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The contributions of transcription skills to paper-based and computer-based text composing in the early years

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Abstract

Digital tools are an integral part of most writing communities across the globe, enhancing the criticality of gaining a comprehensive understanding of both paper and computer-based writing acquisition and development. The relationships between transcription skills and children's paper-based writing performance are well documented. Less is known about the relationships between transcription skills and children's computer-based writing performance. In this study, we examined the unique contributions of transcription skills (i.e., handwriting automaticity, keyboarding automaticity and spelling) in predicting Grade 2 students (N = 544) paper-based and computer-based writing performance (i.e., compositional quality and productivity) after controlling for other student-level factors (i.e., gender, word reading, reading comprehension, and attitudes towards writing) and classroom-level factors (i.e., amount of time teaching handwriting, keyboarding, and spelling). Multilevel modelling showed that, compared to handwriting automaticity, spelling skills accounted for a larger percentage of unique variance in predicting paper-based compositional quality; handwriting automaticity accounted for a larger percentage of unique variance in explaining paper-based compositional productivity. Findings further showed that keyboarding automaticity accounted for a larger percentage of unique variance in students' computer-based compositional quality and productivity when compared to spelling. Gender and word reading skills were also found to be uniquely related to students' writing performance across modalities. These findings underscore the need for educators to address and nurture the automaticity of inscription and spelling skills to enhance students' compositional quality and productivity, whether in traditional paperbased or computer-based text composing.

Keywords Paper-based writing · Computer-based writing · Handwriting · Keyboarding · Spelling

Extended author information available on the last page of the article

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Introduction

In the last two decades, digital writing has been replacing paper-based writing, becoming the most prevalent mode of communication not only for professional but also for personal written interactions (Gong et al., 2022). In some educational contexts, students' literacy skills, including proficiency in text composing, are now assessed via online national tests (e.g., Australian Curriculum, Assessment and Reporting Authority [ACARA], 2018); Biantoro & Arfianti, 2019; National Assessment Governing Board, 2010). Whether in classrooms or national assessments, writing tasks are often designed to assess students' writing proficiency, but handwriting and keyboarding skills are often presumed (Gong et al., 2022). While there is a wealth of studies showcasing relations between transcription skills, such as handwriting and spelling, and effective paper-based text composing (e.g., Feng et al., 2019; Kent & Wanzek, 2016), much less research has investigated whether and how keyboarding and spelling skills relate to computer-based text composing (Cerni & Job, 2023; Rønneberg et al., 2022). According to the Writer(s)-within-Community (WWC) model (Graham, 2018), writing is "simultaneously shaped and constrained by context, the capabilities, and perceptions of writers and collaborators, and the interaction between the two" (p. 258). It is also argued that digital tools are now an integral part of most writing communities across the globe and that such a digital shift is likely to impact writing acquisition and development (Graham, 2018). Since research highlights the urgency of preparing young developing writers to become hybrid writers, able to produce paper and computer-generated texts in today's digital age (Beers et al., 2017), gaining a comprehensive understanding of both paper and computer-based text writing in the early years is critical.

The current study aimed to address this gap by examining the contributions of transcription skills on paper and computer-based text composing of Year 2 students after controlling for student and classroom-level factors. This study adopted the WWC model (Graham, 2018) as its primary theoretical framework since the model offers a detailed description of student and contextual-level factors associated with writing acquisition and development. Two main purposes guided the present study. The first was to confirm theoretical and empirical research showing associations between handwriting automaticity, spelling, and paper-based text composing (i.e., compositional quality and productivity) in the first years of writing development (e.g., Graham, 2018; Kent & Wanzek, 2016). The second purpose was to expand knowledge about associations between keyboarding automaticity, spelling, and computer-based text composing (i.e., compositional quality productivity). Aligned with these two main goals, we also aimed at understanding the contributions of other students-level factors (i.e., gender, reading skills, and attitudes towards writing) and classroom-level factors (i.e., amount of time teaching spelling, handwriting, and keyboarding) in explaining the paper and computer-based text composing of beginning writers.

Automaticity of transcription skills in writing

Research shows that the automaticity of transcription skills is a critical step toward proficiency in written composition. Inscription skills such as handwriting and keyboarding are seen as peripheral-motor aspects of writing that involve the coordination and development of phonological, orthographic, visual, and motor skills. Spelling is a central-linguistic aspect of writing that involves the coordination of phonological, orthographic, and morphological information (Berninger et al., 2006; Cerni & Job, 2023) and a componential skill of beginning writing (Kim et al., 2011). As emphasised in theoretical models of writing (e.g., Graham, 2018; Juel et al., 1986; McCutchen, 1996), the automaticity of transcription skills is critical for beginning writers since it frees cognitive load necessary to support compositional processes and the focus on higher level processes such as ideation and planning during text composing. As per the capacity theory of writing (McCutchen, 1996), skilful writing is constrained by capacity limitations in working memory. Text composing imposes considerable process and storage demands since it involves the development of a wide range of skills, including foundational skills like handwriting, keyboarding, and spelling, as well as higher-order text composing skills, including planning, goal setting, and revision (Berninger et al., 2009). The cognitive demands of writing are particularly challenging for young writers or typists since they need to place considerable attention on letter production when writing by hand or on correct keystrokes when writing on a keyboard (Preminger et al., 2004).

There are differences between handwriting and keyboarding which may be associated with text composing in varying ways (Preminger et al., 2004). First, as opposed to handwriting, keyboarding involves the coordination of two hands and, subsequently, the coordination of two contralateral cerebral hemispheres, which may be particularly difficult for beginning writers (Berninger & Richards, 2002; Berninger et al., 2009). Also, while in text composing via paper and pencil young writers can focus on letter formation and its textual context simultaneously, computer-based text composing demands constant shifts of attention between the keyboard and the screen, consuming cognitive resources (Alamargot & Morin, 2015). Computer-based text composing can be particularly challenging for children in the first phases of keyboarding acquisition since they rely heavily on visual feedback when searching for the right keys to press, as opposed to later stages of keyboarding acquisition, when writers rely primarily on kinaesthetic feedback to compose texts (Preminger et al., 2004). Acquiring and developing handwriting competency is not less demanding for young writers since it requires integrating multiple cognitive and motor processes (Afonso et al., 2020). As a language skill, handwriting entails the acquisition and fast recall of orthographic information and simultaneously, as a perceptual-motor ability, it requires fine motor control, sustained attention for the execution of hand movements, visual integration, and visual perception (Feder & Majnemer, 2007). Accurate spelling may also tax capacity limitations since it requires the retrieval of phonological and morphological information, subsequent mapping with graphemes (letters and groups of letters that represent phonemes) and final assembling of graphemes in the correct sequence (Kim et al., 2023). Hence, when children's handwriting, keyboarding or spelling has not reached a level of

fluency that allows them to place minimal conscious effort, text composing will be compromised (Cerni & Job, 2023; Gong et al., 2022; Skar et al., 2022).

Integrating previous cognitive and sociocultural models of writing, the WWC model (Graham, 2018) proposes that writing acquisition and development is more comprehensively understood when considering two basic organising structures, namely the *writing community* and the *writers and their collaborators*, and the interactions between them. The writing community is described by historical, social, and cultural factors of the context where writing development takes place, including the operational role of teachers in supporting effective writing. Under the second organising structure, the WWC model describes an individual's cognitive architecture impacting text composing, namely production processes (i.e., physical and mental operations to compose texts); long-term memory resources (i.e., knowledge and beliefs about writing); and control mechanisms (i.e., attention, working memory, and executive control processes). Importantly, the WWC model emphasises the role of writing tools for skilful writing, arguing that writing communities and an individual's cognitive architecture are shaped by the type of writing tools made available to achieve specific writing goals and actions (Graham, 2018). Substantiated by previous seminal cognitive models of writing (Berninger & Winn, 2006; Hayes, 1996), the WWC model reinforces the critical role that handwriting, keyboarding and spelling play in the writing development of beginning writers, with empirical evidence confirming that inscription skills and spelling work together in constraining paper-based written composition in the primary grades (Kent & Wanzek, 2016; Medwell et al., 2009).

The contributions of handwriting and spelling to paper-based compositional quality and productivity

There is a wealth of studies showing that handwriting automaticity (often called handwriting fluency, measuring students' ability to produce legible letters under time limits) and proficient spelling are key component skills impacting skilful writing. Kent and Wanzek's (2016) meta-analysis examined the role of multiple potential component skills of writing in explaining writing quality and productivity across K-12. Results showed an effect size (ES) of 0.59 for the relationship between handwriting fluency/automaticity and writing quality of beginning writers (K-3) and an overall ES of 0.48 for writing productivity. Similarly, findings supported the role of spelling in paper-based writing, with results showing positive relationships between spelling and writing quality and productivity for beginning writers (ESs of 0.47 and 0.26, respectively). In another meta-analysis, Feng et al. (2019) found a 0.41 ES for the relationship between handwriting automaticity and substantive quality indicators of writing performance (i.e., content and text structure), with results also confirming relationships between handwriting automaticity and compositional productivity (number of words in handwritten texts; ES of 0.53).

Spelling and handwriting automaticity are particularly relevant for young writers during literacy acquisition since they may support or constrain the development of text composing skills (Kim et al., 2013). Specific studies examining paper-based text

composing in the first years of schooling (K-3) found relationships between handwriting automaticity and compositional quality (Kim et al., 2013; Malpique et al., 2020; Puranik & Al Otaiba, 2012) and productivity (often called writing fluency, as referring to measuring number of words, sentences, and/or ideas produced by students in response to a specific writing prompt) (Jiménez & Cabrera, 2019; Malpique et al., 2020; Olinghouse & Graham, 2009). For example, when examining student-level factors contributing to the writing performance of elementary-grade students (Grades 2 and 4), Olinghouse and Graham (2009) found that handwriting fluency made a significant contribution to writing quality ($\beta = 0.05$, $p = .01$) and that both handwriting fluency ($p = .00$) and spelling ($\beta = 0.05$, $p = .03$) uniquely contributed to explaining productivity (i.e., text length), even after controlling for other student-level factors including gender, basic reading skills, spelling, and attitude toward writing.

Further studies investigating the role of spelling in paper-based text composing for beginning writers have found relationships between spelling skills and both compositional quality and productivity/fluency (Berninger & Rutberg, 1992; Graham et al., 1997; Jiménez & Cabrera, 2018; Puranik & Al Otaiba, 2012). For example, in their seminal study, Graham et al. (1997) found that handwriting automaticity and spelling accounted for 66% of the variance in Grades 1–3 students' compositional fluency. Their findings showed that while handwriting automaticity contributed to predicting compositional quality for younger writers, spelling only contributed indirectly to compositional quality via its correlation with handwriting. Theoretical and empirical research also support close relationships between spelling and handwriting automaticity, especially for beginning writers (Afonso et al., 2020; Summer et al., 2013; Van Galen, 1991), with findings suggesting that handwriting automaticity increases with age and that it is mostly affected by spelling abilities till children reach the age of 10 (Afonso et al., 2020). Fewer studies, however, have focused on investigating the contributions of transcription skills in explaining young writers' computer-based text composing.

The contributions of keyboarding and spelling to computer-based compositional quality and productivity

While there are few studies examining the role of keyboarding automaticity in explaining computer-based writing in the early years (Berninger et al., 2009; Jiménez & Cabrera, 2019), research shows positive associations between keyboarding automaticity (also called fluency, measuring students' ability to type letters under time limits) and text composing in primary grades. For example, following an accelerated cohort design with two groups of elementary students (Grades 1–5; Grades 3–7), Berninger et al. (2009) investigated the role of transcription modes in explaining compositional fluency (number of words produced in a timed writing prompt) in Grades 1 to 7. Findings related to students' keyboard-based writing showed that keyboarding automaticity predicted compositional fluency across grades. In a similar study, Beers et al. (2017) investigated the effects of transcription abilities on writing outcomes of students in Grades 4 to 9, with findings showing positive relationships

between keyboarding automaticity and compositional fluency. When investigating the role of transcription skills in keyboard-based writing, Alstad et al. (2015) found moderate correlations between keyboarding automaticity and the written expression (combined written word fluency, sentence combining, and paragraph writing assessments) of typically developing writers in Grades 4–7. In another study investigating the contributions of transcription skills, Connelly et al. (2007) found keyboarding speed moderately related to the keyboard-based compositional quality of texts produced in Grades 5–6. Hence, like research on paper-based writing, empirical studies confirm that primary students with higher typing automaticity will likely compose longer and higher quality texts.

Studies examining the contributions of keyboarding automaticity and spelling in explaining computer-based text composing in the early primary are rare (Jiménez & Cabrera, 2019; Malpique et al., 2024; Valcan et al., 2024). When examining the contributions of transcription skills to keyboard-based writing for beginning writers in Spain (Grades 1–2), Jiménez and Cabrera (2019) found that typing fluency and spelling, taken together or separately, contributed to writing fluency. As noted by the authors, however, a limitation of their study was not examining relations between typing fluency and writing quality. In a previous study examining the role of transcription skills for Grade 2 students' written composition in Australia, we (Malpique et al., 2024) found that, after controlling for variance due to gender, writing attitudes, word reading, reading comprehension, and nesting due to classroom, keyboarding automaticity ($\beta = 0.45$, $p = .02$) and spelling ($\beta = 0.24$, $p = .01$) contributed to computer-based compositional quality, but only keyboarding automaticity ($\beta = 2.21$, $p < .01$) contributed to explaining compositional productivity. Considering the digital shift in education in many educational contexts (ACARA, nd; European Commission, 2012, 2023; Rohatgi et al., 2020), larger-scale research examining the contributions of keyboarding automaticity in explaining computer-based text composing in early primary is warranted.

The contributions of gender, reading, and attitudes towards writing

As proposed in the WWC model (Graham, 2008), gender, reading and attitudes toward writing are individual-level factors that may impact skilful writing, with empirical evidence supporting this proposition in novice writers. Research recurrently reports gender differences in writing typically favouring female students, who are found to display greater handwriting automaticity (Malpique et al., 2017, 2020; Skar et al., 2022) and keyboarding automaticity (Malpique et al., 2024); better spelling skills (Reynolds et al., 2015); more positive attitudes toward writing (e.g., Graham et al., 2012a; Lee, 2013); and produce longer and higher quality texts (e.g., Cordeiro et al., 2018; Malpique et al., 2020). Results from national proficiency assessments across countries have also reported a pattern of female advantage in writing outcomes (Reilly et al., 2019), including in Australian primary (Grades 1–6) and secondary grades (Grades 7–12) (Thomas, 2020).

Reading proficiency is another relevant individual-level factor impacting skilful writing (Graham, 2018). Empirical evidence showcases connections between

reading and writing. Research shows that reading and writing are developmental skills that influence each other throughout schooling (Alves et al., 2020). In a meta-analysis examining reading-writing relations, Kim et al. (2023) found that these relations were moderated by developmental stages and that they varied depending on reading and writing subskills. When examining a total of 395 studies, meta-analytic results showed strong relations between word reading-spelling ($r = .82$) and moderate ones between word reading-written composition ($r = .42$) and reading comprehension-written composition ($r = .44$). Word reading-spelling relations were found to be stronger for primary-grade students.

Motivational factors, including attitudes toward writing, are also said to play a key role in explaining skilful writing since they shape the writers' efforts and willingness to complete a writing task (Graham, 2018). In a systematic review of 46 studies published between 1990 and 2017, Ekholm et al. (2018) examined relationships between students' writing attitudes and writing performance. Mixed results were found from the few studies investigating writing attitudes in early primary (Grades 1–3), with two studies reporting positive relationships between children's writing attitudes and their writing outcomes, including compositional quality and fluency (Graham et al., 2007, 2012a) and one study with Grade 2 students reporting that writing attitudes did not predict children's written composition (Olinghouse & Graham, 2009). In contrast with the substantial amount of research investigating the role of gender, reading and attitudes towards writing in paper-based text composing, understanding the contributions of these individual-level factors in keyboard-based text composing in primary education has received little attention from researchers. In a time when computer writing is an integral part of written communications worldwide, such research is critical to inform educational practices.

Teaching transcription skills

The WWC model (Graham, 2018) presents writing as a socialized activity, reiterating the critical role played by teachers as mentors in supporting effective writing development via explicit teaching and opportunities for feedback and practice. Unfortunately, studies investigating instructional practices for writing have consistently found that teachers typically allocate limited time for writing practice and writing instruction in primary classrooms worldwide (for a review, see Graham, 2019). In Australia, findings from a national study investigating primary teachers (Years 1–6) instructional practices for writing (de Abreu Malpique et al., 2023b) suggested that teachers typically allocate less than three hours a week for writing practice in their classrooms. Findings from this national survey further suggested that primary teachers devote more time to teaching spelling (88 min per week) than any other foundational skills in Australian classrooms, with teachers reporting that they typically allocate 34 min per week to teaching handwriting and only 11 min per week to teach typing skills (de Abreu Malpique et al., 2023b). Such focus on teaching spelling in primary education when compared to teaching handwriting and keyboarding has also been reported in other national studies, including in the US (Cutler & Graham, 2008) and in England (Dockrell et al., 2016).

In some educational contexts, supporting the development of digital writing skills is included in curriculum guidelines across different years of schooling (European Commission, 2012, 2023; Rohatgi et al., 2020). It's important to note that in most educational contexts, however, children are introduced to writing by hand, and typing is only added as an extra skill once handwriting has been mastered (Cerni & Job, 2023; Donica et al., 2018; Jiménez & Cabrera, 2019). In Australia, where the current research took place, curriculum standards supporting the acquisition and development of digital writing skills are included in the English curriculum, and students are expected to be able to start developing their typing skills as soon as they enter schooling (Foundation year, typically 5-year-olds) (ACARA, nd). The teaching of information and communication technology (ICT) is further included as a general capability in the Australian curriculum and teachers are expected to support the development of ICT skills across curriculum areas and years of schooling (ACARA, nd). Considering this situation, it becomes relevant to gain a more comprehensive understanding of the unique role that transcription skills play in explaining young children's paper and computer-based writing to inform evidence-based recommendations for teaching writing in primary education.

The current study: research questions and hypotheses

The present study is part of a larger research project examining student and classroom-level factors explaining Grade 2 students' paper-based and computer-based text composing (Malpique et al., 2023a, 2024; Valcan et al., 2024). This study aims to expand knowledge about the unique role of handwriting automaticity, keyboarding automaticity, and spelling in the early years of writing development. We addressed the following research questions:

1. Does handwriting automaticity and spelling account for unique variance in Grade 2 students' paper-based text composing (compositional quality and productivity) after controlling for student-level (i.e., gender, word reading, reading comprehension, attitudes toward paper-based writing) and teaching-level factors (i.e., amount of time teaching spelling and handwriting)?
2. Does keyboarding automaticity and spelling account for unique variance in Grade 2 students' computer-based text composing (compositional quality and productivity) after controlling for student-level (i.e., gender, word reading, reading comprehension, attitudes toward computer-based writing) and teaching-level factors (i.e., amount of time teaching spelling and keyboarding)?

Considering previous research studies reviewed here (e.g., Graham et al., 1997; Kent & Wanzek, 2016), we expected that both handwriting automaticity and spelling accounted for variance on paper-based compositional quality and productivity. With research suggesting stronger contributions of handwriting automaticity on compositional quality and fluency when compared to spelling (Graham et al., 1997), we further expected that handwriting automaticity accounted for a larger variance in students' paper-based writing outcomes. In view of the limited research examining

keyboarding automaticity and spelling for computer-based text composing in early primary (Jiménez & Cabrera, 2019; Malpique at al., 2024; Valcan et al., 2024), we anticipated that both keyboarding automaticity and spelling accounted for unique variance in students' computer-based writing outcomes, with potential stronger effects of keyboarding automaticity (Malpique et al., 2024).

Research comparing paper and computer-based writing shows grade level impacting modality effects (Goldberg et al., 2003; Malpique et al., 2023b). In a meta-analysis of 26 studies published between 1992 and 2002 comparing students writing with computers vs paper in K-12, Goldberg and colleagues (2003) found significant effect sizes favouring computers for writing quantity (number of words, $d = .50$, $n = 14$) and writing quality ($d = .41$, $n = 15$). Moderation analyses showed that these effects could vary depending on grade level, with larger effects for quantity and quality for computer-based writing in middle and higher school than for elementary students. In a recent meta-analysis of 22 studies published between 2000 and 2022, Malpique et al. (2023b) also found that grade level moderated the effect sizes of writing production. More specifically, results suggested that Grades 4–6 students produce more letters and words using a keyboard while K-3 students produce more letters and words via paper and pen(cil). Findings were also indicative that typically developing writers in K-6, on average, write higher quality writings using paper and pen(cil) (ES = 0.53, $n = 5$), with the authors emphasising the need for higher quality and larger scale studies accounting for the nested nature of classroom data. As in other educational contexts (Cerni & Job, 2023; Donica et al., 2018; Jiménez & Cabrera, 2019), in Australia students are first introduced to text composing via handwriting and spelling experiences during literacy instruction, and keyboard-based writing is typically added as an additional skill (Australian Education Research Organisation [AERO], 2022). Hence, we anticipated that Grade 2 students' keyboarding automaticity would potentially constrain their abilities to produce high quality computer-based texts, and that students' compositional quality and productivity scores would be higher in paper-based text composing when compared to computer-based text composing.

Student and classroom-level factors have been found to account for variability in the writing performance of beginning writers (Graham, 2018; Kim et al., 2011, 2013; Malpique et al., 2019). Hence, to examine the unique variance attributable to transcription skills in students' paper and computer-based writing, we controlled for students' gender, reading skills and writing attitudes, all found to play a significant role in children's writing development (Kim et al., 2011, 2013; Malpique et al., 2019). Considering the body of research showing gender differences in writing in primary education (e.g., Malpique et al., 2023a, 2024; Skar et al., 2022), we expected gender would account for a significant variance in the compositional quality and productivity in both paper and computer-generated texts. Likewise, since recent meta-analytic findings show moderate relations between word reading-written composition and reading comprehension-written composition in primary education (Kim et al., 2023), we expected significant variance in students' paper and computer-based text composing attributable to their reading skills. Considering research showing some conflicting findings regarding relationships between children's attitudes toward writing and written composition (Ekholm et al., 2018), we were

expecting a smaller amount of variability attributable to student's writing attitudes. Given several meta-analyses confirming the impact of teaching transcription skills to support the development of effective writing (Graham & Santangelo, 2014; Graham et al., 2012c; Santangelo & Graham, 2016), we further controlled for teaching-level factors (i.e., amount of time teaching spelling, handwriting, and keyboarding) potentially contributing to students' writing performance in both written modes. We focused on teachers' reported time teaching transcription skills under the assumption that the more time allocated to teaching these skills, the more students would be able to develop their handwriting, keyboarding, and spelling skills to compose paper and computer-generated texts (Graham et al., 2012b).

Method

Participants and setting

The present study involved 544 Year 2 students (Mage = 7.00, SD = 0.27; range = 6–8 years; 54.2% female) enrolled in 47 classrooms from 17 primary schools within the Perth Metropolitan Region, Western Australia. Initial recruitment was completed via invitation letters sent to 390 government-funded schools, 79 independent schools, and nine catholic schools, with the final sample recruited from the first 17 schools who agreed to take part in the study. We used the Index of Community Socio-Educational Advantage (ICSEA), which is calculated on the basis of the socioeconomic status of each school's intake area (ACARA, 2012), to evaluate each school socio-demographic representativeness. As per the ICSEA average (1000), six participating schools were within the average range (950–1050) and 11 participating schools were above average range (> 1050). The percentage of students with language backgrounds other than English ranged from 7 to 47% (M = 18.3, SD = 10.3) and the enrolment of Indigenous students ranged from 0 to 12% (M = 2.8, SD = 2.9). Following ethics approvals by the University Human Research Ethics Committee and by the Department of Education of Western Australia, written informed consent was sought from each student and their primary guardian. Given conditions stipulated during the ethical approval process, it was not possible to capture family data on guardians' educational level and family income. Within participating schools, a total of 46 teachers agreed to participate (all female). Most teachers (84.8%) reported having completed a bachelor's degree and 10.9% graduate degrees in education, with large variability in terms of their professional experience (Myears = 12.89, SD = 10.86, range = 1–42 years).

Data collection was completed during the second semester of the school year in two separate assessment sessions. In the first individual assessment session, students were asked to complete tasks assessing their handwriting and keyboarding automaticity, spelling skills, reading skills, and attitudes towards writing paper and computer-based texts. In the second group session (three students), children were asked to compose short stories using paper and pencil and a computer laptop to assess written quality and productivity in both written modalities. To account for order effects, the presentation of paper-based and computer-based tasks was

counterbalanced. Assessment sessions took place in a quiet room outside the classroom during the school day, with length, times, and venues for each assessment session discussed with the teachers to ensure children's comfort and suitable monitoring of task completion. Before the commencement of the present study, assessment protocols and task administration were piloted with a similar group of students ($n = 49$) in Perth, Western Australia (Malpique et al., 2023a, 2024). For the current study, the first author administered the tasks, along with four education and psychology graduate research assistants (RAs) who were systematically trained to apply task protocols consistently.

Student-level factors

Handwriting and keyboarding automaticity

The alphabet writing task (Berninger & Rutberg, 1992) was used to evaluate students' handwriting and keyboarding automaticity. The task is said to provide "an index of automaticity in retrieving alphabet letters from memory and producing them legibly and quickly in the correct order" in a specific time period (Berninger et al., 2009, p. 128). Following previous assessment protocols (Grade 2, Alves et al., 2016; Berninger et al., 2009), children were asked to write or type the 26 letters of the alphabet in order as fast and accurately as they could. For the paper-based condition, students were asked to write the alphabet letters in lower case on lined paper using a pencil; for the computer-based condition, students were asked to type the alphabet letters using a laptop running a Microsoft Windows operating system with both spelling and grammar checks turned off. Students' work received a score of 1.0 for each correctly formed and sequenced letter (paper-based condition) and correctly typed and sequenced letter (computer-based condition) produced within the first 15 s of task completion. A RA trained to use the alphabet writing task to assess students' handwriting and keyboarding automaticity in the pilot study of this project scored all protocols (RA1). Two members of the research team (first author and a second RA) rescored 50% of protocols. Inter-rater reliability was calculated using intraclass correlation coefficients (ICC), yielding a score of 0.99 for both paper-based and computer-based conditions.

Spelling and reading skills

The Wechsler Individual Achievement Test WIAT- III Australian and New Zealand Standardised (Wechsler, 2016) was used to assess students' spelling and reading skills. The Spelling subtest was used to measure written spelling of letter sounds and single words from dictation. Following directions from the examiner's manual, students were asked to write a target sound or word after listening to the sound or word by itself and in the context of a sentence. Final scores reflected the total number of correctly spelt items. Two subtests were used to assess students' reading abilities. The Word Reading subtest is presented as a measure of word recognition (speed and accuracy) without the aid of context. As per the examiner's manual, students were

prompted to read out loud a list of increasingly difficult words without context. Final scores reflected word accuracy, namely the total number of words that students were able to read accurately under untimed conditions. The Reading Comprehension subtest was used to measure reading comprehension of different types of text, such as fictional stories and informational texts. Students were prompted to read year-level passages out loud or silently and respond to comprehension questions asked by the examiner. Final scores represented the total number of accurate responses. Following the norms in the test manual, raw scores were converted to standard age scores. WIAT-III validity, including content, construct, and criterion-related evidence, confirm that the instrument composites and subtests adequately measure each construct (Pelling & Burton, 2017). Two members of the research team rescored 50% of the spelling, word reading and reading comprehension, and inter-rater reliability was high (ICC = 1.0 for spelling and reading comprehension subtests; ICC = .99 for word reading subtest).

Attitudes toward writing

Semi-structured interviews were used to assess students' attitudes toward writing paper and computer-based texts and were conducted during individual assessment sessions. We were unable to locate any survey instrument assessing the attitudes towards writing keyboard-based texts of beginning writers (Grades 3 and below). The survey questions and the method to quantify students' answers were adapted from the Writing Attitude Survey (WAS) (Kear et al., 2000), which included validated questions assessing Grades 1–3 children's attitudes towards writing. Following previous studies examining relations between attitudes toward writing and the written composition of beginning writers (Skar et al., 2023), we reasoned that directly asking students about their attitudes towards writing paper and keyboard-based stories would make the task accessible for the young cohort participating in this study. A pilot study with Grade 2 students was undertaken to assess and streamline the assessment instrument (Malpique et al., 2023a, 2024). Students were asked to answer four closed-ended questions presented in a 5-point Likert scale and were prompted to circle their answers using face emojis ranging from *awful* (1) to *fantastic* (5) (i.e., How much do you like writing using paper and pencil?/ using a keyboard?; How do you feel when you are asked to write a story using paper and pencil?/ using a keyboard?). Additional questions prompted students into explaining the reasons for their choices (i.e., Why so?). For the current analysis and model testing, we only used the four closed-ended questions. Factor analysis of the 4 writing attitudes questions, using an oblique rotation, produced a two-factor solution. Two questions loaded at .85 or higher on the first factor (eigenvalue = 1.67) and accounted for 42% of variance. We named this factor as Attitudes Towards Keyboard-Based Writing (coefficient alpha was 0.74). The score for this factor was the average score for the two questions focusing on keyboarding. Two questions loaded at .67 or higher on the second factor (eigenvalue = 1.30) and explained 32.5% of variance. We named this factor as Attitudes Towards Paper-Based Writing (coefficient alpha was 0.73). The score for this second factor was the average score for the two questions referring

to handwriting. Two members of the research team rescored 50% of protocols and inter-rater reliability was high (ICC = 0.98).

Paper-based and computer-based text composing

Students' paper and computer-based text composing outcomes were assessed using extended writing prompts adapted from previous research examining paper and keyboard-based text composing of beginning writers (Berninger et al., 2009) and subsequently piloted with a similar group of Grade 2 students (Malpique at al., 2023a, 2024). To complete the paper-based writing task, students were given a prompt to write a short story ("On my way home from school, I found a robot") on a sheet of A4 lined paper and a pencil; to complete the computer-based writing task, students were given a prompt to write a short story ("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. Students were given 10 min to complete each writing task. The writing prompts were similar to control for students' knowledge and motivation (see Berninger et al., 2009, for similar procedures). The order of the handwritten and typed tasks was counterbalanced to control for order effects.

Two assessment protocols were followed to examine students' paper and computer-based text composing performance, namely compositional quality and compositional productivity. To assess compositional quality in each writing modality, we followed an analytical scoring scheme, which included 10 assessment criteria. These included Audience (e.g., ability 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 capitalisation; and Spelling (e.g., spelling of grade-level words). Scores for each criterion were allocated from 1 (low quality) to 5 (high quality) and the final scores for compositional quality in each modality reflected the average of the 10 marking criteria (maximum of 50 for final score). This assessment protocol was adapted following the Australian National Assessment Program, Literacy and Numeracy (NAPLAN) narrative writing marking (ACARA, 2016) and the 6 + 1 Trait® Writing rubric for Primary Grades (NREL, 2011). This specific assessment protocol was adapted to follow the judging standards for writing and creating texts set in the Western Australia English curriculum for Grade 2 (School Curriculum and Standards Authority [SCSA], 2016). To assess compositional productivity, we used the total number of words (TNW) students were able to produce in the corresponding paper-based and computer-based text composing writing tasks. Each word representing a spoken word was counted, regardless of spelling. This assessment protocol has been used in previous studies evaluating compositional productivity (e.g., Graham et al., 2016).

Three RAs (two primary school teachers and one PhD student) were trained to use the analytical scoring scheme and to follow the TNW assessment protocol.

Namely, raters were provided with anchor texts from high, middle, and low scores texts produced by Grade 2 students that participated in the pilot phase of this study. After independently scoring each practice text, raters were encouraged to discuss the specific features of each marking criterion and reached a level of agreement through discussion. A primary school teacher blind to the purpose of this study marked all paper-based compositions and the first author rescored 50% of students' paper-based texts (random selection). Interrater reliability measured by the intraclass correlation coefficient (ICC) was .93 for paper-based compositional quality and .98 for compositional productivity. ICC values for compositional quality ranged from .74 to .90. The average ICC values for *Audience* was .90; for *Ideas* .88; for *Text Structure* .89; for *Character and setting* .89; for *Vocabulary* .87; for *Cohesion* .82; for *Paragraphing* .88; for *Sentence structure* .74; for *Punctuation and capitalisation* .88; and for *Spelling* .87. A second primary teacher also blind to the purpose of this study marked all computer-based compositions and a PhD student rescored 50% of students' computer-based texts (random selection). Interrater reliability measured by the intraclass correlation coefficient (ICC) was .92 for computer-based compositional quality and .99 for compositional productivity. ICC values for compositional quality ranged from .79 to .91. The average ICC values for *Audience* was .91; for *Ideas* .89; for *Text Structure* .86; for *Character and setting* .85; for *Vocabulary* .87; for *Cohesion* .83; for *Paragraphing* .82; for *Sentence structure* .79; for *Punctuation and capitalisation* .89; and for *Spelling* .89.

Classroom-level factors: amount of time teaching transcription skills

Following data collection of student-level measures, the 47 teachers of the 544 participating students were invited to complete a Likert-type survey assessing the instructional practices for writing that they had implemented in their classrooms during the school year. The survey was adapted from a national survey investigating writing instruction in Australian primary classrooms (Grades 1–6, typically aged 6–12) developed by de Abreu Malpique et al. (2023b). To address the current study's research questions and subsequent multilevel analyses, we used data from one scale in which teachers were asked to report on the amount of time they had spent teaching handwriting, keyboarding, and spelling per week in their participating classrooms. The reliability coefficient of the items examining the amount of time for teaching foundational skills reported in de Abreu Malpique et al. national study (2023b), as assessed by Cronbach's alpha, was .81. In the present study, Cronbach's alpha values for the amount of time teaching foundational skills was .71.

Data analysis strategy

In addressing our research questions, we conducted a series of multilevel models within the Mplus software (Muthén & Muthén, 2012). Multilevel modelling is designed to handle data with a nested or hierarchical structure, where observations are not independent but instead grouped within higher-level units. Ignoring this structure and using traditional models may lead to biased parameter estimates

and incorrect standard errors, impacting the reliability of significance tests and confidence intervals. These models were carefully selected to explore the specific contributions of handwriting and keyboarding automaticity, spelling proficiency, and key covariates to Grade 2 students' text composition quality and productivity. Multilevel modelling may not be inherently necessary for nested datasets, especially when there is no variability in the outcome variable across level-2 units, as noted by Peugh (2010). However, the estimates of both ICC (ranging from 0.12 to 0.18) and design effect (ranging from 2.27 to 2.90) suggested the need for implementing multilevel modelling in the analysis of our data (Muthen & Satorra, 1995). We opted for multilevel modelling as the statistical approach to account for the hierarchical structure of our dataset, where students comprised Level 1, nested within classrooms at Level 2 (Raudenbush & Bryk, 2002). In the context of multilevel modelling (also known as hierarchical linear modelling), the terms "Level 1" and "Level 2" signify distinct tiers within the hierarchical data structure. Specifically, Level 1 pertains to the individual or lower-level unit, while Level 2 corresponds to the group or higher-level unit of analysis.

Adequate sample sizes are essential in multilevel modelling to ensure unbiased estimates and sufficient statistical power (Lee & Hong, 2021). According to the relevant literature (Bell et al., 2014; Maas & Hox, 2004), our sample size was deemed appropriate. To address this hierarchical structure and better understand the unique effects of various predictors, we used random intercepts models with Maximum Likelihood (ML) estimation. In accordance with the suggestion made by scholars (Enders & Tofighi, 2007; Hofmann & Gavin, 1998), we employed grand-mean centring for student and classroom level variables in our analysis.

For research question 1, the focus was placed on students' paper-based text composition quality and productivity. These outcome variables served as fundamental indicators of paper-based text composition skills. Similarly, for research question 2, we examined students' keyboard-based text composition quality and productivity as our outcome variables, which allowed us to evaluate computer-based composition skills.

To systematically investigate the impacts of automaticity, spelling, and control variables on our outcome variables, we specified five distinct multilevel models for each outcome variable. Model 1 (Null Model) served as our baseline model (Kreft & de Leeuw, 1998) without any predictors. Its primary purpose was to calculate the Intraclass Correlation Coefficient (ICC), helping us understand the proportion of variability in the outcome variables due to classroom differences. In Model 2 (Control Model), we included key student-level factors such as gender, word reading proficiency, reading comprehension, attitudes toward paper-based (or computer-based) writing, and classroom-level factors including the time dedicated to teaching spelling, handwriting and keyboarding. This allowed us to control for essential covariates. Model 3 (Automaticity Model) expanded on Model 2 by adding handwriting (or keyboarding) automaticity as a predictor, allowing us to examine its unique contribution. In Model 4 (Spelling Model) we further assessed the independent impact of spelling proficiency by introducing it alongside the variables in Model 2. Finally, Model 5 (Full Model) included both

handwriting (or keyboarding) automaticity and spelling, along with the variables from Model 2, providing insights into their combined effects.

We reported standardised coefficients to convey the change in the outcome variable associated with a one standard deviation increase in the predictor while holding all other variables constant. This data analysis strategy was designed to offer a comprehensive exploration of the relationships between handwriting and keyboarding automaticity, spelling, and various control variables in the context of Grade 2 students' paper and computer-based text composing.

Results

Descriptive statistics and bivariate correlations for student and classroom-level variables are provided in Tables 1 and 2.

Contribution of transcription skills to paper-based text composing

The findings from multilevel analyses pertaining to research question 1 are presented in Tables 3 and 4.

Table 3 presents the multilevel results for the measure of handwriting compositional quality. The table displays five different models (Model 1 to Model 5) that progressively incorporate various predictors at both the student level (Level-1) and the classroom level (Level-2). The findings of the null model (Model 1) demonstrated significant variations in intercepts, signifying a notable discrepancy in the mean quality of handwriting composition across various classroom settings. Intraclass Correlation Coefficient (ICC) analysis revealed that 16% of the variance in children's handwriting compositional quality outcomes could be attributed to the classroom to which they belonged.

Handwriting automaticity in Model 3 had a significant positive relationship ($\beta = 0.18$, $p < .001$) with handwriting compositional quality. This effect remained consistent and significant ($\beta = 0.18$, $p < .001$) in Model 5, indicating that students with higher handwriting automaticity tended to produce higher-quality handwritten compositions. Handwriting automaticity explained 2.8% unique variance of student-level variance above and over gender, word reading, reading comprehension, attitudes toward handwriting and the classroom-level variables included.

Spelling also had a significant positive relationship with handwriting compositional quality in Model 4 ($\beta = 0.36$, $p < .001$) and remained significant in Model 5 ($\beta = 0.35$, $p < .001$). Spelling explained 4.5% unique variance of student-level variance above and over all the other variables included in Model 4.

When considered collectively in Model 5, the combined effects of handwriting automaticity and spelling accounted for 7.1% of the variability observed at the student level. These effects were in addition to the variables at both the student and classroom levels that were included in this study.

Handwriting attitudes, while significant in Model 2 ($\beta = 0.09$, $p < .01$) and Model 3 ($\beta = 0.10$, $p < .01$), became non-significant in Models 4 and 5. This suggested that

Table 1 Descriptive statistics and bivariate correlations for student-level (n = 544) measures

Variable	M	SD	Min–Max	1	2	3	4	5	6	7	8	9	10	11	12
1. Gender (Male = 1, Female = 0)	0.46	0.50	0–1	1											
2. HW automaticity	7.19	3.02	0–17	−0.12**	1										
3. KB automaticity	8.89	4.39	0–24	−0.11*	0.42**	1									
4. Spelling	99.99	14.17	49–158	−0.02	0.30**	0.47**	1								
5. HW attitudes	3.91	0.82	1–5	−0.16**	−0.04	0.61	0.15**	1							
6. KB attitudes	4.02	0.97	0–5	0.05	0.10*	0.20**	0.10*	−0.11**	1						
7. Word reading	104.24	16.47	63–150	0.03	0.35**	0.45**	0.79**	0.06	0.06	1					
8. Reading comprehension	68.22	8.41	0–81	−0.10*	0.28**	0.30**	0.52**	0.05	0.04	0.58**	1				
9. HW Compositional fluency	71.39	33.66	4–190	−0.27**	0.30**	0.30**	0.33**	0.15**	0.01	0.29**	0.17**	1			
10. HW Compositional quality	27.85	5.26	10–46.5	−0.18**	0.38**	0.44**	0.61**	0.14**	0.07	0.57**	0.42**	0.67**	1		
11. KB Compositional fluency	39.90	28.22	0–211	0.14**	0.31**	0.53**	0.42**	0.06	0.15**	0.42**	0.25**	0.50**	0.47**	1	
12. KB Compositional quality	21.69	5.47	1–41	0.11*	0.31**	0.50**	0.53**	0.02	0.13**	0.53**	0.38**	0.44**	0.53**	0.71**	1

HW handwriting, *KB* keyboarding

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

Table 2 Descriptive statistics and bivariate correlations for classroom-level (n = 47) measures

Variable	M	SD	Min–Max	1	2	3
1. Time teach spelling	120.17	57.63	40–270	1		
2. Time teaching handwriting	42.02	19.30	0–90	0.39**	1	
3. Time teaching keyboarding	28.00	38.33	0–240	0.39**	0.24	1

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

Table 3 Multilevel results of handwriting compositional quality measure

	Model 1	Model 2	Model 3	Model 4	Model 5
Level-1 predictors (student)					
HW automaticity			0.18 (0.04)***		0.18 (0.04)***
Spelling				0.36 (0.05)***	0.35 (0.05)***
HW attitudes		0.09 (0.04)**	0.10 (0.03)**	0.05 (0.03)	0.06 (0.03)
Reading comprehension		0.12 (0.04)*	0.10 (0.04)*	0.08 (0.04)*	0.06 (0.04)
Word reading		0.50 (0.04)***	0.45 (0.04)***	0.25 (0.06)***	0.20 (0.06)***
Gender (*male*)		–0.18 (0.04)***	–0.15 (0.04)***	–0.18 (0.03)***	–0.15 (0.03)***
Level-2 predictors (classroom)					
Time teach spelling		0.09 (0.20)	0.08 (0.20)	0.04 (0.22)	0.03 (0.22)
Time teach handwriting		–0.56 (0.18)***	–0.63 (0.17)***	–0.50 (0.20)*	–0.57 (0.19)**
Random components (variance)					
Student	23.48	15.55	14.98	14.57	14.00
Classroom	4.38	1.40	1.11	1.12	0.91
Loglikelihood	–1656.04	–1534.33	–1522.16	–1514.85	–1502.43
Variance explained (RL_1^2)		0.39	0.41	0.43	0.46

HW handwriting, standard errors are in parentheses

*$p < .05$, **$p < .01$, ***$p < .001$

students' attitudes toward handwriting might have a limited impact on compositional quality when other factors are considered. Similarly, reading comprehension showed a significant positive association in Model 2 ($\beta = 0.12$, $p < .05$), Model 3 ($\beta = 0.10$, $p < .05$) and Model 4 ($\beta = 0.08$, $p < .05$), but this effect diminished and became non-significant in Model 5. Word reading had a strong positive effect on handwriting compositional quality in Model 2 ($\beta = 0.50$, $p < .001$) and Model 3 ($\beta = 0.45$, $p < .001$). While this effect remained significant in Model 4 ($\beta = 0.25$, $p < .001$), it reduced further in Model 5 ($\beta = 0.20$, $p < .001$) suggesting that proficient word readers tended to produce higher-quality handwritten compositions. Gender, with a negative coefficient, indicated that being male was associated with lower compositional quality scores. This relationship was significant in all models, emphasising that female students tended to produce higher-quality handwritten compositions.

Table 4 Multilevel results of handwriting compositional fluency measure

	Model 1	Model 2	Model 3	Model 4	Model 5
Level-1 predictors (student)					
HW automaticity			0.19 (0.04)***		0.19 (0.04)***
Spelling				0.16 (0.07)*	0.15 (0.07)*
HW attitudes		0.13 (0.04)**	0.14 (0.04)***	0.11 (0.04)**	0.12 (0.04)**
Reading comprehension		0.02 (0.05)	–0.00 (0.05)	–0.00 (0.05)	–0.02 (0.05)
Word reading		0.29 (0.05)***	0.24 (0.05)***	0.18 (0.07)**	0.14 (0.07)*
Gender (*male*)		–0.28 (0.04)***	–0.26 (0.04)***	–0.28 (0.04)***	–0.26 (0.04)***
Level-2 predictors (classroom)					
Time teach spelling		–0.13 (0.18)	–0.14 (0.18)	–0.15 (0.18)	–0.16 (0.18)
Time teach handwriting		–0.32 (0.18)	–0.35 (0.17)*	–0.30 (0.18)	–0.33 (0.18)
Random components (variance)					
Student	923.75	750.41	727.39	746.08	723.23
Classroom	210.60	165.27	150.30	153.21	139.30
Loglikelihood	–2658.02	–2600.97	–2591.49	–2598.28	–2588.84
Variance explained (RL_1^2)		0.20	0.23	0.21	0.24

HW handwriting, standard errors are in parentheses

*$p < .05$, **$p < .01$, ***$p < .001$

The time dedicated to teaching spelling at the classroom level did not show a significant effect on handwriting compositional quality in any of the models. Conversely, the time allocated to teaching handwriting at the classroom level demonstrated a consistent negative effect on compositional quality. This effect was significant in all models.

Table 4 provides an interpretation of the multilevel results for the measure of handwriting compositional productivity. The results from the null model (Model 1) indicated significant differences in intercepts, indicating a substantial variation in the average quality of handwriting composition among different classroom environments. An analysis of the ICC showed that 18% of the variance in children's handwriting composition quality scores could be attributed to the specific classroom they were part of.

In Model 3, there was a significant and positive association between handwriting automaticity and handwriting compositional productivity ($\beta = 0.19$, $p < .001$). This relationship persisted and remained statistically significant in Model 5 ($\beta = 0.19$, $p < .001$), suggesting that students with greater handwriting automaticity tended to exhibit higher levels of handwriting compositional productivity. Handwriting automaticity accounted for 2.9% of the unique variance in student-level outcomes, even after considering factors such as gender, word reading, reading comprehension, attitudes toward handwriting, and classroom-level variables.

Similarly, in Model 4 spelling demonstrated a significant and positive correlation with handwriting compositional productivity ($\beta = 0.16$, $p < .05$), and this relationship

continued to be significant in Model 5 ($\beta = 0.15$, $p < .05$). Spelling explained 0.9% of the unique variance in student-level outcomes, even when considering all other variables included in Model 4.

Incorporated within the scope of Model 5, the cumulative impact of handwriting automaticity and spelling contributed to 3.8% of the variability discerned at the student level above and over variables considered at both the student and classroom levels in this study.

Handwriting attitudes demonstrated a positive impact on productivity, with significant effects in Model 2 ($\beta = 0.13$, $p < .01$), Model 3 ($\beta = 0.14$, $p < .001$), Model 4 ($\beta = 0.11$, $p < .01$), and Model 5 ($\beta = 0.12$, $p < .01$). This suggested that students with more positive attitudes toward handwriting tended to write longer handwritten compositions. Across all models, reading comprehension revealed no significant impact on handwriting compositional productivity. Word reading had a significant positive effect on productivity in Model 2 ($\beta = 0.29$, $p < .001$) and Model 3 ($\beta = 0.24$, $p < .001$). This effect remained significant in Model 4 ($\beta = 0.18$, $p < .01$) and Model 5 ($\beta = 0.14$, $p < .05$), indicating that students with stronger word reading skills tended to write longer handwritten compositions. In all models, spanning from Model 2 to Model 5, gender exhibited a significant association with handwriting compositional productivity, with female students consistently outperforming male students. The time dedicated to teaching spelling at the classroom level did not exhibit significant effects on handwriting compositional productivity in any of the models. Similarly, time teaching handwriting was not a significant predictor of compositional productivity when all the other variables were controlled for.

Contribution of transcription skills to computer-based text composing

The findings from multilevel analyses pertaining to research question 2 are presented in Tables 5 and 6.

Table 5 presents the multilevel results for the measure of keyboarding compositional quality. The results from the null model (Model 1) revealed substantial variations in intercepts, indicating significant differences in the average quality of keyboarding composition across various classroom environments, with an analysis of the ICC indicating that 12% of the variance in children's keyboarding composition quality scores could be attributed to their specific classroom.

A significant and positive relationship was observed between keyboarding automaticity and keyboarding compositional quality in Model 3 ($\beta = 0.29$, $p < .001$) and Model 5 ($\beta = 0.27$, $p < .001$), indicating that students with greater keyboarding automaticity consistently generated higher-quality keyboarded compositions. Keyboarding automaticity accounted for 5.9% of the unique variability in student-level outcomes, beyond and in addition to gender, word reading, reading comprehension, attitudes towards keyboarding, and the classroom-level variables examined in this study.

Spelling demonstrated a noteworthy and positive association with keyboarding compositional quality in Model 4 ($\beta = 0.22$, $p < .001$), and this relationship continued to be statistically significant in Model 5 ($\beta = 0.15$, $p < .01$). Spelling contributed

Table 5 Multilevel results of keyboarding compositional quality measure

	Model 1	Model 2	Model 3	Model 4	Model 5
Level-1 predictors (student)					
KB automaticity			0.29 (0.04)***		0.27 (0.04)***
Spelling				0.22 (0.06)***	0.15 (0.06)**
KB attitudes		0.09 (0.04)**	0.05 (0.04)	0.08 (0.04)*	0.04 (0.04)
Reading comprehension		0.12 (0.04)**	0.09 (0.04)*	0.09 (0.04)*	0.08 (0.04)
Word reading		0.50 (0.04)***	0.38 (0.04)***	0.34 (0.06)***	0.29 (0.06)***
Gender (male)		–0.12 (0.04)**	–0.09 (0.04)*	–0.12 (0.04)**	–0.09 (0.04)*
Level-2 predictors (classroom)					
Time teach spelling		0.14 (0.20)	0.13 (0.21)	0.15 (0.20)	0.13 (0.21)
Time teach keyboarding		0.11 (0.19)	0.06 (0.19)	0.09 (0.19)	0.05 (0.19)
Random components (variance)					
Student	26.18	17.61	16.15	17.16	15.93
Classroom	3.70	2.59	2.11	2.55	2.13
Loglikelihood	–1681.60	–1574.33	–1549.152	–1567.55	–1545.84
Variance explained (RL_1^2)		0.36	0.42	0.37	0.42

KB keyboarding, standard errors are in parentheses

*$p < .05$, ** $p < .01$, *** $p < .001$

Table 6 Multilevel results of keyboarding compositional fluency measure

	Model 1	Model 2	Model 3	Model 4	Model 5
Level-1 predictors (student)					
KB automaticity			0.39 (0.04)***		0.38 (0.04)***
Spelling				0.13 (0.06)*	0.03 (0.06)
KB attitudes		0.12 (0.04)**	0.06 (0.04)	0.12 (0.04)**	0.06 (0.04)
Reading comprehension		0.02 (0.05)	–0.02 (0.05)	0.00 (0.05)	–0.02 (0.05)
Word reading		0.41 (0.05)***	0.26 (0.05)***	0.32 (0.07)***	0.24 (0.06)***
Gender (*male*)		–0.17 (0.04)***	–0.12 (0.04)**	–0.17 (0.04)***	–0.12 (0.04)**
Level-2 predictors (classroom)					
Time teach spelling		0.01 (0.20)	–0.03 (0.23)	0.02 (0.20)	–0.03 (0.23)
Time teach keyboarding		0.29 (0.18)	0.28 (0.20)	0.28 (0.18)	0.28 (0.20)
Random components (variance)					
Student	687.65	549.14	485.44	546.56	485.36
Classroom	125.65	79.49	43.43	75.52	43.13
Loglikelihood	–2574.30	–2509.75	–2470.16	–2507.84	–2470.04
Variance explained (RL_1^2)		0.23	0.34	0.24	0.34

KB keyboarding, standard errors are in parentheses

*$p < .05$, **$p < .01$, ***$p < .001$

to 1.7% of the distinctive variability in student-level outcomes above and over all the other variables incorporated in Model 4.

Within the framework of Model 5, the combined influence of keyboarding automaticity and spelling accounted for 6.7% of the variation observed at the student level, surpassing the impact of variables considered at both the student and classroom levels in this study.

Keyboarding attitudes exhibited a positive effect on computer-based compositional quality in Model 2 ($\beta = 0.09$, $p < .01$), however, this effect weakened and became non-significant in our final model (Model 5) in which we included all other variables. A parallel trend in terms of diminishing impact was also evident in the context of reading comprehension. Word reading had a strong positive effect on compositional quality in Model 2 ($\beta = 0.50$, $p < .001$) and Model 3 (0.38, $p < .001$). This effect remained significant in Models 4 and 5 ($\beta = 0.34$ and $\beta = 0.29$, respectively, both $p < .001$), suggesting that students with stronger word reading skills tended to produce higher-quality keyboarded compositions. Across all models, female students scored significantly higher than males in computer-based compositional quality measure.

The time dedicated to teaching spelling and keyboarding at the classroom level did not exhibit significant effects on computer-based compositional quality in any of the models.

Table 6 provides a summary of the multilevel results for the measure of computer-based compositional productivity. Results of the baseline (null) model revealed significant variations in intercepts, indicating that the mean for computer-based compositional productivity scores differed across classrooms. ICC indicated that 15% of the variation in children's computer-based compositional productivity scores could be accounted for by differences among classrooms.

In Model 3, keyboarding automaticity demonstrated a significant positive effect ($\beta = 0.39$, $p < .001$) on computer-based compositional productivity. This effect remained consistent and significant in Model 5, indicating that students with higher keyboarding automaticity tended to compose longer keyboarded texts. Keyboarding automaticity explained 11.0% unique variance of student-level variance above and over all the other variables included in Model 3.

Spelling demonstrated positive association with computer-based compositional productivity in Model 4 ($\beta = 0.13$, $p < .001$), however this effect decreased and became non-significant in Model 5 ($\beta = 0.03$, $p > .05$) when other variables were incorporated. Spelling contributed to 0.7% of the unique variance in student-level outcomes above and over all the other variables included in Model 4.

When modelled together (Model 5), the combined influence of keyboarding automaticity and spelling contributed to 11.0% of the observed variability at the student level, beyond the variables examined at both the student and classroom levels in this study.

Keyboarding attitudes showed a positive impact on productivity in Model 1 ($\beta = 0.12$, $p < .01$) however, this effect lessened and became non-significant in Models in which keyboarding automaticity was included. Reading comprehension did not yield significant effects on computer-based compositional productivity in any of the models. Word reading had a strong positive effect on productivity in Model 2

($\beta = 0.41$, $p < .001$) and Model 3 ($\beta = 0.26$, $p < .01$). This effect remained significant in Models 4 and 5 ($\beta = 0.32$ and $\beta = 0.24$, respectively, both $p < .001$), suggesting that students with stronger word reading skills tended to compose longer keyboarded texts. Gender had a negative effect on productivity, with male students exhibiting lower productivity in computer-based compositions. This effect remained significant in Model 2 to Model 5. None of the classroom-level predictors was found to have a significant relationship with computer-based compositional productivity.

Additional independent t-test results showed that compositional quality and productivity scores were statistically significantly higher in paper-based text composing ($t(543) = 27.319$, $p = .000$, $d = 1.15$; $t(543) = 21.89$, $p = .000$, $d = 1.01$, respectively); and handwriting automaticity scores were statistically significantly higher than keyboarding automaticity scores ($t(543) = 9.026$, $p = .000$, $d = .45$). Results further showed gender differences favouring female students in handwriting automaticity ($t(542) = -2.91$, $p = .004$, $d = .25$); keyboarding automaticity ($t(542) = -2.53$, $p = .012$, $d = .22$); attitudes toward handwriting ($t(542) = -3.75$, $p = .000$, $d = .16$); and reading comprehension ($t(542) = -2.30$, $p = .022$, $d = .19$). T-test results showed that teachers reported allocating statistically significantly more time teaching spelling than handwriting ($t(543) = 32.027$, $p = .000$, $d = 1.88$) or keyboarding ($t(543) = 37.863$, $p = .000$, $d = 1.88$); and more time teaching handwriting than keyboarding (($t(543) = 15.603$, $p = .000$, $d = .46$).

Discussion

The main goal of the current study was to expand knowledge regarding the role of transcription skills in explaining the written composition of beginning writers across writing modalities. For that purpose, we investigated Grade 2 students' paper-based and computer-based text composing outcomes, namely compositional quality and productivity, and the variance explained by students' handwriting automaticity, keyboarding automaticity, and spelling. To gain a more comprehensive understanding of the role of these transcription skills across writing modalities, we controlled for student-level variables which were found to explain the writing performance of beginning writers, namely gender, reading skills, and attitudes towards writing, and classroom-level variables, namely the time teachers allocated for teaching handwriting, keyboarding, and spelling.

The role of inscription automaticity and spelling in paper-based and computer-based text composing

There is a strong body of theoretical and empirical research showing that handwriting and spelling play a critical role in explaining writing acquisition and development (e.g., Graham, 2018; Kent & Wansek, 2016). Hence, the first aim of our study was to investigate the distinct role of handwriting automaticity and spelling in explaining Grade 2 students' paper-based text composing. Very few studies investigating relations between handwriting automaticity/fluency and paper-based text

composing have controlled for variance due to student and contextual-level factors (Kent & Wanzek, 2016; Skar et al., 2022), and we were not able to locate any study examining the unique contributions of spelling after controlling for variance due the student and classroom-level factors investigated in this study. Findings from the current study showed that the combined effect of handwriting automaticity and spelling (Model 5) accounted for 7.1% of variance in compositional quality and 3.8% of variance in compositional productivity, even after controlling for the other student and classroom-level variables examined in this study. Hence, our findings confirm and emphasise the role of handwriting automaticity and spelling in explaining paper-based text composing for beginning writers (Graham et al., 1997; Skar et al., 2022). In a large-scale study investigating relations between handwriting fluency and writing quality in Grades 1–3, Skar et al. (2022) found that handwriting fluency accounted for 7.4% of the variance in students' writing quality after controlling for other student-level factors (e.g., gender and attitudes words writing) and nesting due to school and classroom. However, the authors highlighted the criticality of controlling for other transcription skills, including spelling, to gain a deeper understanding of the unique contribution of handwriting fluency in explaining the writing composition of beginning writers. In our study, and contrary to our expectations, handwriting automaticity accounted for a smaller variance in students' paper-based compositional quality compared to spelling (2.8% and 4.5%, respectively). While our study offers further evidence confirming the key role of handwriting and spelling in explaining the paper-based compositional quality and productivity of young writers, it also serves to generate several questions for future research. This result warrants further investigation, but a tentative explanation could be that children's handwriting automaticity may have reached a level that allowed them to place more attention on the conventional orthography of language in text transcription rather than on the automatic production of letters. Hence, spelling accuracy may have interfered more with the quality of students' paper-based texts than handwriting automaticity. Further research examining this possibility is warranted.

The second aim of the current study was to investigate the unique role of transcription skills in explaining computer-based text composing in the early years of schooling. As previously noted, studies investigating relations between keyboarding automaticity and spelling in computer-based writing in the early years of schooling are very rare (Jiménez & Cabrera, 2019; Malpique et al., 2024; Valcan et al., 2024). These previous studies with Grade 2 students found positive contributions of both keyboarding automaticity and spelling in explaining writing productivity (Jiménez & Cabrera, 2019; Malpique et al., 2024) and only keyboarding automaticity contributing to compositional quality (Malpique et al., 2024). Findings from the current study showed a combined contribution of 6.7% of spelling and keyboarding automaticity in explaining students' computer-based compositional quality and an 11% combined contribution in explaining students' computer-based compositional productivity, above and beyond all the other student and classroom variables examined in this study. As anticipated, results further revealed that keyboarding automaticity accounted for a larger percentage of the unique variability in students' computer-based compositional quality and productivity (5.9% and 11%, respectively) when compared to spelling (1.7% and 0.7%, respectively) and that, after controlling for

other student and classroom-level factors analysed in this study, the spelling effect on compositional productivity become non-significant. A possible explanation for the larger effect of keyboarding automaticity might be related to students' experiences with computer-based writing. As previously noted, children's first experiences with writing in Australia are by hand, and keyboarding is not systematically and explicitly taught in primary classrooms (de Abreu Malpique et al., 2023; AERO, 2022). Indeed, in the current study, teachers reported allocating on average less than 30 min of weekly time to teaching keyboarding in their classrooms and 33.6% of teachers reportedly did not teach keyboarding in their classrooms at all (0 min scores). Hence, the lack of keyboarding experience and training may have taxed students' computer-based text composing over and above spelling accuracy.

In the current study, results were also indicative that keyboarding automaticity, when compared to handwriting automaticity, explained more variance in both compositional quality and productivity. More specifically, handwriting automaticity accounted for nearly 3% of the unique variance in compositional quality and productivity while keyboarding automaticity accounted for a larger percentage of variance in compositional quality (5.9%) and productivity (11%). Considering that we controlled for the same student and classroom-level factors for paper and computer-based text composing, these differences may be due to less trained keyboarding skills when compared to handwriting (Gong et al., 2023). This explanation is particularly relevant when considering that teachers reported spending significantly more time teaching handwriting (42 min) than teaching keyboarding (28 min) on a weekly basis. When examining computer-based text composing in middle schools (Grades 6–9), Gong et al. (2022) found that keyboarding fluency had the strongest association with compositional quality for less experienced typists. In the current study, it is plausible that handwriting was automatised further compared to keyboarding, which enabled students to allocate relatively more cognitive resources to other writing processes when composing paper-based texts compared to when composing keyboard-based texts. Additional analyses showing that students composed longer and higher quality texts via paper and pencil reinforce this interpretation of results.

Control variables: the contributions of student and classroom-level factors

According to the WWC model of writing (Graham, 2018), skilful writing can be supported or undermined by specific factors within the individual writer's cognitive architecture (e.g., reading skills, attitudes towards writing and writing identity) and contextual factors, including classroom-level factors, where writing is typically taught. In the WWC model (Graham, 2018), it is further argued that the writing tools (e.g., paper/pen(cil) and computers) are likely to impact the development of writing skills and final written products. Given the value of specific writing tools in the context where writing takes place, individual writers need to develop specialised writing knowledge about when and how to use such tools for writing. Hence, in the current study we aimed to examine the contributions of student and classroom-level

factors in explaining the writing performance of beginning writers when using two different tools for text composing, namely paper/pencil and computer laptops.

Aligned with the WWC model of writing (Graham, 2018), we found significant positive correlations within and between student-level factors across writing modalities. Results from our multilevel analyses suggested that, apart from the unique role of transcription skills, other individual-level variables may have a significant impact on students' writing performance across writing modalities. Replicating findings from previous research (Ekholm et al., 2018; Olinghouse & Graham, 2009), our findings demonstrated a positive impact of attitudes toward writing paper and computer-based texts on compositional quality and productivity across writing modalities. However, effects weakened and become non-significant when all other student and classroom-level variables were included in our final comprehensive model 5. Similarly, reading comprehension showed a significant positive association with paper-based and computer-based compositional quality, but these effects become non-significant in our final comprehensive model. However, word reading skills were found to have a consistently significant positive effect in all the models tested in the current study and for both paper-based and computer-based compositional quality and productivity. These findings further reinforce theoretical and empirical research recognising relationships between reading and writing (Kim et al., 2023; Malpique et al., 2017, 2020; Shanahan & Lomax, 1986). Meta-analytic results (Kim et al., 2023) do show that reading and writing skills are strongly related (.72), with word reading moderately related to written composition (.42). Our study reinforces these findings and expands knowledge concerning reading-writing connections in computer-based text composing, with results suggesting that students with stronger word reading skills produced longer and higher quality computer-generated texts.

Findings from the current study also showed gender to be uniquely related to students' writing performance across modalities. Indeed, gender differences were found to have a consistently significant positive effect in all the models tested in the current study, showing that female students were able to produce longer and higher quality paper and keyboarded compositions even after controlling for other student and classroom-level factors. Results further showed statistically significant differences favouring female students in handwriting automaticity, keyboarding automaticity, attitudes towards writing paper-based texts, and reading comprehension. Recent reports from the National Assessment Program Literacy and Numeracy (NAPLAN) in Australia reinforce the gender gap in writing in Australian primary and secondary education, with findings showing a consistent gender gap favouring female students in Grades 3, 5, 7 and 9 (ACARA, 2023). Biological factors were found to explain gender differences in writing, with females showing a more advanced development in language and fine motor skills compared to males (Hartley, 1991; Reilly et al., 2019; Yang et al., 2020). Research also suggests that there are societal expectations impacting writing instruction and writing development, with female students more recurrently described as better writers and as having better handwriting abilities when compared to their male counterparts (Graham, 2018; Skar et al., 2022; Spear, 1989). With findings from the current study emphasising the gender gap in writing performance across modalities and as early as in Grade 2, further research is needed to examine the impact of teaching practices factoring gender differences in writing.

The present study offers further support to the WWC model (Graham, 2018) proposal that students' writing performance is shaped by contextual-level factors in which writing takes place, including classroom contexts. In the current study, the ICCs for both paper-based compositional quality and productivity (16% and 18%, respectively) and computer-based compositional quality and productivity (12% and 15%, respectively) were large at the classroom-level, empirically supporting the critical role of classroom contexts in shaping the writing performance of beginning writers across modalities. Subsequent multilevel analyses revealed, however, a lack of effects of time teaching spelling and keyboarding on computer-based compositional performance outcomes, and a negative effect of time teaching handwriting on paper-based compositional quality. Non-interventional studies examining the contributions of teaching practices in explaining the writing performance of beginning writers are scarce (Coker et al., 2018). In one of the few observational studies examining the role of writing instruction in predicting young students' writing achievement in the United States (Grade 1), Coker and colleagues (2018) found no direct positive effects between instructional practices for writing and students' writing outcomes. As Coker et al. (2018), we argue that the impact of the teaching practices assessed in the current study may not have been sufficiently strong to affect students' writing outcomes. The lack of impact of teaching keyboarding could be explained by the limited amount of time teachers reported allocating for the teaching of keyboarding skills. A potential reason to explain the negative effects of teaching handwriting on paper-based compositional quality may be related to overall instructional practices for writing. Namely, the teaching of text composing skills may not have been prioritised in classrooms where teachers prioritised the teaching of handwriting skills, which could have impacted the compositional quality of student's paper-based texts. There was also considerable variability in the amount of time spent on teaching transcription skills, which may have also impacted the lack of effects. Research testing these potential explanations is needed to provide a more comprehensive picture of instructional factors impacting the writing performance of beginning writers across writing modalities.

Limitations and future research

The findings from the present study provide additional evidence regarding the role of transcription skills in explaining the writing performance of beginning writers in paper and computer-based text composing. However, there are several limitations which need to be considered when interpreting findings. First, while the current study offers evidence of the contributions of transcription skills in an English language context, attention must be place in generalising our findings to countries with more consistent orthographies. Research conducted in countries with relatively transparent orthographies report inconsistent findings regarding relationship between transcription skills and writing performance (Spain, Jiménez et al., 2018; Portugal, Limpo & Alves, 2017; Norway, Skar et al., 2022). In one of the few cross-linguistic studies, orthographic consistency was found to moderate world-level writing but to have a reduced effect in text-level performance (Salas, 2013). Additional

research is needed to replicate findings from the current study, including cross-linguistic studies comparing the effects of transcription skills across writing modalities.

Second, even though the current study offers important information about the contributions of student-level factors in explaining the variance of paper and computer-based text composing for beginning writers, future research should examine other student factors found to be particularly relevant to explaining written composition, including oral language proficiency. Text generation involves oral language representation (Juel et al., 1986; Kim et al., 2011), and meta-analytic findings show positive relationships between oral language and the writing quality and productivity of beginning writers (ESs of .30 and .17, respectively, Kent & Wanzek, 2016). With accumulating evidence showcasing the importance of oral language in explaining written composition (Kim et al., 2018), research investigating the contributions of oral language proficiency in explaining paper and computer-based compositional quality and productivity is warranted.

In the current study, building on the few studies investigating relations between transcription skills and the paper and computer-based text composing of beginning writers (Jiménez & Cabrera, 2018; Malpique et al., 2024), we focused on examining only two dimensions of written composition, namely quality and productivity. Other dimensions, however, were found to be related to letter writing automaticity and spelling for early elementary school students, including syntactic complexity (Kim et al., 2014; Wagner et al., 2011) and macro-organization (Wagner et al., 2011). A better understanding of different dimensions explaining paper and computer-based text composing could inform our understanding of writing development across writing modalities. Also, the use of only one writing prompt is a limitation of the current study. Further research with multiple samples of children's writings is warranted to increase measurement reliability. Finally, caution must be taken when interpreting findings from our cross-sectional study since we were not able to establish casual relationships. Longitudinal research examining concurrent developmental growth patterns in paper and computer-based writing could help disentangle the effects of transcription skills across writing modalities.

We believe that the current research makes important contributions in understanding the role of transcription skills since we were able to control for specific classroom-level factors, namely time allocated for teaching transcription skills in individual classes. However, the current study did not include direct observation of teachers' writing practices. Teachers' responses to our survey may have been influenced by the difficulty of estimating time allocated for the specific instructional practices assessed in this study. Aiming to control for this potential effect, we asked teachers to complete the survey following data collection with their students to increase the likelihood of teachers reporting actual practices (Malpique et al., 2020). While findings from this study are aligned with survey-based (De Smedt et al. (2016) and observational studies (Coker et al., 2018) reporting a lack of effects of writing instruction variables on the writing performance of primary school students, direct observation of instructional practices to promote paper and computer-based writing is warranted to gain a more comprehensive understanding regarding actual teaching practices and the specific impact of such practices in supporting students' writing development in both writing modalities. It is important not only to study the

amount of time allocated to teaching specific writing practices but also the nature and the quality of such instructional practices (De Smedt et al., 2016).

A cornerstone of the WWC model (Graham, 2018) is that children develop different writing skills, knowledge, and motivation for writing by interacting with mentors and more experienced writers who support them in accomplishing writing goals and actions. Children's first informal experiences with writing are often at home, and it's in home-based contexts that children often have the first opportunities to interact with writing tools, whether via pen(cil) and paper or via tablets and similar digital tools. The contributions of home contexts for writing acquisition and development are under-studied (Alston-Abel & Berninger, 2018), but there is some empirical evidence supporting positive associations between parental involvement and children's writing outcomes, including handwriting and spelling accuracy (Camacho & Alves, 2017). Future research should aim to examine the contributions of home-based contexts to provide a more comprehensive understanding of writing development across writing modalities.

Implications for classroom practice

Findings from the present study emphasise the significance of automatising inscription and spelling skills as determinants of writing quality and productivity across writing modalities. Like for paper-based text composing, findings from our study suggest that keyboarding automaticity and spelling play a role in explaining computer-based writing in the early years. These findings provide additional support to theoretical models of writing (e.g., Graham, 2018; McCutchen, 1996) arguing that transcription skills constrain young writer's processing capacity to focus on higher-order skills of text composing and extend findings from the few empirical studies examining computer-based writing in early primary (Jiménez & Cabrera, 2018; Malpique et al., 2024). Two main implications of these collective findings must be considered to inform classroom practice. First, our multilevel analyses suggest that allocating little time to teaching handwriting and keyboarding may not impact children's paper and computer-based text composing. Hence, writing instruction should include extensive teaching and practice of handwriting and keyboarding since it will potentially free cognitive resources that children may use to focus on compositional processes and on higher level ideation processes. Indeed, as Beers and colleagues (2017), we argue that primary school teachers should be alerted to the importance of emphasizing the explicit teaching of handwriting and keyboarding to prepare beginning writers to become 'hybrid writers', able to produce paper and computer-generated texts with a similar level of proficiency. Second, the contributions of spelling on children's paper and computer-based text composing should not be underestimated, and primary school teachers should include systematic spelling instruction and practice since it is likely to free resources that children may use for text composing in both writing modes.

Overall findings underscore the need for educators to include instructional practices promoting the automaticity of transcription skills to enhance students' writing performance whether in traditional paper-based or computer-based text composing.

In the Australian context, where this study took place, the Australian Education Research Organization (AERO) has recently published a series of pedagogical recommendations aligned with our findings (AERO, 2022). Specifically, AERO encourages teachers to "…ensure adequate foundational instruction in handwriting and spelling; teach typing skills and provide students with opportunities to compose using digital writing tools; review the instructional quality and opportunities for boys and girls, and seek to close the writing achievement gap, and create motivating and supporting writing environments where writing is valued, routine and collaborative…" (p.21). While evidence-based recommendations are a step forward in the right direction, it must be acknowledged that their translation into practice remains a challenge and that further research that focuses on the understanding of teachers' in-situ instructional practices and their longitudinal impacts on writing performance on students is needed.

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Conflict of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

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