Handwriting Legibility and Fluency and their Patterns of Concurrent Relations with Spelling, Graphomotor, and Selective Attention Skills

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Handwriting legibility and fluency and their patterns of concurrent relations with spelling, graphomotor, and selective attention skills

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ABSTRACT

Recent research suggests that handwriting comprises two separate subskills: legibility and fluency. It remains unclear, however, how these subskills differ in their relationship to other abilities associated with handwriting, including spelling, graphomotor, and selective attention skills. In this study, we sought to examine the extent and nature of concurrent relationships that may exist among these skills. Children in Year 3 (n = 293), Year 4 (n = 291), and Year 5 (n = 283) completed a large, group-administered battery to assess each of the above skills. Using multigroup structural equation modeling, we found that spelling, graphomotor, and selective attention skills together explained a moderate amount of variance in handwriting legibility (R^2 = .37–.42) and fluency (R^2 = .41–.58) and that these subskills differed in their concurrent relations. Graphomotor skills accounted for a relatively greater proportion of variance in legibility than did spelling. Conversely, there were relatively stronger contributions from variations in spelling ability to variations in fluency than from graphomotor skills. Furthermore, selective attention predicted handwriting fluency only, and it partially mediated the influence of graphomotor skills. This study further demonstrates that handwriting legibility and fluency are separable and complex skills, each differentially related to spelling,

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graphomotor, and attentional abilities even during later primary school years.

Introduction

In recent years, there has been a renewed interest in understanding handwriting development (e.g., Caravolas et al., 2020; Gosse et al., 2021; Pritchard et al., 2021(Gosse et al., 2018)). This likely reflects the recognition that handwriting remains an important skill for literacy in the classroom (Wiley & Rapp, 2021) and that difficulties with handwriting are apparent in several developmental disorders such as dyslexia and developmental coordination disorder (DCD) (Afonso et al., 2020; Martínez-García et al., 2021; Prunty et al., 2014; Sumner et al., 2014). Current evidence points to the existence of two separable handwriting skills: fluency and legibility (e.g., Gosse et al., 2021; Karlsdottir & Stefansson, 2002). However, there is little clarity about the concurrent patterns of relations between these two constructs and the skills assumed to be related to them, namely spelling, graphomotor, and selective attention skills. In this study, we examined in detail these putative relationships.

Handwriting fluency and legibility

The not-so-simple model of writing (Berninger & Winn, 2006) views handwriting under the umbrella of transcription skills. Transcription skills are deemed critical for the conversion of ideas into language for text generation and are guided by executive functions. Whereas this model specifies that handwriting is an important aspect of writing development, it views handwriting as a unitary construct. Similarly, the psychomotor model of handwriting (van Galen, 1991) describes how higher-level cognitive processes of writing (e.g., ideation) cascade through to lower-level processes (e.g., motor processes; see Fig. 1) to influence handwriting production mainly focusing on the dynamics of handwriting. The dynamics of handwriting refer to measures of proficiency such as stroke duration, speed, and velocity and are considered in this article to be online proxy measures of *handwriting fluency*, that is, how well an individual can write consistently at speed. Van Galen's (1991) model does not consider the cascading effects of higher-level skills on the quality or readability of the production, termed here as *legibility*. As such, legibility is the measure of how easily decipherable the handwriting is to the reader (Downing & Caravolas (in press). It is generally measured by applying predetermined criteria to a written product (see Rosenblum et al., 2003).

Whereas theoretical models of writing development and production do not delineate handwriting into separable constructs, empirical evidence suggests that handwriting fluency and legibility should be considered as independent of one another. Studies pointing to the separability of fluency and legibility typically examine the correlations between the constructs and/or their developmental trajectories. In some studies with smaller samples ($N \sim 70$), the reported correlations between measures of handwriting fluency and legibility have been relatively large (r = .49–.61) among children in Grade 3 (Parush et al., 2010) and Grade 6 (Rogers & Case-Smith, 2002), suggesting more commonality than difference between them. However, studies with larger samples ($N > 100$) examining several grades either cross-sectionally (e.g., Graham et al., 1998) or longitudinally (Gosse et al., 2021; Karlsdottir & Stefansson, 2002) have reported weak intercorrelations across the school grades. The disparity between these findings could reflect differences in the sample sizes, with studies with smaller samples being more susceptible to identifying spurious correlations. The differences may also be explained by the use of different tasks and measures for assessing handwriting, particularly legibility (see Rosenblum et al., 2003).

Studies examining the developmental trajectories of fluency and legibility are also consistent with these as different constructs. In a cross-sectional comparison of fluency and legibility among children in Grades 1 to 9, Graham et al. (1998) found that whereas fluency generally increased with age, leg-

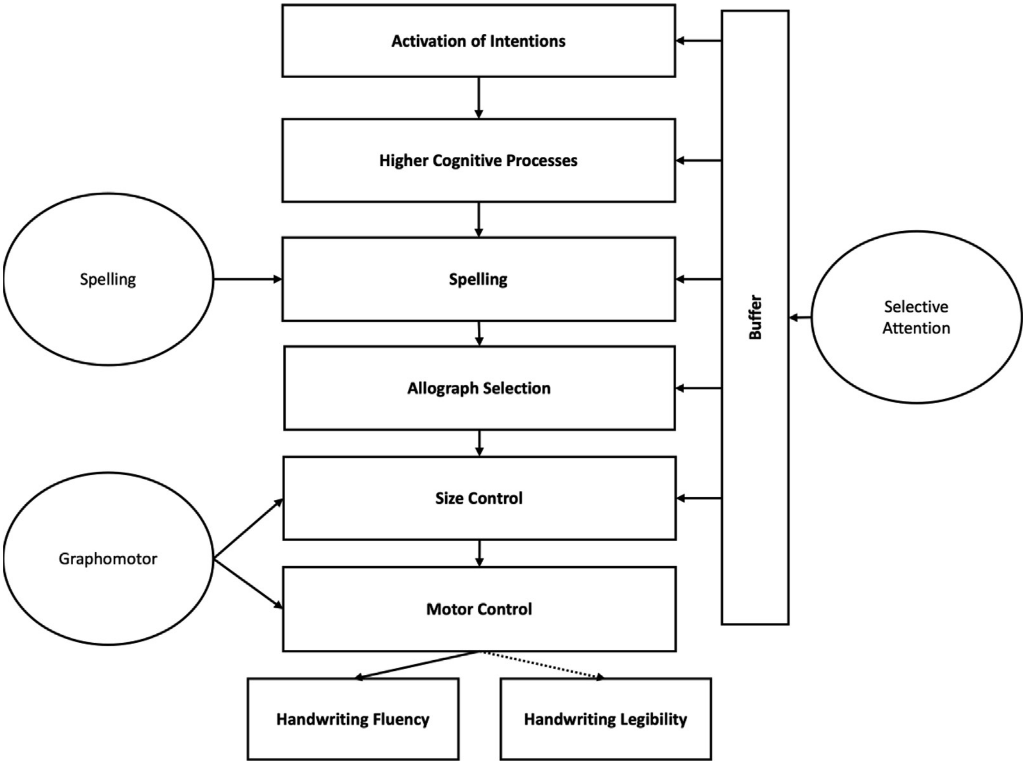

Fig. 1. A modified version of van Galen's (1991) psychomotor model. This figure maps handwriting correlates onto van Galen's original model and also applies handwriting legibility as well as handwriting fluency. The dotted line denotes handwriting legibility as an addition to the original model.

ibility remained quite stable across most of the grades. Children's legibility increased significantly only from Grade 4 to Grade 6. The longitudinal studies of Karlsdottir and Stefansson (2002) and Gosse et al. (2021) reported growth in handwriting fluency among primary-school-aged children but did not find any growth in legibility skills after 7 years of age.

These studies are broadly in alignment about the growth of handwriting fluency; however, they report a differing trajectory for legibility growth. To date, theoretical models of writing that consider handwriting fluency and legibility as separable constructs are missing. In such a view, these constructs should be at best moderately intercorrelated and have different patterns of relationships with various abilities that are theoretically and empirically linked to handwriting. We briefly review the extant literature on the relationships between handwriting fluency and legibility and their three potential correlates: spelling, graphomotor, and selective attention skills.

Spelling and handwriting

The not-so-simple view of writing describes spelling and handwriting under the umbrella of transcription skills, implying that these two skills are closely related (Berninger & Winn, 2006), yet it does not describe the nature of their association. Van Galen's (1991) psychomotor model (see Fig. 1), on the other hand, does predict that spelling processes are assumed to cascade downward, exerting influence on the motor processes associated with handwriting. This view is supported by experimental work examining the effects of spelling complexity and spelling ability on the dynamics or fluency of handwriting production (Afonso et al., 2018; Suárez-Coalla et al., 2020). More recent experimental work offers insight into potential mechanisms between spelling and handwriting. Online experiments have shown that lexical and sublexical processing regulates handwriting production whereby writing words with low or no frequency (i.e., pseudowords) or inconsistent words led to greater dysfluency in children's productions (Kandel & Perret, 2015; Kandel et al., 2017). This suggests that handwriting fluency represents the efficiency with which children are able to access orthographic representations.

Correlational studies have also found support for this directional relationship between spelling and handwriting fluency. Abbott and Berninger (1993) examined the relationship between latent variables comprising orthographic coding skills and fine motor skills and handwriting fluency in 6- to 11-year-old children. Orthographic coding skills, but not fine motor skills, were a significant predictor of handwriting fluency. In a further study by Abbott et al. (2010) examining the reciprocal relationships between handwriting, spelling, and written expression in 6 to 8 year-old children, the authors found that spelling was a stronger predictor of handwriting than handwriting was of spelling. The likely mechanism underlying this relationship entails ever faster lexical/sublexical processing (as orthographic knowledge grows with age and experience) placing fewer constraints on handwriting fluency—the time taken for (Kandel & Perret, 2015). Therefore, handwriting fluency appears to represent the growing efficiency with which children are able to access orthographic representations, and this relationship should strengthen with age.

Relatively fewer studies have examined the nature of the relationship between spelling and handwriting legibility. Following the theoretical rationale of van Galen (1991), Caravolas et al. (2020) examined the concurrent relations between spelling ability and handwriting legibility in children aged 8 to 10 years. They found spelling ability to be the strongest predictor of handwriting legibility over and above that of schooling experience and reading ability. This pattern held even when using a measure of spelling ability not associated with the handwriting task, suggesting that the relationship between spelling and handwriting legibility is not task dependent. Pritchard et al. (2021) also examined the relationship between spelling and handwriting legibility in younger children. The authors took the view that the quality of motoric representations realized in handwriting legibility holds an important role in later spelling development. In line with this view, the authors found a small but significant relationship between handwriting legibility at Time 1 and word spelling at Time 2 (6 months later).

Gosse et al. (2021) reported the longitudinal relations between spelling and handwriting fluency and legibility. Using an experimental task in which measures of spelling accuracy, handwriting fluency, and handwriting legibility were derived from single-word writing, the authors found that spelling accuracy was related to the development of fluency, yet no association between spelling accuracy and legibility was observed (see also Karlsdottir & Stefansson, 2002). The lack of a significant relationship between spelling and handwriting legibility is at odds with the findings of Caravolas et al. (2020) and Pritchard et al. (2021).

A tentative explanation is that the predictive relationships in question change over the course of development. According to this view, in early writing acquisition developing one's motor representations of written letters influences early letter spelling knowledge (e.g., Hulme, 1981; Hulme, 1981; Wiley & Rapp, 2021). Here, handwriting legibility reflects the quality of orthographic representations until the development of motor programs stabilizes (Palmis et al., 2017). After this time, the association between spelling ability and handwriting legibility gradually attenuates due to the accruing stability in handwriting legibility over the later childhood years. On the other hand, spelling and handwriting fluency remain consistently related, and handwriting fluency may in part reflect the efficiency of access to spelling representations. That is, early legibility may reflect the quality of orthographic representations, whereas handwriting fluency reflects the efficiency of accessing these representations. These hypotheses have yet to be investigated comprehensively, but they provide a theoretical basis for considering handwriting fluency and legibility as separable constructs. Nevertheless, Gosse et al.'s (2021) findings highlight that there may be separable and developmentally varying patterns of associations between spelling and handwriting fluency and legibility.

Graphomotor skills and handwriting

Motor skills play an important role in handwriting development and production (Palmis et al., 2017). The ability to integrate visuospatial and motor information—a key graphomotor skill—has been consistently associated with handwriting fluency and legibility (e.g., Tseng & Chow, 2000). Furthermore, visual motor integration ability explains a significant amount of variance in both handwriting constructs in children with poorer handwriting (Volman et al., 2006). Thus, correlational designs indicate that graphomotor ability is related to handwriting production, and it appears to be particularly important in children with poorer handwriting, possibly because they have not developed stable motor representations of letters (Palmis et al., 2017).

Training designs with properly randomly allocated controls (i.e., randomized controlled trials) afford a stronger test of any relationship between skills than correlational designs (Foster, 2010). Santangelo and Graham (2016) conducted a meta-analysis of eight training studies examining the effects of motor skills training on handwriting legibility and fluency. The overall effect of motor skills training on both handwriting legibility and fluency was nonsignificant; however, there was variation in reported positive and negative effects, and the studies reporting positive effects focused training on graphomotor skills rather than on more distal motor-related skills such as kinesthetic sensitivity. Furthermore, training graphomotor skills appeared to exert a stronger effect on legibility than on fluency. Thus, it is clear that graphomotor skills contribute to handwriting ability; however, their relative contribution to handwriting legibility versus fluency remains unclear.

The literature remains vague about the potential mechanisms underlying the relationship between graphomotor ability and handwriting fluency and legibility. Van Galen's (1991) psychomotor model of writing suggests that in skilled writers the selection and realization of motor representations (motor program) of letters cascades to influence handwriting production. In developing writers, graphomotor ability may influence the ability to learn sequenced motor actions necessary for fluent and legible handwriting (van Galen, 1991). Accordingly, children with poor graphomotor ability may learn motor sequences more slowly (see Biotteau et al., 2016), which may result in less legible and fluent handwriting (Prunty & Barnett, 2020; Prunty et al., 2014).

Attention and handwriting

A third, and perhaps the least well-understood, correlate of handwriting is attentional abilities. The not-so-simple view of writing argues that executive skills (including working memory and attention) assist in the management of the writing process (Berninger & Amtmann, 2003; Berninger & Winn, 2006; Hayes & Berninger, 2014). Here, we focused specifically on selective attention because this is likely to be involved in the control of multiple cascading processes necessary for handwriting (van Galen, 1991; see Fig. 1). We view selective attention as the ability to focus attention while ignoring competing stimuli (Lange et al., 2007). It has been proposed to be engaged for specific aspects of writing activity while ignoring/inhibiting other components (Berninger & Winn, 2006). However, relatively few studies have examined the relationship between attention and handwriting in children and adults (Hooper et al., 2011).

Studies with nonclinical samples have reported that children with less fluent handwriting perform more poorly on measures of attention (Tseng & Chow, 2000). Tucha and Lange (2005) found that adults' handwriting fluency decreased when they were asked to selectively attend to specific aspects of their handwriting (e.g., visually tracking their pen tip) while copying a short sentence. Given the participants' age and task, we assume that spelling and graphomotor processes had largely been automatized (Bourdin & Fayol, 1994), and so these findings suggest that attention processes can exert influence over handwriting production.

Perhaps the strongest evidence for a link between attention and handwriting comes from studies of children with attention-deficit/hyperactivity disorder (ADHD), a disorder characterized by impairments in attention. It is often reported that children with ADHD present with handwriting legibility and fluency difficulties and that these difficulties are related to the severity of their attentional impairments (Langmaid et al., 2014; Racine et al., 2008). Indeed, pharmacological treatment of ADHD with methylphenidate—which improves selective attention function (Lange et al., 2007)—has been found to improve handwriting legibility, although handwriting has been found to be more dysfluent (Tucha & Lange, 2001, 2005). Tucha and Lange (2001, 2005) argued that although the drug enables children to deploy selective attention more effectively and thereby to write more legibly, it does so at the cost of a methylphenidate-induced dysfluency in written production (see also Tucha & Lange, 2005).

Generalizations of findings from studies of children with ADHD are problematic in two ways. The first issue relates to the high degree of comorbidity between ADHD and other disorders such as dyslexia and DCD, which also present with handwriting difficulties (Downing & Caravolas, 2020; Prunty et al., 2014; Sumner et al., 2014). As such, the handwriting difficulties found in ADHD could be explained in part by unchecked comorbidity. A second issue is that studies reporting handwriting difficulties among children with ADHD do not typically set out in detail how attentional processes act on handwriting processes. It remains unclear whether attentional skills act directly on handwriting or whether attention mediates the effect of other correlates of handwriting. There is some evidence in support of this latter possibility. Adi-Japha et al. (2007) examined the types of errors made by children with ADHD—who did not have comorbid dyslexia or DCD—while writing. These children made more graphemic errors, which were not linguistically plausible, than children without ADHD. Furthermore, children with ADHD were more dysfluent when writing more motorically complex letters and words, a sensitivity not apparent in typically developing children. The authors concluded that handwriting difficulties among children with ADHD result from attentional deficits interfering with motor processes (see also Kaiser et al., 2015). This suggests that attentional skills may mediate motor skills in handwriting production. However, such a hypothesis has not been tested directly among children without ADHD.

The current study

The balance of evidence reviewed here points to handwriting legibility and fluency as separable constructs. However, what remains unclear is the strength of the association between handwriting legibility and fluency and abilities related to handwriting, namely spelling, graphomotor, and (selective) attention abilities. To our knowledge, the current study is the first to examine the concurrent relationships between handwriting legibility and fluency with these correlates. We investigated specifically whether spelling, graphomotor, and selective attention skills uniquely predict handwriting fluency and/or legibility and, if so, whether the patterns of the predictions are similar for legibility and fluency, respectively. Finding different patterns would bolster the claim that legibility and fluency are separable constructs of handwriting.

We hypothesized that handwriting legibility is related to the quality of spelling representations and that as the quality and stability of legibility improve, the association between the two skills may attenuate (Gosse et al., 2021). In turn, handwriting fluency is likely to be related to efficiency of accessing these representations (e.g., Kandel & Perret, 2015). Given that our sample were already moderately experienced writers (7–10 years old), spelling ability was likely to explain a significant amount of variance in handwriting legibility and fluency. Our age-appropriate measures of spelling ability were expected to estimate, on average, reasonably well-specified spelling representations, and so we anticipated a weaker relationship between spelling and legibility than between spelling and handwriting fluency.

In relation to graphomotor skills, we hypothesized that children with better graphomotor ability would have higher-quality motor programs. At 7 to 10 years of age, children are still acquiring these motor representations (Palmis et al., 2017), and so it was anticipated that children's graphomotor ability would be more related to legibility than to fluency. Furthermore, per the findings of Adi-Japha et al. (2007), we expected selective attention to influence motor processes but less so spelling processes. On this basis, it was plausible that selective attention would mediate the relationship between graphomotor ability and handwriting.

To test these predictions, we measured spelling, graphomotor ability, selective attention, and handwriting fluency and legibility in children aged 7 to 10 years. We selected this age range because it appears to be a critical period of literacy and handwriting development, where children have acquired handwriting skills and are automatizing them (Palmis et al., 2017; Thibon et al., 2019). Given that children's handwriting profiles change during this sensitive period (e.g., Graham et al., 1998), it remains an open question as to whether the patterns of the inter-relations between handwriting correlates and handwriting skills also change during this time. We expected the structural relations between spelling, graphomotor, and selective attention skills and handwriting fluency and legibility to be no different across the age groups. However, we did expect a waning of the strength of these relations because increased development reduces the individual variability of the relevant skills. In relation to the relationship between spelling and handwriting, we hypothesized that as orthographic knowledge grows—with age and experience—children's orthographic representations become more stable and the strength of the relationship between spelling and handwriting legibility decreases. Moreover, as retrieval becomes more fluent, the relationship between spelling and handwriting fluency may increase. Similarly, as motor sequences of letters are acquired—with age and experience—and become automatized, graphomotor skills may become less important for handwriting, and this would be observed via a reduction in the strength of the relationship between graphomotor ability and handwriting. We tested these hypotheses using multigroup latent modeling in the current study, which allowed us to test invariances of the factor structure, factor loadings, and intercepts across the age groups.

Method

Participants

A total of 867 children from six primary schools in North Wales, United Kingdom, were recruited to take part in a large study examining the basis of handwriting difficulties. Of those children, 293 were in Year 3 (M_{age} = 8.16 years, *SD* = 0.49; 53% female), 291 were in Year 4 (M_{age} = 9.11 years, *SD* = 0.54; 48% female), and 283 were in Year 5 (M_{age} = 10.10 years, *SD* = 0.55; 48% female). All the schools were English medium, and 97% of the sample classed their first language as English. Ethical approval for this study was given by the School of Human and Behavioural Sciences Ethics Committe, Bangor University, and this study complied with the British Psychological Society's Code of Ethics and Conduct.

Materials

All participants completed measures of handwriting legibility, handwriting fluency, spelling, graphomotor skills, and selective attention. These measures are described below, and the means, standard deviations, ranges, and reliabilities are reported in Table 1.

Handwriting legibility

Legibility was assessed using the Spelling and Handwriting Legibility Test (SaHLT; Downing & Caravolas (in press)). Children were instructed to write 10 sentences (63 words) in English (see "Spelling" section for elaboration on task) in their normal handwriting. The written product of these sentences was assessed using measurable criteria on four dimensions tapping four key aspects of handwriting legibility (Rosenblum et al., 2003). The four dimensions were (a) Letter Formation, which measures the accuracy in constructing the form, including orientation, consistency, angle, and size; (b) Letter Spacing, which measures the amount and consistency of the spacing between letters within a word; (c) Word Spacing, which (similarly) measures the amount and consistency of the spacing between words within a sentence; and (d) Line Alignment, which measures the degree and consistency of the words being written onto the line. Each of the sentences was scored on each dimension by applying detailed guidelines (see Downing & Caravolas (in press)) to a 5-point Likert scale from 1 (*highly illegible*) to 5 (*highly legible*). The score for each dimension was calculated by averaging the scores over the 10 sentences. The overall legibility score was derived by summing the average score for each dimension. These dimensions and associated scales were found to be psychometrically valid and reliable (e.g., test–retest reliability intraclass correlation coefficient [ICC] = .76 and inter-rater reliability ICC = .81; Downing & Caravolas (in press)).

Table 1
Descriptive statistics as a function of school year group.

Measure	Year 3			Year 4			Year 5			Reliability
	M	*SD*	Range	*M*	*SD*	Range	*M*	*SD*	Range	
Nonverbal ability										
Raw	25.20	6.60	11–36	29.45	5.68	16–38	30.12	6.27	15–39	.78[a]
Std.	104.72	17.03	52–144	107.47	15.02	50–142	105.27	14.43	51–132	
Spelling										
Words										
Raw	25.60	5.48	12–44	28.69	5.74	9–46	31.21	6.82	10–45	.91[a]
Std.	108.23	18.64	62–145	108.62	16.65	55–145	107.84	18.14	55–145	
Sentence										
Raw	36.34	11.88	3–59	42.80	10.27	10–61	46.48	10.74	8–62	.94[a]
Fine motor										
VMI										
Raw	19.21	2.87	13–30	20.70	3.10	12–28	21.88	3.40	13–29	.71[a]
Std.	92.98	11.11	62–133	93.22	11.92	64–122	92.94	12.67	60–121	
Coordination										
Raw	19.82	4.34	9–29	21.67	4.13	9–30	21.62	4.40	6–30	.73[a]
Std.	93.59	14.83	61–127	91.88	14.86	61–123	87.78	14.23	60–117	
Attention										
Map										
Raw	22.26	6.59	1–42	25.01	6.60	2–45	27.80	7.12	10–48	.88[b]
Std.	8.5	2.89	5–12	9.72	3.31	4–12	9.40	2.23	5–12	
Symbol										
Raw	16.49	6.56	1–31	19.05	6.05	1–37	21.26	6.96	1–42	.79[c]
Std.	8.17	3.70	3–15	10.40	2.43	3–15	10.75	2.49	3–15	
Coding										
Raw	31.85	6.90	12–50	35.55	8.99	7–72	40.05	8.76	11–61	.85[c]
Std.	9.35	2.98	4–15	10.29	3.5	3–15	10.50	2.20	3–15	
Legibility										.81[d]
LF	2.66	0.56	1–4	2.82	0.56	1–5	2.91	0.66	1–5	
LS	3.23	0.48	2–4	3.33	0.48	1–5	3.32	0.50	2–5	
WS	3.36	0.54	1–5	3.43	0.52	2–5	3.45	0.52	2–5	
LA	3.55	0.61	2–5	3.72	0.59	2–5	3.75	0.55	2–5	
Fluency										
Best 1	9.04	3.61	4–18	9.65	3.45	3–19	12.94	5.41	4–27	.71[e]
Best 2	7.83	3.32	2–17	9.35	3.68	3–18	10.93	4.32	3–21	
Fast 1	14.15	5.07	5–28	16.62	4.92	8–29	19.43	5.34	9–31	.82[e]
Fast 2	10.52	4.07	2–19	13.47	4.53	4–23	15.94	5.15	2–27	

Note. Standard scores *M* = 100, *SD* = 15. Std., standardized score; VMI, visual motor integration; LF, letter formation; LS, letter spacing; WS, word spacing; LA, line alignment.
[a] Internal consistency (Cronbach's alpha) derived from the current data.
[b] Test–retest correlation reported in Manly et al. (1998).
[c] Average internal consistency reported in the Wechsler Intelligence Scale for Children–Fourth Edition manual (Wechsler et al., 2003).
[d] Inter-rater (two-way random effects intraclass correlation) reported in Downing and Caravolas (in press).
[e] Test–retest (two-way mixed effects intraclass correlation) derived from the current data.

Handwriting fluency

Handwriting fluency was measured using the Detailed Assessment of Speed of Handwriting (DASH; Barnett et al., 2007) subtests: Copy Best and Copy Fast, which were administered according to published guidelines. In both tasks, children were asked to write the sentence "The quick brown fox jumps over the lazy dog" for a duration of 2 min. After the first minute, children were instructed to mark their progress using two slashes and to continue writing. In the Copy Best task, children were asked to use their best handwriting. In the Copy Fast task, they were asked to write as quickly as possible but to ensure that every word was readable. To score, we counted the number of words written for each minute, excluding completely illegible words and the unfinished final word, as recommended by the scoring manual. This is an established technique for measuring handwriting fluency (cf. Abbott & Berninger, 1993; Barnett et al., 2007).

Spelling

Wide Range Achievement Test-4 (WRAT-4). We assessed both word and sentence spelling. Word spelling was measured using the Spelling subtest from the WRAT-4 (Wilkinson & Robertson, 2006), which we adapted for group administration. Accordingly, children were asked to spell 13 alphabet letters and 36 words. The words were graded in difficulty, and participants were given approximately 30 s to spell each item. We selected 36 words as the cutoff because this translates to a standard score of 145 for a child in Year 5, and it was deemed unlikely that many children in the sample would achieve a higher score. For scoring, we followed the published guidelines and awarded 1 point for every correct response and discontinued scoring after 10 consecutive incorrect responses.

Spelling and Handwriting Legibility Test. The SaHLT (used to score handwriting legibility; Downing & Caravolas, in press) was also scored for spelling accuracy. The 10 sentences, originally used in Caravolas et al. (2005), each comprise four to eight words and are graded in their phonological, morphological, orthographic, and lexical complexities, reflecting the national curriculum guidelines for spelling in England (cf. Caravolas et al., 2005). Each correctly spelled word was awarded 1 point. Spellings on this task were scored by a research assistant who did not score the handwriting legibility.

Graphomotor skills

Graphomotor skills were measured using the Visual Motor Integration and Motor Coordination subtests from the Beery VMI (Beery–Buktenica Developmental Test of Visual–Motor Integration; Beery & Beery, 2010) and was administered according to the published guidelines for group administration. In the Visual Motor Integration subtest, children were required to copy 24 forms of increasing complexity, drawing each shape into an empty box directly below, exactly as they were presented without using additional aids (e.g., ruler). Only one attempt was allowed per form, and no time limit was imposed. In the Motor Coordination subtest, children were required to trace inside 24 forms of increasing complexity as accurately as possible without allowing their pencil trace to leave the shape's boundary line. The earlier forms included dots as cues for beginning and ending tracing, whereas the latter forms did not include any cues. Only one attempt was allowed per form, and children were asked to stop after 5 min, although most children completed the task in this time. Scoring for both subtests followed detailed published guidelines. Each correct response was awarded 1 point. Scoring was discontinued when a child made three consecutive errors.

Selective attention

Selective attention was measured using the Map Mission subtest from the Test of Everyday Attention for Children (TEA-Ch; Manly et al., 1998) and the Symbol Search and Coding subtests from the Wechsler Intelligence Scale for Children–Fourth Edition (WISC-IV; Wechsler et al., 2003). The Symbol Search and Coding subtests are commonly used as speed of processing measures. However, these tasks require children to selectively attend to specific visual information, and as such they likely tap selective attention (Sattler, 2001); accordingly, Symbol Search and Coding have been found to discriminate between children with and without attentional difficulties (Dickerson Mayes et al., 1998).

Map Mission (TEA-Ch). In the Map Mission subtest (Manly et al., 1998), children were presented with an A3 color map of a city. Children were asked to circle as many knife and fork symbols (targets) as they could in 1 min while ignoring all the other symbols typically found on a map (distractors). Each correctly circled target (out of a maximum of 80) was awarded 1 point.

Symbol Search (WISC-IV). Following published guidelines for the Symbol Search subtest (Wechsler et al., 2003), children were presented with several rows of symbols. In each row, two symbols (targets) were presented on the left, with five symbols presented on the right. Children were instructed to mark "yes" for each row where the target was repeated among the five symbols (47% of items) and to mark "no" in instances where the target was not repeated (53% of items). They were to work as quickly and accurately as they could until asked to stop (at 2 min). Scoring followed the manual, where each correct response was awarded 1 point.

Coding (WISC-IV). Per the published guidelines for the Coding subtest (Wechsler et al., 2003), children used a numbered key of symbols printed at the top of their booklets to reproduce the symbols in boxes labeled with the corresponding number, completing as many as possible in 2 min. The number of symbols correctly copied in 2 min gave an index of selective attention.

Design and procedure

Children completed the above measures in prepared booklets in their classrooms. They completed all tasks over two 60-min sessions, often on the same day but with at least a 1-hr break between sessions. All sessions were conducted by the first author along with three or four research assistants to ensure that all participants understood the instructions and to maintain oversight while they completed the tasks.

Results

To examine the structural relationships between spelling, graphomotor skills, attention, and handwriting, we conducted structural equation modeling (SEM). Prior to running SEM, we Winsorized outlier scores (comprising 0.4%–4% of the data) to within 2.7 standard deviations of their school year group's mean following Tukey (1977), where Tukey's inner fences correspond to ±2.7 standard deviations of the mean. In addition to Winsorizing, sentence spelling underwent squared transformations and copy best minute 1 underwent logarithmic transformations; both transformations were necessary to deal with negatively skewed distributions. Copy best minute 2 was positively skewed and so underwent square root transformations. These transformations improved the distributions of the data. The means, standard deviations, ranges, and reliabilities for all measures administered to each year group are reported in Table 1. The means and standard deviations for age-standardized measures show scores that were similar to the tests' norms. Standardized scores on the graphomotor tasks (VMI and coordination) were on average lower than performance on other tests; however, performance was still within the normal range. The descriptive statistics on the raw scores show large variations in ability across all measures without evidence of floor or ceiling effects. Overall, performance increased with school year except for coordination, letter spacing, word spacing, and line alignment, where performance was similar in Years 4 and 5.

Bivariate correlations between measures are reported separately for school Years 3, 4, and 5 in Tables 2, 3, and 4, respectively. As expected, there were moderate to strong correlations between variables measuring the same skills (e.g., between word and sentence spelling), and the size of these correlations was generally stable across year groups, suggesting good validity and reliability. In addition, some noteworthy patterns emerged between handwriting and the correlated skills. Across all year groups, letter formation moderately correlated with word and sentence spelling. Furthermore, there were small to moderate statistically significant correlations between the other handwriting legibility and fluency variables with the spelling measures. There were also small to moderate correlations between handwriting legibility and the visual motor integration and coordination variables; however, the correlations between handwriting fluency and the graphomotor variables were considerably smaller and in some cases negligible. Conversely, the correlations between the legibility variables and map search, symbol search, and coding were small, whereas the correlations between the handwriting fluency and selective attention variables were larger.

Factor structure invariance across school year groups

In the ensuing analyses, we standardized all raw and transformed variables. We used Mplus 8.1 (Muthén & Muthén, 2018) with full information maximum likelihood (FIML) to handle the small amount of missing data (2.65%–3.80%). We began by running multiple group confirmatory factor anal-

Table 2

Correlations between measures of spelling, graphomotor, selective attention, and handwriting legibility and fluency skills in children in Year 3.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Word spelling	–													
2. Sentence spelling	.88***	–												
3. VMI	.32***	.34***	–											
4. Coordination	.34***	.32***	.46***	–										
5. Map search	.19***	.18**	.32***	.30***	–									
6. Symbol search	.29***	.29***	.35***	.31***	.41***	–								
7. Code	.12*	.19***	.30***	.21***	.31***	.37***	–							
8. Letter formation	.41***	.43***	.41***	.45***	.18**	.28***	.23***	–						
9. Letter spacing	.12*	.16**	.19**	.24***	.06	.14*	.09	.56***	–					
10. Word spacing	.30***	.29***	.21***	.19***	.09	.16**	.14*	.54***	.37***	–				
11. Line alignment	.26***	.31***	.30***	.37***	.10	.21***	.13*	.51***	.32***	.46***	–			
12. Copy best (min 1)	.29***	.29***	.10	.15*	.25***	.08	.24***	.05	−.06	−.01	−.06	–		
13. Copy best (min 2)	.28***	.27***	.09	.15*	.30***	.17**	.20***	.10	−.05	.02	−.07	.62***	–	
14. Copy fast (min 1)	.31***	.30***	.13*	.09	.35***	.20***	.33***	.18***	.07	.13*	.05	.47***	.51***	–
15. Copy fast (min 2)	.34***	.37***	.17**	.22***	.31***	.24***	.36***	.29***	.08	.20***	.13*	.46***	.55***	.63***

Note. VMI, visual motor integration.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

Table 3

Correlations between measures of spelling, graphomotor, selective attention, and handwriting legibility and fluency skills in children in Year 4.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Word spelling	–													
2. Sentence spelling	.88***	–												
3. VMI	.28***	.34***	–											
4. Coordination	.08	.15*	.52***	–										
5. Map search	.05	.05	.20***	.21***	–									
6. Symbol search	.23***	.20***	.26***	.25***	.51***	–								
7. Code	.21***	.22***	.27***	.28***	.41***	.49***	–							
8. Letter formation	.36***	.39***	.33***	.37***	.17**	.22***	.23***	–						
9. Letter spacing	.17**	.23***	.15*	.17**	.12*	.09	−.02	.53***	–					
10. Word spacing	.14*	.19***	.20***	.21***	.17**	.10	.06	.37***	.42***	–				
11. Line alignment	.15*	.18**	.29***	.24***	.16**	.11	.18**	.58***	.33***	.36***	–			
12. Copy best (min 1)	.27***	.25***	.08	−.06	.12	.24***	.23***	−.04	−.03	−.03	−.08	–		
13. Copy best (min 2)	.28***	.24***	.08	−.03	.21**	.29***	.36***	.07	−.02	−.06	−.01	.68***	–	
14. Copy fast (min 1)	.34***	.37***	.11	.05	.24***	.29***	.41***	.18**	.09	.11	.03	.46***	.51***	–
15. Copy fast (min 2)	.26***	.33***	.16**	.08	.35***	.28***	.39***	.19**	.08	.13*	.12	.33***	.44***	.65***

Note. VMI, visual motor integration.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

Table 4
Correlations between measures of spelling, graphomotor, selective attention, and handwriting legibility and fluency skills in children in Year 5.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Word spelling	–													
2. Sentence spelling	.86***	–												
3. VMI	.30***	.34***	–											
4. Coordination	.26***	.29***	.47***	–										
5. Map search	.17**	.17	.27***	.27***	–									
6. Symbol search	.26***	.22***	.22***	.20***	.30***	–								
7. Code	.31***	.26***	.22***	.32***	.40***	.37***	–							
8. Letter formation	.37***	.41***	.39***	.30***	.23***	.16**	.23***	–						
9. Letter spacing	.29***	26***	.24***	.14*	.15*	.24***	.19***	.61***	–					
10. Word spacing	.19**	.20***	.32***	.26***	.21***	.17**	.27***	.47***	.38***	–				
11. Line alignment	.26***	.25***	.20***	.17**	.15*	.06	.14*	.58***	.38***	.38***	–			
12. Copy best (min 1)	16**	.17**	.03	.02	.14*	.07	.25***	−.03	−.08	.01	−.09	–		
13. Copy best (min 2)	.25***	.25***	.06	−.03	.25***	.16**	.30***	.15*	.05	.10	.10	.45***	–	
14. Copy fast (min 1)	29***	.33***	.16**	.15*	.25***	.14*	.32***	.20***	.21***	.25***	.01	.40***	.42***	–
15. Copy fast (min 2)	.34***	.36***	.20***	.16**	.26***	.16**	.25***	.29***	.21***	.19**	.10	.34***	.41***	.69***

Note. VMI, visual motor integration.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

ysis (MGCFA) to examine whether the same factor structure held across the year groups. As such, we tested for similarity across groups in terms of the number of factors and pattern of factor–indicator loadings (configural invariance), the factor loadings (metric invariance), and the indicator intercepts (scalar invariance). This step is important for validating the battery we used to measure the abilities of interest and to further test the statistical independence of handwriting legibility and fluency by producing and testing a model where the measures load onto separate factors.

We loaded the word and sentence spelling measures onto the latent variable of spelling. Visual motor integration and motor coordination measures were loaded onto the latent variable graphomotor skills. Map search, symbol search, and coding were loaded onto the latent variable of selective attention. The sentence copying measures were loaded onto handwriting fluency, and the respective measures of legibility were loaded onto handwriting legibility. The residuals were correlated between minute 1 and minute 2 measures of the sentence copying (fluency) tasks to account for shared task variance (see Fig. 2). The configural model was a good fit to the data, $\chi^2(234) = 425.20$, $p < .001$, root mean square error of approximation (RMSEA) = .053 (90% confidence interval [CI] = .045–.061), standardized root mean squared residual (SRMR) = .051, comparative fit index (CFI) = .96, Tucker–Lewis index (TLI) = .95. Next, constraining factor loadings to be equal across groups resulted in a well-fitting model, $\chi^2(254) = 439.98$, $p < .001$, RMSEA = .050 (90% CI = .042–.058), SRMR = .052, CFI = .96, TLI = .95, with no significant loss of fit ($\chi^2_{\text{diff}} = 14.79$, $\Delta_{df} = 20$, $p = .789$). Finally, we constrained indicator intercepts to be the same across year groups, and the resulting model was a good fit, $\chi^2(274) = 447.87$, $p < .001$, RMSEA = .046 (90% CI = .038–.054), SRMR = .052, CFI = .96, TLI = .96, with no significant loss of fit ($\chi^2_{\text{diff}} = 2.88$, $\Delta_{df} = 20$, $p = 1.00$). The model had strong factor loadings across all year groups. All the correlations between factors were statistically significant except the cor-

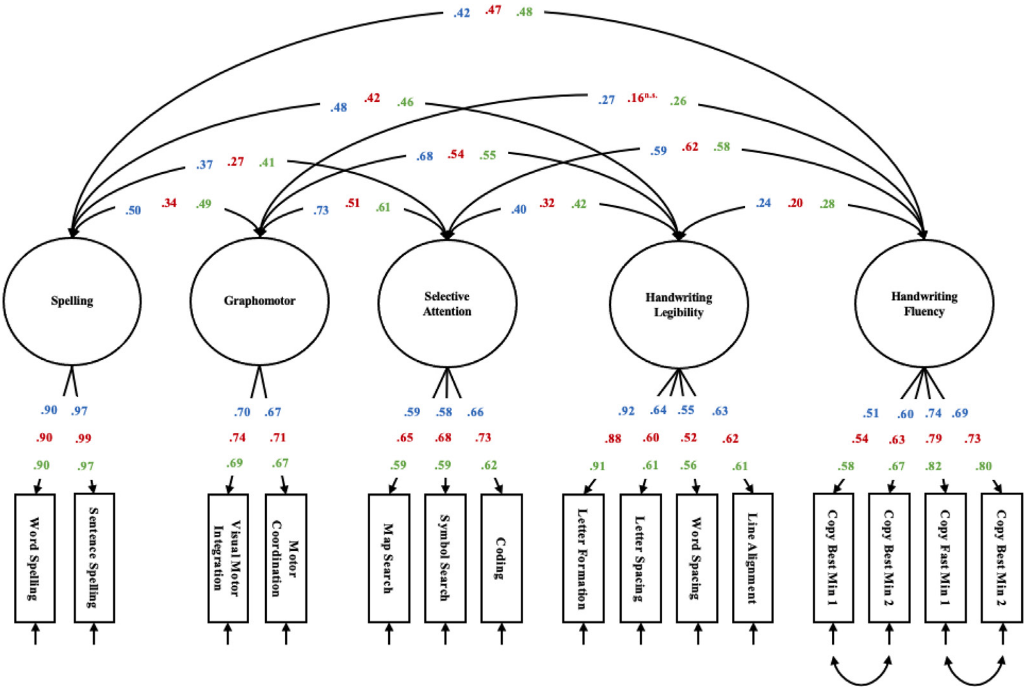

Fig. 2. Path model of the scalar multigroup confirmatory factor analysis. This model examined the factor structure of the 13 measures of spelling, graphomotor, selective attention, and handwriting fluency and legibility skills. Blue path estimates correspond to Year 3, red path estimates correspond to Year 4, and green path estimates correspond to Year 5. All factor loadings for all year groups were significant at $p < .01$ except the path between graphomotor and handwriting fluency in the Year 4 group, which was nonsignificant. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

relation between graphomotor skills and handwriting fluency in Year 4. Correlations between these factors were small in Years 3 and 5 as well. To summarize, the confirmatory factor analyses produced latent constructs of spelling, fine motor, selective attention, and handwriting legibility and fluency, which were stable over Years 3, 4, and 5. This further demonstrates the validity of the measures (indicators) of their respective constructs.

Concurrent structural relations between spelling, fine motor, selective attention, and handwriting legibility and fluency

Next, we assessed how and to what degree spelling, graphomotor skills, and selective attention concurrently predicted handwriting legibility and fluency. To do so, we fitted structural equation models using the latent constructs derived in the earlier MGCFA. We began by fitting direct paths between spelling, graphomotor skills, selective attention, and handwriting legibility and fluency across the whole group. The fit of this first model (Fig. 3A) was acceptable, $\chi^2(78) = 199.55$, $p < .001$, RMSEA = .042 (90% CI = .035–.050), SRMR = .039, CFI = .97, TLI = .97; however, the path between selective attention and handwriting legibility and the covariance between handwriting legibility and fluency were nonsignificant. This indicates a lack of statistical relationship between (a) selective attention and handwriting legibility and (b) handwriting legibility and fluency. As such, we removed these paths. The resulting model (Fig. 3B) produced a good fit, $\chi^2(80) = 199.74$, $p < .001$, RMSEA = .042 (90% CI = .034–.049), SRMR = .038, CFI = .97, TLI = .97. Removing these paths did not significantly alter the fit of the model ($\chi^2_{\text{diff}} = 0.19$, $\Delta_{df} = 2$, $p = .909$).

Interestingly, we found a significant negative relationship between graphomotor ability and handwriting fluency (−.262, $p < .001$). This was unexpected given the weak positive correlations reported between the measures (r = .02–.22; Tables 2–4) and between the latent constructs in the MGCFA (r = .16–.27; Fig. 2). Furthermore, the weight between selective attention and handwriting fluency (.606, $p < .001$) was much stronger than expected based on the correlations between the measures (r = .14–.32; Tables 2–4). We suspected that this was a case of negative suppression, whereby when selective attention ability is controlled, a relationship between graphomotor ability and handwriting fluency emerges (cf. Kline, 2011). We tested this hypothesis by removing selective attention from the model. In this model (Fig. 3C), $\chi^2(47) = 137.58$, $p < .001$, RMSEA = .047 (90% CI = .038–.056), SRMR = .039, CFI = 0.98, TLI = 0.97, there was no longer a significant path between graphomotor ability and handwriting fluency. This finding highlights the importance of controlling for selective attention while examining the relationship between graphomotor ability and handwriting fluency.

Given the potential interaction between fine motor skills and attention on handwriting fluency outlined earlier (see Adi-Japha et al., 2007), we tested whether selective attention concurrently mediates fine motor skills, following Baron and Kenny's (1986) procedure. We did so by adding additional paths between fine motor skills and handwriting fluency via selective attention. The resulting model (Fig. 3D) produced a good fit to the data, $\chi^2(81) = 203.52$, $p < .001$, RMSEA = .042 (90% CI = .035–.049), SRMR = .039, CFI = .97, TLI = .97. There was no significant loss of fit between this partial mediation model and the previous model ($\chi^2_{\text{diff}} = 3.78$, $\Delta_{df} = 1$, $p = .052$). As in the previous models, all paths remained significant, and Baron and Kenny's (1986) mediation conditions were met. A significant path was present between (a) graphomotor skills and selective attention and (b) graphomotor skills and handwriting fluency, and (c) the addition of selective attention as mediator reduced the path weight between graphomotor skills and handwriting fluency from −.35 ($p < .001$) to −.29 ($p < .001$), indicating partial mediation. The total standardized indirect effect was (graphomotor skills → selective attention → handwriting fluency) = .43, $p < .001$. In sum, when controlling for the effect of selective attention, increases in graphomotor skills were associated with decreases in handwriting fluency. We return to this finding in the Discussion.

Do these relations vary with school year?

To test whether the same model applies for each school year, we conducted multigroup SEM using the same partial mediation model described above (Fig. 3C). In this model, we used FIML with Huber–

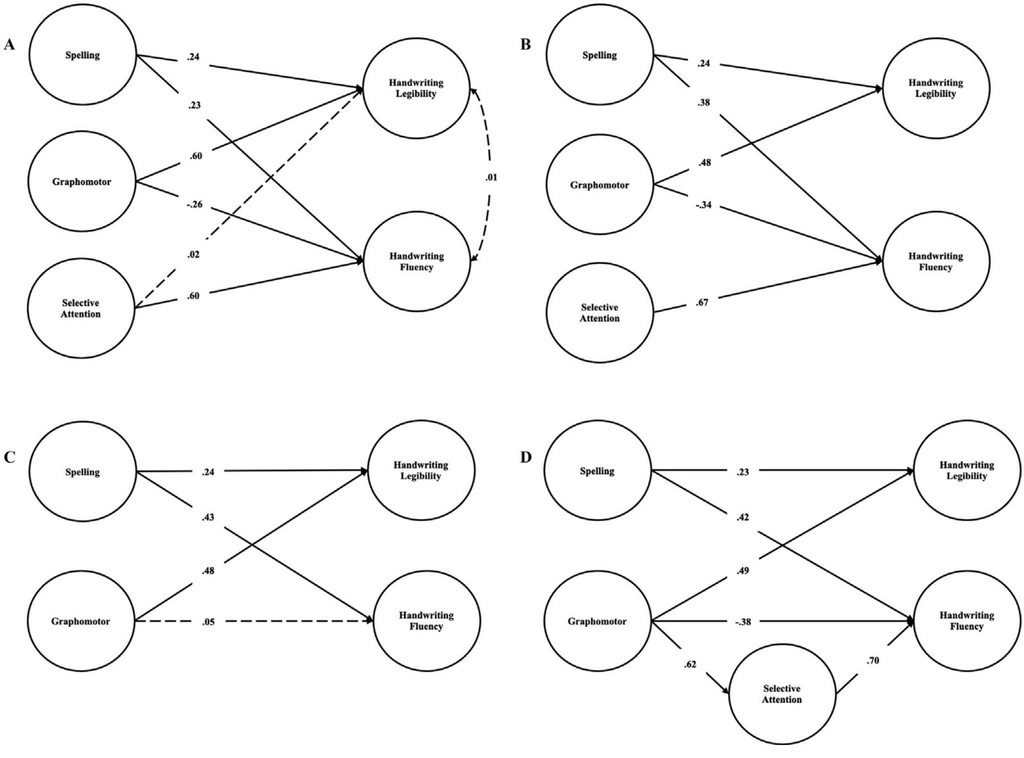

Fig. 3. Path diagrams of structural equation models testing relations between the component skills of spelling, graphomotor, and selective attention skills and handwriting legibility and fluency. (A) In the first model, all component skills were regressed onto both legibility and fluency. (B) In the second model, spelling and graphomotor skills were regressed onto both legibility and fluency and selective attention was regressed onto fluency only. (C) In the third model, selective attention was removed to test for the presence of negative suppression. (D) In the fourth model, selective attention was added as a mediator between graphomotor skills and fluency. All weights are standardized estimates. All weights are significant at p < .001 except those represented by dashed arrows, which denote nonsignificant paths.

White (robust) standard errors to account for clustering effects of children within classrooms. This model gave a good fit to the data, $\chi^2(283)$ = 405.89, p < .001, RMSEA = .039 (90% CI = .030–.047), SRMR = .053, CFI = .97, TLI = .97, and all paths were significant across the year groups. We further tested whether the strength of these paths was similar across the grades by constraining the paths between latent variables across the year groups. This model was also a good fit to the data, $\chi^2(295)$ = 410.18, p < .001, RMSEA = .037 (90% CI = .038–.045), SRMR = .054, CFI = .97, TLI = .97. Using the Satorra–Bentler scaled chi-square difference test, we found that there was no significant loss of fit between the more constrained and less constrained multigroup models (χ^2_{diff} = 3.41, Δ_{df} = 12, p = .992).

The standardized path weights and R^2 of the latent handwriting variables for each group are reported in Fig. 4. In total, just over a third of the variance in handwriting legibility is explained in this model. Graphomotor skills emerged as the strongest predictor of legibility, followed by spelling; however, selective attention did not predict legibility. A larger amount of variance in handwriting fluency was predicted by this model. Indeed, around half the total variance in handwriting fluency was predicted in Years 4 and 5. Graphomotor skill, mediated by selective attention, emerged as the strongest path. The standardized total indirect effects were .42 for Year 3, .43 for Year 4, and .46 for Year 5 (all ps < .001). Even with this indirect path, the direct path between graphomotor skill and handwriting fluency remained statistically significant, suggesting a partial mediation relationship.

Discussion

We sought to examine the patterns of concurrent relationships between handwriting legibility and fluency and spelling, graphomotor ability, and selective attention. We assessed these patterns across groups of children aged 7 to 10 years, a critical period of handwriting development (Palmis et al., 2017). All indicator measures of the respective constructs correlated well, suggesting good validity. Together, the latent variables of spelling, graphomotor ability, and selective attention explained a moderate amount of variance in handwriting legibility and fluency across the age groups. It was apparent that handwriting legibility and fluency are statistically separate constructs with different patterns of relationships to the correlated skills. As expected, graphomotor ability and spelling were related to handwriting legibility, with graphomotor ability having the stronger association. Graphomotor ability, spelling, and selective attention were related to handwriting fluency, such that spelling associated more strongly with fluency than did graphomotor ability. Moreover, graphomotor ability was negatively related to handwriting fluency when controlling for the partially mediating effects of selective attention. Finally, we found this pattern of relationships to be the same across the three school year groups.

Handwriting fluency and legibility as separable constructs

An aim of this study was to examine to what degree handwriting fluency and legibility are separable constructs. The lack of large correlations between measures of fluency and legibility in larger

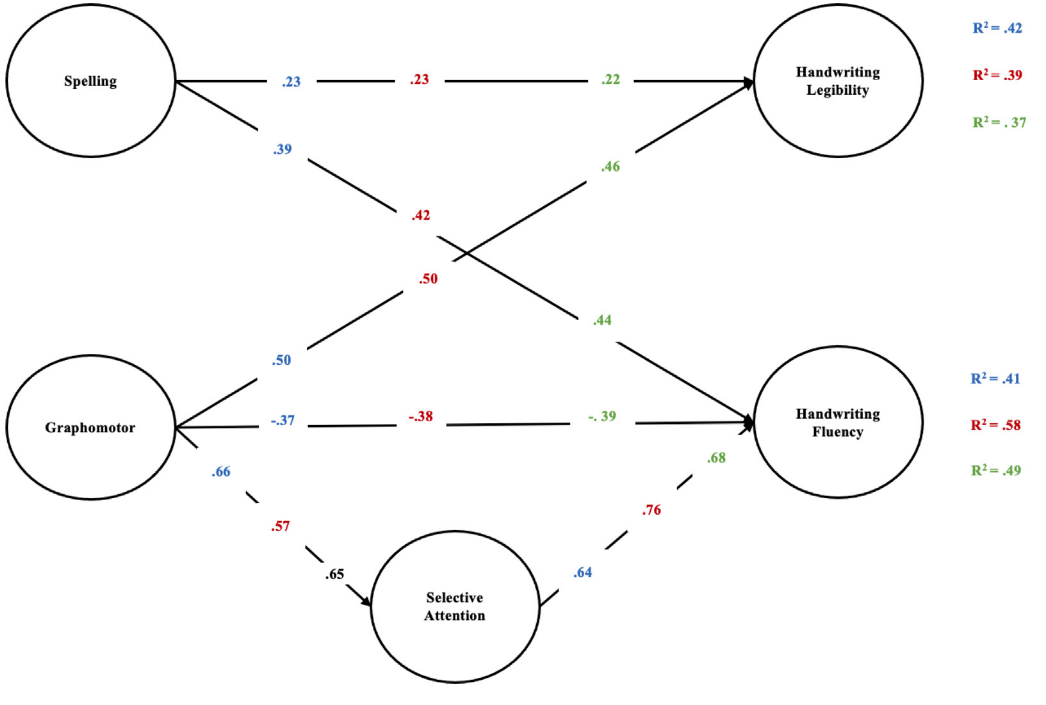

Fig. 4. Path diagram with standardized path weights of multigroup structural equation model of the concurrent prediction of handwriting legibility and fluency. This figure presents the final model of concurrent prediction of handwriting legibility and fluency from spelling and graphomotor skills, with selective attention partially mediating graphomotor skills on handwriting fluency. Paths were constrained to be equal across groups. Blue path weights correspond to Year 3 estimates, red path weights correspond to Year 4 estimates, and green path weights correspond to Year 5 estimates. All weights are significant at $p < .001$. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

samples and the divergent developmental trajectories of these constructs reported in earlier studies (e.g., Gosse et al., 2021; Graham et al., 1998) provided a reasonable premise for considering their independence. Our results unambiguously concurred with this hypothesis. The measurement models demonstrated that the best fitting model was one that loaded the measures of legibility and fluency onto separate factors. This held true across the three year groups that were tested. Furthermore, the structural models revealed that there was no significant correlation between these two constructs. Taking these findings one important step further, we asked whether there were different patterns of relationships between the handwriting constructs and the related skills of spelling, graphomotor ability, and selective attention. Different patterns of relationships would add weight to the claim that legibility and fluency should be considered separable constructs.

Concurrent relationships between handwriting constructs and handwriting-related skills

As expected, we found different patterns of relationships between handwriting and related skills for legibility and fluency. Spelling ability was related to both handwriting constructs; however, it was a stronger predictor of fluency than of legibility. This finding is in line with previous studies (e.g., Gosse et al., 2021). The association between spelling and handwriting legibility is found less consistently across studies and may be subject to instructional and orthographic depth influences (e.g., Gosse et al., 2021; Karlsdottir & Stefansson, 2002); the potential moderating effects of these variables should be investigated in further cross-linguistic studies.

Also as expected, we found graphomotor skills to predict legibility and fluency. Conversely to spelling, graphomotor skills were consistently a stronger predictor of legibility than of fluency. Better graphomotor ability was associated with more legible handwriting, replicating previous findings of a relationship between graphomotor skills and legibility in typically developing children and children with graphomotor difficulties (e.g., those with DCD; Barnett et al., 2018; Cornhill & Case-Smith, 1996).

Based on our findings of the inter-relations between spelling and graphomotor skills and handwriting legibility and fluency, we argue that existing models (e.g., Berninger & Winn, 2006; van Galen, 1991) of writing development and production should be further developed to consider legibility and fluency as separable constructs. Moreover, developmental models should clearly state the inter-relations—and possible reciprocal relations—between spelling and graphomotor skills and handwriting.

An unexpected finding was the negative relationship between graphomotor skills and handwriting fluency. That is, greater graphomotor ability was associated with less fluent handwriting when controlling for selective attention. This finding is at odds with the current literature, which suggests that greater graphomotor ability is associated with more fluent handwriting in children of a similar age to the sample studied here (e.g., Prunty et al., 2014; Tseng & Chow, 2000). However, these studies often demonstrate this relationship through group differences between children with good/poor graphomotor ability and/or correlations in small samples. In re-examining Abbott and Berninger's (1993) analysis, we found a negative, albeit nonsignificant, trend between motor ability and fluency in children who were the same age as those in the current study.

To probe this finding further, we examined the structural relations between selective attention and handwriting legibility and fluency. Although there is some theoretical rationale to suggest that attention is related to handwriting (e.g., Berninger & Winn, 2006), empirical evidence is limited and mainly relies on clinical (ADHD) samples. We believe that this study reports the first systematic attempt at examining the role attentional processes play in handwriting. Specifically, we tested a claim—made in the clinical literature—suggesting that attentional processes mediate the relationship between motor processes and handwriting. Here, we found that in typically developing children, selective attention was related to handwriting fluency but not to handwriting legibility. Our tentative interpretation of this finding is that fluency taps a greater number of component skills to a greater degree, as is evidenced by the path weightings in the MGSEM. We suggest that attentional resources may be necessary while children are still developing fluency because they must effectively select which motor processes to use and when to use them. As such, children who can selectively attend appropriately are more likely to have more fluent handwriting. Our results suggest that selective attention partially mediates this relationship, in line with Adi-Japha et al.'s (2007) hypothesis. Future models of writing development that account for the role of attention in handwriting fluency will aid in developing testable questions on this subtle relationship.

A secondary question of our study was whether the structural relations were stable developmentally across the mid to primary school years (i.e., Years 3, 4, and 5). This is particularly important given that this period seems to be critical for handwriting development (Palmis et al., 2017; Thibon et al., 2019). Here, we expected that as children's orthographic representations became more robust through increasing age and writing experience, their written productions would reflect weaker associations between spelling and handwriting legibility but increasingly strong associations between spelling and handwriting fluency as retrieval became automatized. Furthermore, we expected the influence of graphomotor skills to also decrease with age. However, we found that although both legibility and fluency increased with grade, the patterns of relations between handwriting-related correlates and handwriting skills remained stable. This unexpected stability in the strength of the relationship may reflect that the children in our study had not yet automated their handwriting skills to an extent where we could see an attenuation of these relationships. In line with this view, handwriting instruction is highly variable in the United Kingdom (Barnett et al., 2006). On a related note, a high proportion of variance explained by selective attention suggests that children are needing to proactively control different processes associated with writing, suggesting a lack of automatization. In relation to both spelling and graphomotor skills, our measures were predominantly capturing accuracy rather than fluency. Perhaps measures designed to assess fluency of these skills would reveal a decreasing strength of relationships over development. Overall, however, the predictors of individual differences in handwriting development remain important throughout the later primary school years.

Theoretical and educational considerations

The current findings suggest that existing models of writing development, such as the not-so-simple model of writing (e.g., Berninger & Winn, 2006) and the psychomotor model of writing (e.g., van Galen, 1991), require further elaborations that accommodate handwriting fluency and legibility as separate constructs with differential associations between handwriting and other abilities. Refining these models will bring new questions to further our understanding of writing development.

The current findings have relevance for educators in highlighting that handwriting development does not occur independently of other abilities. Although the design of this study precludes conclusions about the causal relations between handwriting and the correlates discussed here, the current findings suggest that children presenting with difficulties relating to their spelling, graphomotor, or selective attention abilities should be assessed for handwriting fluency and possibly handwriting legibility difficulties as well.

Future directions

This study is an initial attempt to map out the structural relations between theory and empirically derived correlates of handwriting and two handwriting constructs. In doing so, we chose to use a cross-sectional design to examine whether this structure changes over a relatively short period of time in handwriting development. This design, although useful for mapping the relations, limits their interpretation in several ways, namely in the direction of causality (which we have assumed here based on the extant literature) and in investigating the reciprocal nature of any relationship. Thus, as a next step, we believe that it is timely to undertake longitudinal studies of the relationships between spelling, graphomotor, and attentional skills and handwriting legibility and fluency. Such studies would confirm the direction of the relationships and any reciprocity to be examined throughout development, for example, between spelling and handwriting fluency (cf. Pritchard et al., 2021). In addition, longitudinal and experimental studies could further probe the relatively novel findings of a negative relationship between graphomotor ability and handwriting fluency and of the influence of (selective) attention on graphomotor processes and handwriting fluency.

The pattern of relationships found in 7- to 10-year-olds tentatively suggests that legibility may be, in part, a proxy measure for the quality of spelling representations (cf. Gosse et al., 2021; Pritchard et al., 2021). However, in our participant groups, the association between legibility and spelling ability remained stable yet relatively weak ,probably because the variability in legibility scores was quite restricted. On the other hand, the relationship between spelling and handwriting fluency remained more stable (and stronger) across the year groups relative to handwriting legibility. It is plausible that handwriting fluency partially indexes the efficiency of access to spelling representations, as suggested by findings that children are less fluent when writing words that are more complex or less frequent (e.g., Kandel & Perret, 2015) or when children have spelling-related difficulties (i.e., dyslexia; Suárez-Coalla et al., 2020). We propose that further work should directly examine the extent to which handwriting fluency and legibility estimate access to and the quality of spelling representations.

We considered the role of selective attention in handwriting based on our theoretical frameworks (e.g., van Galen, 1991). However, selective attention is not the only executive skill involved in handwriting development. We argue that sustained attention is likely to be important for children's ability to maintain attention on task when learning to write (Feder & Majnemer, 2007). Furthermore, working memory may also contribute to handwriting development. Olive (2014) argued that working memory is important for dealing with simultaneous processing demands during writing, particularly in developing writers (see also Berninger & Winn, 2006; Kim & Park, 2019). Further work should also consider the relative contribution and inter-relationships with other handwriting correlates over development. It would be of particular interest to study these relations while also considering potential influences on or interactions with cognitive–linguistic areas such as vocabulary and morphological knowledge or processing.

Conclusion

We sought to examine the relations between the handwriting-related skills of spelling, graphomotor ability, and selective attention and handwriting legibility and fluency. Different patterns of relationships between these related skills and legibility and fluency emerged, whereby both spelling and graphomotor ability were related to both handwriting skills. However, graphomotor ability emerged as the strongest predictor of legibility, whereas spelling was the strongest direct predictor of fluency. Furthermore, selective attention mediated the relationship between graphomotor skills and handwriting fluency. Taken together, this study further demonstrates that handwriting legibility and fluency are separable and highly complex skills that are differentially related to spelling, graphomotor, and attentional abilities during later primary school years.

Data availability

Data will be made available on request.

Acknowledgments

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Data availability

The data that support the findings of this study are available from the corresponding author (C.R.D.) upon reasonable request.

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