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The effects of automaticity in paper and keyboard-based text composing: An exploratory study

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ABSTRACT

The predictive relationship between handwriting automaticity and children's writing performance is well documented. However, less is known about the relationship between keyboarding automaticity and children's keyboard-based writing performance. In this exploratory study, we examined the unique contributions of automaticity in both writing modalities in predicting Grade 2 students ($N = 49$) paper-based and keyboard-based writing performance (i.e., compositional quality and fluency) after controlling for students' literacy skills (i.e., spelling, word reading, and reading comprehension), attitudes toward writing, gender, and nesting due to classroom. Multilevel modelling results showed that automaticity predicted students' paper-based compositional quality and keyboard-based compositional quality and fluency. Findings further suggested that the relationship between automaticity and writing performance was stronger in keyboard-based text composing than in paper-based text composing. These results reinforce the role of automaticity of transcription skills in predicating the writing performance of beginning writers across modalities and stress the significance of explicit pedagogy and frequent instances of practice to promote the mastery of transcription skills across modalities in the early years of schooling.

Introduction

Skilful writing is a powerful mean of communication, and it is a main goal in educational contexts worldwide (UNESCO, 2019). Learning to write is a complex and protracted process, which involves the development of both foundational (e.g., handwriting and spelling) and process writing skills (e.g., planning and revising texts) (Kellogg, 2008). In today's digital world, children's first writing experiences are often using keyboards, and in some educational contexts children are expected to use computers for text composing as early as they start schooling (Parette et al., 2000; Wollscheid et al., 2016; Zhang & Min, 2019). In some countries, there has been a move to online assessment of students' literacy skills in high-stakes testing, including writing (e.g., Australian Curriculum, Assessment

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and Reporting Authority [ACARA] 2018, Biantoro and Arfianti 2019, National Assessment Governing Board 2010).

Despite the current emphasis on digital means of writing, little is known about students' keyboarding abilities and student-level factors contributing to the development of computer-based compositional skills (Feng at al., 2019; Kimmons et al., 2017). In the current exploratory study, we thought to address this gap by investigating the unique contributions of handwriting and keyboarding automaticity in predicting Grade 2 students' compositional performance in both modalities after controlling for other student-level factors, namely literacy skills (i.e., spelling, word reading, reading comprehension), attitudes toward writing in both modalities, gender, and nesting due to classroom.

Automaticity of handwriting and keyboarding

The complexity of writing acquisition and development has been recently illustrated in the Writer(s)-within-Community (WWC) model (Graham, 2018), which proposes that "writing is simultaneously shaped by the community in which it takes place and the cognitive capabilities and resources of community members who create it" (p. 271). The present study adapted the WWC model as its underlying theoretical framework since it provides a comprehensive illustration of individual writers' cognitive capabilities impacting text production, including automaticity of transcription skills. Aligned with previous cognitive models of writing (Hayes, 1996; Kellogg, 1996; McCutchen, 1996), the WWC model proposes two basic organising structures impacting writing acquisition and development namely: (1) the *writing community* in which writing takes places, including historical, social, and cultural features of the context; (2) the *individual writer's cognitive architecture*, featuring production processes, which refer to mental and physical operations that writers execute for text production; long-term memory resources, which refer to beliefs and knowledges that writers hold about writing and that affect final written products; and control mechanisms, which support writers in making decisions about different aspects of text composing (Graham, 2018). Featured in the productions processes, transcription skills, such as handwriting and keyboarding, are said to play a critical role in the text composing of beginning writers (Graham, 2018).

Indeed, there is a strong body of research showcasing the important role that the automaticity of transcriptions skills plays in effective writing development. When examining 25 years of literature in the field, Kent and Wanzek (2016) found that transcription skills accounted for approximately 25 % of the variance in the quality of the written texts produced by primary and secondary school students (K-12), proposing that insufficient transcription automaticity in the first years of schooling could affect students' writing development. Research shows that handwriting automaticity is the best unique predictor of the writing skills of novice writers (Berninger et al., 2009) since limited handwriting automaticity constrains the writer's ability to focus on other complex aspects of writing, such as ideation and word selection (McCutchen, 1996; Van Waes & Leijten, 2015). In a longitudinal study investigating the writing performance of kindergarten and Grade 1 students, Malpique et al. (2020) found that handwriting automaticity predicted the quality of the texts students wrote in their kindergarten year and one year later. Skar et al. (2022) examined the unique contributions of handwriting automaticity in Grades 1–3 and found that handwriting automaticity accounted for variance in the quality of the texts children produced even after controlling for other student-level factors, including attitudes towards writing, gender, and contextual factors, such as classrooms and schools. Hence, research clearly showcases relationships between handwriting automaticity and children's paper-based writing performance.

Limited research, however, has examined relationships between keyboarding automaticity and primary students' keyboard-based writing performance (Berninger et al., 2009; Connelly et al., 2007). It is expected that, regardless of the written modality, automaticity of these transcription skills will allow writers to direct their attention to more complex writing processes and, subsequently, improve compositional quality and fluency (Berninger & Swanson, 1994; Weigelt-Marom & Weintraub, 2018). Handwriting (HW) and keyboarding (KB) require writers to access and retrieve alphabet letters and, as highly complex skills, they share some developmental features linked to other linguistic, cognitive, and sensory-motor skills (Preminger et al., 2004). However, HW and KB are distinct in several sensory-motor aspects. For example, when writing paper-based texts, children need to match specific motor functions to form letters, including the speed and size of each letter. In contrast, when writing keyboard-based texts, children rely more on kinaesthetic feedback that supports effective typing, as they need to be able to visually recognize and select alphabet letters on a keyboard and learn how to use movement patterns and keystrokes to compose a text (Preminger et al., 2004). In many educational contexts today, keyboard-based text composing is included in curriculum achievement standards as early as in the first year of schooling, and some countries have already started to move to online national assessment of students' literacy skills, including on writing (for a review, see Woolscheid et al. 2016). Hence, examining the contributions of each writing modality in explaining children's writing performance is paramount.

Findings from research studies comparing students' writing performance in paper-based and keyboard-based text composing in primary education provide some relevant insights regarding the role of keyboarding automaticity. For example, Connelly et al. (2007) found significant positive correlations between KB automaticity and the quality of the keyboard-based texts produced by primary students (Grades 5–6). In a similar study, Berninger et al. (2009) found positive associations between KB automaticity and productivity (number of words produced) when examining the written work of students in Grades 2, 4, and 6. Hence, despite of the limited number of studies examining the role of automaticity in keyboard-based text composing, the evidence suggests that automaticity may play a role in primary students' writing performance, namely on compositional quality (overall quality of texts) and fluency (total number of words in texts). Considering the complexity of writing acquisition and development, as illustrated by the WWC model (Graham, 2018), it becomes critical to examine the role of automaticity in both modalities after controlling for other student-level factors potentially impacting writing acquisition and development. The criticality relates to informing future foundation and process writing practices within the classroom (Kellogg, 2008).

Student-level factors impacting writing performance

Among the long-term memory resources described in the WWC model (Graham, 2018), motivational factors, including attitudes toward writing, are said to play a critical role in text composing since they shape the writers' efforts and willingness to complete specific writing tasks. Research on motivation for writing describes writing attitudes as an affective motivational state that influences writing performance across school grades (Ekholm et al., 2018; Pajares, 2003). Theoretically presented as a multidimensional construct, students' writing attitudes are shaped by different contextual factors, from macro-level factors, such as educational policies, to meso-level factors, such as teaching practices and family environments (Graham et al., 2018). As such, students' attitudes toward composing paper-based and keyboard-based texts are likely to differ, subsequently impacting students' writing performance. Ekholm et al. (2018) conducted a systematic review of studies examining relationships between students' writing attitudes and writing performance. They found only four studies investigating the writing attitudes of early primary school students (Grades 1–3) (Graham et al., 2007, 2012a; Knudson, 1992; Olinghouse & Graham, 2009). With the exception of Olinghouse and Graham's study (2009), where Grade 2 students' writing attitudes did not predict their writing performance, studies reported positive relationships between children's writing attitudes and their writing achievement, including compositional quality and fluency (Graham et al., 2007, 2012a). Primary and secondary school students also generally have positive attitudes toward writing using word processing (e.g., Bangert--Drowns 1993, Morphy and Graham 2012), so research examining novice writers' attitudes towards keyboard-based text composing and relationships to writing performance is necessary.

The WWC model proposes that individual writers' beliefs about their identities, including gender, may affect writing performance (Graham, 2018). Empirical research substantiates this theoretical stance, with a pattern of female advantage in writing performance being reported across studies internationally, including in high-stakes national tests (Reilly et al., 2019; Thomas, 2020). In primary education, studies have consistently reported that female students write longer and higher quality texts (Cordeiro et al., 2018; Malpique et al., 2017); show more positive attitudes toward writing when compared to their male counterparts (e.g., Graham et al. 2012a, Lee 2013); and exhibit greater handwriting automaticity, impacting compositional quality and fluency (Malpique et al., 2020; Skar et al., 2022). Research examining primary students' attitudes toward and use of technology, however, has consistently reported male students outperforming their female counterparts in computer-related activities (see Cai et al. 2017 for a review). Hence, gender is an important variable to consider when examining students' paper-based and keyboard-based writing.

Included in the WWC model, reading skills are presented as a critical knowledge-based component of text composing because they allow writers to analyse and comprehend different texts, which inform subsequent writing tasks (Graham, 2018). There is empirical support for connections between reading and writing, with research showing that reading and writing are developmental skills that influence each other across schooling (Alves et al., 2020; Andersen et al., 2018). For example, Ahmed et al. (2014) examined reading and writing connections in primary education (Grades 1–4) and found stronger reading-to-writing effects in comparison to writing-to-reading effects at the word, sentence, and text levels. Malpique et al. (2020) investigated Grade 1 students' writing performance and found that children's word reading skills predicted the quality and fluency of their texts. Berninger et al. (2006) also found positive associations between Grade 1 and Year 3 students' reading comprehension skills and their written texts.

As a transcription skill, effective spelling is also critical to allow the management of higher-order writing skills, such as generating and crafting texts (Graham, 2018; Scardamalia et al., 1982). Research shows that spelling abilities contribute to better writing performance especially in early literacy development (e.g., Berninger and Fayol 2008, Graham, Berninger, Abbott, Abbott, & Whitaker, 1997a, 1997b; Kim et al. 2013). For example, Graham et al. (1997b) found that Grade 1–3 students' handwriting and spelling abilities accounted for 66 % of the variance in students' writing fluency and 25 % of the variance in the quality of students' texts. Kim et al. (2013) also found associations between Grade 1 students' spelling skills and writing conventions of text composing, including handwriting, whereas Grade 1 students' handwriting automaticity was associated with the quality of their written texts. Since research has predominantly focused on examining connections between spelling, reading competences and paper-based text composing, research investigating relationships between students' spelling, reading performance and keyboard-based writing is needed to gain insights into writing development across writing modalities (Van Weerdenburg et al., 2019).

The present study

The present study is part of a larger research project investigating individual and contextual level factors impacting Grade 2 students' writing performance (Malpique et al., 2023a, 2023b, 2023c). To our knowledge at the time of writing this paper, this is the first study examining automaticity effects on the writing performance of beginning writers across modalities, after controlling for other individual-level factors and nesting due to classroom. We addressed the following research questions in this study:

1. To what extent does handwriting automaticity predict Grade 2 students' writing performance (compositional quality and fluency) after controlling for gender, attitude towards paper-based text composing, literacy skills (i.e., word reading, reading comprehension, and spelling), and nesting due to classroom?
2. To what extent does keyboarding automaticity predict Grade 2 students' writing performance (compositional quality and fluency) after controlling for gender, attitude towards computer-based text composing, literacy skills (i.e., word reading, reading comprehension, and spelling), and nesting due to classroom?

Methodology

This quantitative study is exploratory in design with the aim of gaining insights about the role of automaticity in writing paper-based and keyboard-based texts in the early years of schooling, after controlling for individual-factors and nesting due to classroom.

Participants

This study was approved by the University Human Research Ethics Committee and by the Department of Education of Western Australia. One government school and one non-government school in the Perth Metropolitan Region of Western Australia participated in this study. Both schools were positioned above the median value of the Index of Community Socio-Educational Advantage (ICSEA). ICSEA is an Australian composite measure of the relative socio-economic advantage of the population of students served by a school (Australian Curriculum Assessment and Reporting Authority - ACARA, 2012). The median value is 1000, with 500 indicating extreme disadvantage and 1300 presenting extreme advantage. The participant schools had an ICSEA value of 1173 (government school) and 1079 (non-government school). The percentage of students with language backgrounds other than English was 23 % and 26 %, respectively. Written informed consent was obtained from Grade 2 teachers, their students, and primary guardians. Three teachers (all female) agreed to participate. They all held bachelor's degrees and their professional experience ranged from 13 to 35 years. Forty-nine students ($Mage = 7.19$; $SD = 0.39$; 25 female), with no identified special educational need, enrolled in three Grade 2 classrooms participated in this study.

Data collection procedures

Data was collected during the final school term in Grade 2 (October–December). Students took part in one individual assessment session and one session in groups of three students. Assessment sessions took place in a quiet room outside the classroom during the school day. Length, times, and venues for each assessment session were discussed with the teachers to ensure children's comfort and suitable monitoring of task completion, as required by each school setting. During the individual sessions, students completed assessments of handwriting and keyboarding automaticity, literacy skills and attitudes towards writing, taking approximately 40 min. During the group sessions three students were assessed on their paper-based and keyboard-based text composing skills (i.e., compositional quality and fluency), taking approximately 15 min. The first and fourth authors administered the tasks, along with one trained research assistant (RA).

Student measures

Automaticity of handwriting and keyboarding

Handwriting and keyboarding automaticity were measured using the alphabet writing task (Berninger & Rutberg, 1992). Students were directed to produce all letters of the English alphabet in lowercase format in order and as fast and accurately as they could. Students were asked to complete the ABC tasks on lined paper with a pencil (handwriting mode) and on a laptop running a Microsoft Windows operating system (keyboarding mode). Students' written work was given a score of 1.0 for each correctly formed and sequenced letter (handwriting mode) and correctly typed and sequenced letter (keyboarding mode) produced at 15 s. The ABC task is defined as "an index of automaticity in retrieving alphabet letters from memory and producing them legibly and quickly in the correct order" and in a given time period (Berninger et al., 2009, p. 128). Since the aim of this study was to compare automaticity on both modalities, we followed assessment protocols used in previous research with the same age group (Year 2, Alves et al., 2016; Berninger et al., 2009). Inter-rater reliability (random 20 % of data) was computed to assess the degree of agreement between two researchers who administered the ABC tasks. Intraclass correlation coefficients yield a score of 1.00 for the handwriting task and 0.99 for the keyboarding task.

Literacy skills

Students' literacy skills were measured using subtests from the Wechsler Individual Achievement Test WIAT- III Australian and New Zealand Standardised (Wechsler, 2016). We used the Word Reading subtest to measure speed and accuracy of word recognition without the aid of context; the Reading Comprehension subtest to measure reading comprehension of various types of text (e.g., fictional stories, informational text, advertisements); the Spelling subtest to measure written spelling of letter sounds and single words from dictation. Research testing WIAT-III validity, including content, construct, and criterion-related evidence, confirm that the instrument composites and subtests adequately measure each construct (Pelling & Burton, 2017).

Attitudes toward writing

Students' attitudes toward writing paper-based and keyboard-based texts were assessed *via* semi-structured interviews. Attitude toward writing was operationalised as "an affective disposition involving how the act of writing makes the author feel, ranging from happy to unhappy" (Graham et al., 2007, p. 518). Semi-structured interviews were included in the individual session, where students were asked to complete a questionnaire using a 5-point Likert scale to assess their writing attitudes in both modalities. The questionnaire included four questions and students were prompted to circle their answer from a variety of options in the form of emotions 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?*). Supplementary questions were included to

Table 1
Descriptive statistics and bivariate correlations for student-level ($n = 49$) measures.

Variable	*M*	*SD*	1	2	3	4	5	6	7	8	9	10	11
1. HW automaticity	6.31	2.14	1.00										
2. KB automaticity	8.59	3.69	0.44**	1.00									
3. HW attitudes	3.83	0.75	−0.05	−0.05	1.00								
4. KB attitudes	3.82	1.14	0.42**	0.40**	0.04	1.00							
5. Spelling	101.94	10.24	0.19	0.45**	0.09	0.24	1.00						
6. Word reading	104.73	10.47	0.20	0.53**	0.08	0.17	0.80**	1.00					
7. Reading comprehension	70.88	6.48	0.05	0.42**	−0.02	0.19	0.68**	0.67**	1.00				
8. HW compositional quality	28.57	4.95	0.33*	0.45**	0.18	0.24	0.56**	0.49**	0.32*	1.00			
9. KB compositional quality	21.51	5.46	0.22	0.60**	0.19	0.42**	0.66**	0.61**	0.46**	0.50**	1.00		
10. HW compositional fluency	71.14	24.73	0.32*	0.28*	0.22	0.28	0.18	0.27	0.06	0.53**	0.42**		
11. KB compositional fluency	38.90	17.09	0.29*	0.62**	0.17	0.43**	0.45**	0.40**	0.28	0.48**	0.77**	0.45**	1.00

Note. HW= handwriting, KB = keyboarding.
* $p < 0.05$.
** $p < 0.01$.

prompt students into explaining the reasons for their choices (i.e., *Why so?*). Considering the developmental needs of the young cohort, questions were read aloud by the researchers.

Paper-based and keyboard-based text composing

Students' paper-based and keyboard-based text composing skills were assessed *via* extended writing prompts. In session two, groups of three students were given 10 min to write a short story following two specific writing prompts ("On my way home from school, I found a robot", by hand; "On my way home from school, I found a spaceship", by keyboard). To complete the paper-based writing task, students were given a sheet of A4 lined paper each and a pencil; to complete the keyboard-based writing task, students were given a laptop running a Microsoft Windows operating system with spelling and grammar checks turned off. The order of the handwritten and typed tasks was counterbalanced to control for order effects. To control for students' knowledge and motivation, the written prompts were similar in both written modalities (see Berninger et al. 2009, for similar procedures).

Students' writing performance in both modalities comprised assessment of compositional quality as well as compositional fluency. The analytical scoring of compositional quality included 10 criteria, namely: 1. Audience (e.g., ability to orient and affect the reader); 2. Ideas (e.g., development of main idea); 3. Text structure (e.g., beginning, middle, and end); 4. Character and setting (e.g., capacity to portray and develop characters and/or time and atmosphere); 5. Vocabulary (e.g., interesting and specific words to convey meaning); 6. Cohesion (e.g., use of grammatical elements to link parts of the text); 7. Paragraphing (e.g., segmenting of text into paragraphs); 8. Sentence structure (e.g., sentence-level grammar and flow); 9. Punctuation and capitalisation; and 10. Spelling (e.g., spelling of grade-level words). Scores for each criterion were allocated from 1 (*low quality*) to 5 (*high quality*). Compositional scores in both modalities reflected the average of the 10 marking criteria (range 1–50). This analytical scoring was adapted from the Australian National Assessment Program, Literacy and Numeracy (NAPLAN) narrative writing marking (ACARA, 2016) and from the 6 + 1 Trait® Writing rubric for Primary Grades (NREL, 2011). This assessment protocol was used since it was aligned with the judging standards for writing and creating texts set in the Western Australia English curriculum for Year 2 (School Curriculum and Standards Authority [SCSA], 2020). Students' texts were further assessed for the total number of words (TNW) to evaluate compositional fluency. TNW is a widely used measure, with research consistently showing it predicts writing quality in primary grades (e.g., Graham et al. 2016). Each word representing a spoken word was counted, regardless of spelling. We used inter-rater reliability (random 20 % of data) to examine the degree of agreement between two researchers who administered the extended writing tasks. The intraclass correlation coefficients for all written tasks were between 0.89 and 0.99 (i.e., 0.89 for compositional quality in paper-based texts; 0.92 for compositional quality in keyboard-based texts; 0.99 for compositional fluency in both modalities).

Data analysis strategy

Given that students were nested within classrooms, we employed multilevel with modelling HLM 7 software (Raudenbush et al., 2011) to account for the hierarchical structure of the data. For multilevel analyses, we preferred Restricted Maximum Likelihood Estimation (REML) estimator which produces less biased estimates with small samples (Boedeker, 2017; Raudenbush & Bryk, 2002). Separate two-level MLMs were employed for each outcome variable namely HW compositional quality, HW compositional fluency, KB compositional quality, and KB compositional fluency. Because student level (Level-1) fixed effects were of our main interest (no Level-2 variables were included) in this research and to control for nestedness in the data, we preferred multilevel modelling over simple ordinary least squares. First, baseline models (Kreft & de Leeuw, 1998) were computed to see whether variability occurred at the classroom level and if so, how much of the total variability (ICC) could be attributed to the differences among classrooms. In the second step, student-level predictors were included simultaneously to address our research questions.

Table 2
HW multilevel analysis: parameter estimates, standard errors, and variance components.

	HW compositional quality			HW compositional fluency		
	β	*SE*	*p*	*β*	*SE*	*p*
Level 1: Student						
Intercept	28.72	0.85	**0.00**	71.14	3.29	**0.00**
Gender (Male=1)	−2.98	1.04	**0.01**	−9.70	6.59	0.15
HW automaticity	0.54	0.25	**0.04**	3.09	1.61	0.06
HW attitudes	0.89	0.72	0.22	7.06	4.52	0.13
Spelling	0.23	0.09	**0.01**	−0.18	0.57	0.75
Reading comprehension	−0.10	0.12	0.39	−0.56	0.75	0.46
Word reading	0.04	0.06	0.49	0.60	0.40	0.14
Variance components						
Classroom	1.34			0.21		
Student	12.82			527.56		

Note. HW= handwriting.
Significant coefficients ($p < 0.05$) are highlighted in bold.

Results

Descriptive statistics and bivariate correlations for student-level measures are presented in Table 1. The sample students' KB automaticity performance ($M = 8.29$, SD=3.69) was higher than their HW automaticity ($M = 6.31$, SD=2.14) performance. Most of the predictors were statistically significantly related to each other, but the magnitudes of the associations varied from trivial ($r = -0.02$ between HW attitudes and reading comprehension) to strong ($r = 0.80$ between spelling and word reading). HW automaticity was moderately and significantly ($p < 0.05$) correlated to both HW outcome measures ($r = 0.33$ with HW compositional quality, $r = 0.32$ with HW compositional fluency). The correlations between KB automaticity and KB outcome variables were both statistically significant ($p < 0.01$) and strong ($r = 0.60$ with KB compositional quality, $r = 0.62$ with KB compositional fluency). The correlations among KB automaticity and KB outcome measures were stronger than the correlations among HW automaticity and HW performance outcomes, with a size of medium effect (Cohen's $q = 0.35$ for compositional quality comparisons and $q = 0.39$ for compositional fluency comparisons).

Multilevel results

In the current study, 49 students were nested within three classrooms. The number of students in classrooms ranged from 10 to 22. Parameter estimates (β unstandardized coefficients), standard errors, and variance components resulting from multilevel analyses are summarised in Tables 2 and 3.

Results of the baseline models indicated that mean HW compositional quality ($\chi2$ (2) = 3.92, $p > 0.05$) and HW compositional fluency ($\chi2$ (2) = 1.15, $p > 0.05$) scores didn't vary significantly across classrooms. Intraclass correlation coefficients (ICC) indicated that 6 % of the variance in children's HW compositional quality and 0.04 % of the variance in children's HW compositional fluency could be accounted for by differences among classrooms.

As shown in Table 2, after accounting for the other variables in the model, gender ($\beta = -2.98$, $p = 0.01$), HW automaticity ($\beta = 0.54$, $p = 0.04$), and spelling ($\beta = 0.23$, $p = 0.01$), were statistically significantly associated with students' HW compositional quality. HW attitudes ($\beta = 0.89$, $p = 0.22$), reading comprehension ($\beta = -0.10$, $p = 0.39$) and word reading ($\beta = 0.04$, $p = 0.49$) didn't significantly predict HW compositional quality. Girls scored significantly higher on HW compositional quality than boys.

Regarding HW compositional fluency, none of the variables in the model was statistically significantly associated with the outcome variable. Girls scored higher on HW compositional fluency than boys, but the difference was not statistically significant.

Null model results showed that mean KB compositional quality ($\chi2$ (2) = 0.23, $p > 0.05$) and KB compositional fluency ($\chi2$ (2) = 0.13, $p > 0.05$) scores didn't differ significantly across classrooms. Belonging to a particular classroom accounted for 0.01 % of variation in children's KB compositional quality and compositional fluency outcomes.

As shown in Table 3, after controlling for the other variables in the model, KB automaticity ($\beta = 0.45$, $p = 0.02$) and spelling ($\beta = 0.24$, $p = 0.01$) statistically significantly predicted students' KB compositional quality. Girls outperformed boys on KB compositional quality, but the gender difference was not statistically significant. With respect to KB compositional fluency, the only significant predictor was KB automaticity ($\beta = 2.21$, $p < 0.01$). On average, boys typed more words than girls, but the difference was not statistically significant.

Discussion

The current study examined the role of automaticity in predicting early primary grade students' writing performance across writing modalities. We investigated whether handwriting and keyboarding automaticity accounted for variability in compositional quality and fluency in both written modalities in a sample of Grade 2 students. In the following sections, we discuss the findings in reference to the extant literature as well as presenting the study's implications for education, limitations, and directions for future research.

Table 3
KB multilevel analysis: parameter estimates, standard errors, and variance components.

	KB compositional quality			KB compositional fluency		
	β	*SE*	*p*	β	*SE*	*p*
Level 1: Student						
Intercept	21.51	0.53	**0.00**	38.90	1.88	**0.00**
Gender (Male=1)	−1.34	1.06	0.21	3.31	3.78	0.39
KB automaticity	0.45	0.18	**0.02**	2.21	0.66	**0.00**
KB attitudes	0.85	0.52	0.11	3.15	1.86	0.10
Spelling	0.24	0.09	**0.01**	0.57	0.33	0.09
Reading comprehension	−0.07	0.12	0.53	−0.38	0.42	0.37
Word reading	0.04	0.07	0.52	−0.07	0.24	0.76
Variance components						
Classroom	0.01			0.03		
Student	13.57			172.06		

Note. KB= keyboarding.
Significant coefficients ($p < 0.05$) are highlighted in bold.

Well aligned with the WWC model and its proposed writer's cognitive architecture impacting text production (Graham, 2018) and consistent with prior empirical research, our findings show that handwritten compositional quality was predicted by HW automaticity (Malpique et al., 2017, 2020; Kent & Wanzek, 2016; Kim et al., 2013); gender (Reilly et al., 2019; Skar et al., 2022), and spelling (Puranik & AlOtaiba, 2012). Our findings therefore confirm well established predictive associations between transcription processes and the quality of written composition, giving further empirical support to developmental models of writing that consider the mastery of such foundational processes as critical in freeing cognitive resources towards more complex processes involved in text-generation (Berninger & Swanson, 1994; Graham, 2018). However, our findings showed that HW automaticity did not significantly predict compositional fluency as it would be expected if prior studies are considered (Feng et al., 2019). Given our sample size, it is possible that these results are more reflective of low power than of the absence of a true association. Future studies with larger samples would enable further examination of associations between HW automaticity and compositional fluency.

As per the WWC model, the introduction of digital tools may impact writing acquisition and development (Graham, 2018). Our study contributes to a rather limited body of research examining associations between KB automaticity and KB fluency and compositional quality (Feng et al., 2019; Gong et al., 2022). Following a similar pattern to the HW findings, both spelling and KB automaticity predicted compositional quality, after controlling for gender, attitude towards writing, reading skills, and nesting due to classroom. In contrast to the HW outcomes, however, KB automaticity also predicted compositional fluency, while no significant gender differences were identified. Associations between KB automaticity and KB compositional quality have been established in prior research with older primary aged students (Berninger et al., 2009; Connelly et al., 2007) and our study extends these findings to students commencing their primary education. For this sample of students, HW automaticity accounted for 11 % of the variance in the quality and 10 % of the variance in fluency in paper-based text composing. On the other hand, KB automaticity accounted for 36 % of the variance in the quality and 38 % of the variance in fluency of keyboard-based text composing. These stronger associations between KB automaticity and KB fluency may suggest that automaticity could potentially play a more significant role in keyboarded writing performance than that observed in handwriting. Recent research by Gong et al. (2022) examining keystroke data on 1300 middle school students in the US, for instance, shows that more fluent typists not only engage in more efficient text generation, but also engage in more and faster editing behaviours. These findings provide support for future studies investigating KB automaticity and its predictive associations with different aspects of writing performance.

Finally, it is important to note the absence of associations observed between text composition, students' attitudes towards handwriting and keyboarding, and reading. Prior research on students' attitudes towards writing and keyboarding suggest a complex picture, with some studies showing evidence of associations between attitudes and compositional quality and fluency (Graham et al., 2007, 2012a) and others not (Olinghouse & Graham, 2009). The absence of associations between composition quality and fluency across modalities and reading is somewhat surprising when considering existing evidence showing positive associations between reading and writing performance (Ahmed et al., 2014; Berninger et al., 2006; Malpique et al., 2020). In interpreting our findings, it is important to consider a number of contextual and measurement related variables that go beyond sample size issues. Participants in research are exposed to different pedagogies, different opportunities for practice, and are assessed using varying measures, all factors that call for further research on areas where there is still presence of ambiguity.

Our findings focus primarily on one of the components of the WWC model (Graham, 2018), addressing variables relevant to the *individuals' cognitive architecture*. As hinted above, variation at this level could be partly explained by the second component of the model, the *writing community*. Future studies, larger in scale, should strive to reach a more nuanced understanding of the interaction of individual and contextual factors and how they impact on paper and computer-based writing outcomes.

Implications for education

The present study adds to a growing body of research that empirically demonstrates associations between transcription skills and text composition, highlighting the significance of developing automaticity across text modalities. It is well-established that achieving automaticity can take several years, with research reporting that handwriting automaticity continues to develop well into middle school (Alves & Limpo, 2015; Cabell et al., 2022). Research also indicates that a large proportion of students (between 5 % and 44 %) experience writing difficulties (Feng et al., 2019, p.36), including in Australia (Malpique et al., 2023a). As argued by López-Escribano et al. (2022), in addition to students with diagnosed specific learning difficulties, struggling writers "are included in this percentage of students with writing difficulties as a silent majority who lack writing proficiency but do not receive additional help" (p.3).

This background calls for evidence-based pedagogies that prioritise the explicit teaching of both handwriting and keyboarding as well as dedicated time for practice to encourage automatization. Unfortunately, current studies that document teacher writing practices suggest that, particularly in the early years of schooling, teachers spend less than the recommended time teaching handwriting/keyboarding and facilitating handwriting/keyboarding practice (Dockrell et al., 2016; Malpique et al., 2017, 2020) and that variation among teachers' observed and reported practice is high (Coker et al., 2016; Cutler and Graham, 2008. For example, in a survey conducted by de Abreu Malpique, Valcan, Pino-Pasternak, and Ledger (2023), primary teachers ($N = 310$) reported spending on average 30 min per week on the teaching of handwriting, and an average of 11 min per week in keyboarding instruction. More than half of the respondents (54.5 %) reported that they never taught typing in their classrooms. These statistics are of concern and are at odds with existing evidenced-based approaches to writing instruction that recommend the teaching of transcription skills such as handwriting and keyboarding in tandem with higher level strategies that support text generation, including planning and revising (Graham et al., 2012b). In Australia, the Australian Education Research Organisation (AERO) issued in 2022 a series of recommendations calling for greater access to evidence-based practices by teachers (AERO 2022), and specifically arguing the importance of daily time to be spent on writing activities, the explicit teaching of foundational skills including handwriting and typing, and the

inclusion of strategy instruction such as planning, drafting, evaluating and revising, all in the context of meaningful writing activities (AERO, 2022).

Limitations and future research

There are several limitations to this study that should be addressed in future research. First, some caution is warranted when interpreting this study's findings due to its small sample of students and classrooms, which can increase the probability of type II errors. Small numbers are likely to preclude finding out significant differences. Secondly, although we assessed compositional quality and fluency in both modalities, we used only one writing prompt for each modality, while multiple samples of students' writings could have increased measurement reliability. Larger scale studies are needed to replicate and confirm the role of automaticity in both modalities in Year 2 and across the primary years of schooling. Importantly, such larger scale studies should aim at also examining the role of specific teaching practices that may promote the development of handwriting and keyboarding automaticity, as well as paper-based and keyboard-based text production. Research shows that transcription automaticity is also 'likely to influence the moment-to-moment production of a text" (Alves et al., 2016, p. 666). Namely, when producing texts, writers follow a succession of burst and pauses to convey meaning, with longer bursts often associated with better writing quality, including in early primary (Alves et al., 2015, 2016; Connelly et al., 2012). Hence, future studies should aim at collecting real-time handwriting and keyboarding data (including keystroke logging, e.g., Van Waes et al. 2021) to provide a more comprehensive view of the role of transcription skills and compositional fluency in both writing modalities.

More broadly, future research examining paper and keyboard-based writing should examine interactions across modalities (Feng et al., 2019) as well as broadening the consideration of contextual factors, including differences in language orthographies (Jiménez & Hernández-Cabrera, 2019). While our study focused on Year 2 students expanding on research on the early years of schooling, there is much to know about developmental trajectories of transcription processes, particularly when it comes to computer-based text composing. Such research will inform educational policies and practices that promote effective writing instruction and empower students into becoming the 'hybrid' writers of today's digital world.

The present study adds to a growing body of research that empirically demonstrates associations between transcription skills and text composition, highlighting the significance of developing automaticity across text modalities. However, as discussed, there is a clear gap between findings resulting from research and teacher practice. We argue that a valuable direction of future research would be to examine opportunities and challenges in processes of implementation of evidence-based practices, focusing not only on what teachers report, but also on what teachers do in classrooms.

Conclusion

Theoretical and empirical research on writing has traditionally placed their focus on understanding how handwritten texts are generated and crafted (Cerni & Job, 2023; Gong et al., 2022). In today's technological driven world, the way we use written language is hastily changing, as we move from a more paper-based to a keyboard-based writing world (Aram & Shachar, 2023). This changing context justifies the need for more research in this field with a specific focus on the development of automaticity across writing modalities. Current findings suggest that, at least in the early years of computer-based writing acquisition and development, keyboarding automaticity may play a more prominent role in text composing that handwriting automaticity. Hence, we argue for the need to expand knowledge on the developmental traits of both paper and computer-based writing. Understanding specific modality developmental paths is of core importance since such knowledge will drive evidence-based educational policies informing when, why, and how to teach handwriting and keyboarding in primary education.

Availability of data and materials

The dataset generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

CRediT authorship contribution statement

Anabela Malpique: Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Deborah Pino-Pasternak:** Writing – review & editing, Writing – original draft, Funding acquisition, Conceptualization. **Susan Ledger:** Writing – review & editing, Writing – original draft, Funding acquisition, Conceptualization. **Debora Valcan:** Writing – review & editing, Project administration, Investigation, Formal analysis, Data curation. **Mustafa Asil:** Writing – review & editing, Writing – original draft, Software, Methodology, Formal analysis.

Declaration of competing interest

We have no conflicts of interest to disclose.

Data availability

Data will be made available on request.

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