- High Quality Language choice is well matched to genre. Has precise and/or vivid word choice. Shows vocabulary is expanding through. Uses everyday words well; often employs more precise and accurate words to create variety.
<b>Cohesion</b>				
1- Low Quality Links are missing; short script; often confusing for the reader.	2- Below Average Quality Attempts to link parts of the text (e.g., using conjunctions), but links are incorrect.	3- Average Quality Some correct links between sentences (do not penalise for poor punctuation); most referring words are accurate; reader may occasionally need to re-read and provide their own links to clarify meaning.	4 – Above Average Quality Cohesive devices are used correctly to support reader's understanding; meaning is clear and text flows well in a sustained piece of writing.	5- High Quality Uses cohesive devices correctly and deliberately to enhance reading; an extended, highly cohesive piece of writing showing continuity of ideas.

(continued on next page)

(continued)

Paraphrasing				
1- Low Quality No use of paraphrasing; script is a block of text.	2- Below Average Quality Text includes some randomly set of paragraph(s), not focused on one consistent idea or set of like ideas.	3- Average Quality Text organised into paragraphs that are mainly focused on a single idea or set of like ideas that assist the reader in following the story.	4 – Above Average Quality Text organised into paragraphs that are well focused on a single idea or set of like ideas that assist the reader in following and understanding the story.	5- High Quality Text deliberately structured to direct the reader's attention to the idea/set of like ideas; single sentences may be used as a dramatic or final comment or for emphasis.
Sentence Structure				
1- Low Quality Has no sentences or has only sentence parts (e.g., uses disconnected words).	2- Below Average Quality Some correct formation of sentences and some meaning can be construed; most sentences contain the same basic structures; may be overuse of the conversational 'and' or 'then',	3- Average Quality Most simple and compound sentences correct and some complex sentences are correct; meaning is predominantly clear.	4 – Above Average Quality All simple and compound sentences correct and most complex sentences are correct but with little variety; meaning is clear.	5- High Quality All simple and compound sentences correct AND all complex sentences are correct; Employs multiple sentence patterns, including a variety of sentence beginnings. Conveys simple and varied sentences effectively.
Punctuation and Capitalisation				
1- Low Quality Has no punctuation present. Contains no evidence that capital letters are for a particular purpose, if used at all.	2- Below Average Quality Attempts some random punctuation. Uses upper- and lower-case letters inconsistently.	3- Average Quality Has end punctuation that is usually correct (e.g., period, question mark, exclamation mark). Has inconsistent capitalisation but shows signs of appropriate use (e.g., some starts of sentences, names, or titles).	4 – Above Average Quality Has end punctuation that is usually correct. Attempts other punctuation, sometimes correctly (e.g., commas, colons, quotation marks). Uses capitals at the beginnings of sentences and for some names and/or titles.	5- High Quality End punctuation is always correct; attempts other punctuation, recurrently correct (e.g., commas, colons, quotation marks). Uses capitals at the beginning of sentences and fairly consistently for names, titles, and/or proper noun.
Spelling				
1- Low Quality Uses letter strings (i.e., pre-phonetic) indicating gaps in knowing letter/ sound relationships; has emerging print sense.	2- Below Average Quality Attempts phonetic spelling that is mostly decodable; may include some simple words spelt correctly.	3- Average Quality Has spotty spelling of grade-level, high-frequency words; spells some high-frequency words correctly and uses phonetic spelling on less common words.	4 – Above Average Quality Shows generally correct spelling of grade-level and high-frequency words; uses phonetic spelling on less frequent words.	5- High Quality Usually spells grade-level, high-frequency words accurately; spells less frequent/difficult words logically with some correctly spelt.

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