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The roles of handwriting and keyboarding in writing: a meta-analytic review

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Abstract According to the simple view of writing (Berninger, Abbott, Abbott, Graham, & Richards, 2002), the two important components of transcription in writing are handwriting and keyboarding, the third one being spelling. The purpose of this paper is to review the contribution of two writing modes—handwriting and keyboarding to writing performance. In the first section, the contribution of handwriting fluency to writing performance was explored through moderator analyses. We found that handwriting fluency contributes to writing significantly and consistently, and significantly contributes to specific writing measures (e.g., writing quality, writing fluency, substantive quality). We then explored the relationship between handwriting and keyboarding, and compared their contributions to writing. Results indicated that performance on fluency of handwriting and keyboarding were significantly related, particularly on speed. Writing qualities under each mode were relatively competitive; however, keyboarding allows for faster writing. The findings from the two sections emphasized the importance of handwriting on writing development even though keyboarding is accessible.

Keywords Handwriting · Writing · Keyboarding · Meta-analysis

Introduction

According to the simple view of writing (Berninger, 2000; Berninger & Amtmann, 2003; Berninger & Graham, 1998), writing subsumes four components: text generation, transcription, working memory, and executive functions. Among them, transcription is a critical support to text generation. Transcription consists of

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handwriting, keyboarding, which are both writing modes, and spelling. Confirmatory factor analyses have already shown that these two components have separate but correlated loadings (Abbott & Berninger, 1993; Berninger, Abbott, Thomson, & Raskind, 2001), and a direct path has been identified from handwriting to composition (Graham, Berninger, Abbott, Abbott, & Whitaker, 1997). Santangelo and Graham (2015) have suggested that instruction in handwriting could improve children's writing performance.

Handwriting is a complex task of forming letters, numbers, and other characters, which requires the combination of cognitive functions, and fine and gross motor skills (Dinehart, 2015). Children's experimentation with handwriting begins around two years of age, and continues to develop through the formation of geometric shapes, horizontal and vertical lines, and crosses (Dinehart, 2015; Feder & Majnemer, 2007). There are two major components of handwriting: fluency and legibility (Graham, 1986; Graham & Miller, 1980; Graham, Berninger, Weintraub, & Schafer, 1998). Handwriting fluency refers to the rate or speed at which the letters or characters are accurately formed, while handwriting legibility refers to the accurate formation of the letters or characters.

The association between handwriting (fluency and legibility) and writing quality

A myriad of studies found that the handwriting proficiency is associated with writing quality. For example, handwriting fluency has been shown to be positively associated with the length and quality of written compositions by beginning writers (Graham et al., 1997; Graham, Harris, & Fink, 2000). In other words, handwriting fluency can facilitate children's development of text generation and writing quality (Graham, Harris, & Chorzempa, 2002; Jones & Chirstensen, 1999). Graham, Harris and Hebert (2011) introduced the term as writer effect to honor the positive relationship between handwriting and writing quality. In reading, fluency frees up working memory space to involve in higher-level tasks, such as comprehension (LaBerge & Samuels, 1974). Similarly, the writer effect serves as a parallel relationship for writing, as handwriting fluency allows the writer to devote working memory to higher-level writing tasks, such as composition (Graham et al., 2011). McCutchen, Covill, Hoyne, and Mildes (1994) also highlight the ability for writers to dedicate attentional resources to higher-level processes in writing when handwriting becomes fluent and automatic. The presence of handwriting difficulties, including a lack of handwriting fluency, has been found to be cognitively demanding for young children so much so that they write more simply and do not participate in writing processes such as planning and revising (Graham et al., 1998; McCutchen, 1996). Furthermore, handwriting difficulties may lead to diminished self-efficacy, further resulting in children avoiding writing (Berninger, Mizokawa, & Bragg, 1991; Graham et al., 1998). Handwriting interventions have been shown to improve writing quality (Berninger et al., 1997; Jones & Christensen, 1999), and help alleviate these results.

In line with the writer effect and McCutchen's (2000) explanation of fluent text generation allowing writers to overcome the limitations of short term working

memory, handwriting automaticity has been found to account for much of the variance in written expression (Jones & Christensen, 1999). As the nature of measurements of handwriting fluency are straight forward and objective, the impact of handwriting fluency, or automaticity, on writing may be considered to be trustworthy and reliable.

Measures of handwriting fluency consist mainly of two types of tasks: copying tasks and retrieval tasks. Copying tasks relate to copying a word, sentence, or paragraph of a given written text. In the copying tasks, children can have direct visual access to the targeted items. For example, Olinghouse and Graham (2009) instructed children to copy a sentence containing all of the letters as many times as possible in 1 min. Similar methods include to ask children copy as much as possible a short story in 90s (e.g., Berninger, Cartwright, Yates, Swanson, & Abbott, 1994; Berninger et al., 1992; Swanson & Berninger, 1996). Retrieval tasks require writers to access, retrieve, and then write letters or characters with automaticity and accuracy based on prior knowledge, instead of visually accessing letters as in copying tasks, which indicates the involvement of memory along with handwriting practices. In the retrieval tasks, handwriting fluency is generally measured based on the number of correct letters or handwriting outcomes produced in a given time period. In English, such retrieval tasks typically include writing all the letters following the alphabetic sequence within a given time period (e.g., Christensen, 2009; Hudson, Lane, & Mercer, 2005; Wagner et al., 2011).

The second aspect of handwriting is legibility, which is identified as correctly forming letters or characters. Handwriting legibility impacts others' perceptions of the writer's competence in composing (Graham et al., 1998). Neatly written papers generally receive higher grades than papers of poor penmanship, regardless of content (Santangelo & Graham, 2015). Graham et al. (2011) refer to this concept as the presentation effect. In a meta-analysis investigating the presentation effect, Graham et al. (2011) found that of the four presentation factors examined (handwriting, spelling, grammar, and word-processing printed text), handwriting legibility produced the largest weighted effect. That is, students' handwriting impacted the reader's scoring of the written composition more than any other factor. In addition, illegible handwriting can challenge the achievement of spelling and composition (Mather & Roberts, 1995), which leads to further barriers on academic progress.

To enhance students' early writing skills and minimize those obstacles, handwriting instruction with emphasis on fluency and legibility would play an important role. For example, the extant studies found that handwriting interventions which have led to improved handwriting skills and writing quality have included instruction in legibility in addition to fluency (Graham et al., 2000; Jones & Christensen, 1999). In a study of first grade students with and without disabilities, Graham et al. (2000) found that children receiving handwriting intervention including instruction in handwriting legibility showed both immediate and long-term improvements in written composition. Such instruction in handwriting legibility may include learning letter names, learning to form each letter of the alphabet, copying letters with numbered arrows providing step-by-step guidelines, and reproducing letters after watching another person write the letter (Graham et al.,

2000). As handwriting legibility instruction may be straight forward, the evaluation of handwriting legibility is more subjective and qualitative than the evaluation of handwriting fluency, potentially leading to inaccurate measurements.

Legibility may be evaluated using dichotomous coding to indicate whether the response was correct or incorrect. Graded credit may also be used to score handwriting legibility. Puranik and AlOtaiba (2012) assigned a score range as missing, incorrect, or non-recognizable letters scoring 0, recognizable but poorly formed or reversed letters scoring 0.5, and well formed, recognizable letters a score of 1. Evaluating handwriting legibility could be embedded within the handwriting fluency evaluation simultaneously.

The importance of handwriting development

Handwriting is not only an important means to communicate, but also an essential life skill for all people. Children rely on handwriting heavily, because the majority of their school time could be related to performing handwriting tasks (McHale & Cermak, 1992). However, a large amount of evidence has been provided for children experiencing handwriting difficulties. The estimates of their handwriting difficulties range from 5 to 44% (e.g., Barnett, Stainthorp, Henderson, & Scheib, 2006; Graham & Weintraub, 1996; Karlsdottir & Stefansson, 2002; Sudsawad, 1999). In addition, although Hamstra-Bletz and Blote (1993) suggested that more boys were at risk of handwriting difficulties than girls, recent results by Weintraub and Graham (2000) suggested that gender did not significantly contribute to the prediction of handwriting abilities. Therefore, poor handwriting would be a major concern for all the children, as those with handwriting problems could be easily and negatively mislabeled (Sandler et al., 1992). The results of their poor handwriting include lower academic achievement and self-esteem as well as behavioral problems (Feder & Majnemer, 2007).

Alternative writing modes: keyboarding and handwriting

The alternative writing mode in the simple view of writing, keyboarding, is another important component of the transcription and positively associated with text generation. Similar to handwriting, keyboarding also carries the responsibility of producing letters promptly and accurately. Along with the spread of technology and financial supports, keyboarding has been increasingly implemented. Integrating technology in instruction has raised up contradictory arguments. Some research indicated the potential to attract more children to get involved in writing (Schwabe & Göth, 2005), while the others asserted that it interrupted class discussion and student learning (Kay & Lauricella, 2011; Yamamato, 2007). However, through using the computers with word-processing programs, children could experience the substantial differences on learning attitudes, interactions, instructional strategies and even written outcomes (Wood, 2000). Besides, research has already found preference on keyboarding, rather than handwriting, especially among young writers (e.g., Harrington, Shermis, & Rollins, 2000; King, Rohani, Sanfilippo, & White, 2008; Lee, 2004).

The differences and similarities between handwriting and keyboarding

Both handwriting and keyboarding require the cognitive ability to retrieve the appropriate letters and hold them in memory. During handwriting, the writer must then access the appropriate motor functions necessary to form the letter, determine the speed with which the letter should be written, and the size in which the letter should be written. Finally, with all of this information, the writer must form the letter (Graham et al., 2000).

In addition to the aforementioned retrieval skills, keyboarding requires the writer to visually recognize and select the appropriate letters on the keyboard. Keyboarders must cognitively learn the location of the keys and utilize movement patterns and keystrokes (Perminger, Weiss, & Weintraub, 2004; Sormunen, 1993). These movement patterns and keystrokes must be memorized so that the keyboarder may begin to recognize accurate typing based on kinesthetic cues, rather than looking at the keyboard to find each letter (Perminger et al., 2004).

While keyboarding requires the writer to memorize the associations between the locations of letters on a keyboard and verbal codes (Gopher & Raij, 1988; Perminger et al., 2004) along with correct positioning and timing (Perminger et al., 2004), writers executing handwriting must accurately and efficiently form each letter. The different physical requirements of handwriting and keyboarding may have different effects on writing quality and fluency while using each method of transcription.

Although keyboarding seems to assert some advantages over the traditional writing mode, handwriting, Berninger (2000) proposed that it would not make handwriting obsolete. However, little has been known about whether the attention on the relationship of handwriting and writing is still necessary, when the appealing alternative writing mode is available.

Research purposes

Several reviews regarding handwriting and writing have been completed in recent years. Santangelo and Graham (2015) researched on the significance of handwriting instruction for writing and writing development. Furthermore, Kent and Wanzek (2016) examined the association of handwriting fluency and identified a positive relationship. However, no investigation on keyboarding has been conducted. The current paper consisted of two studies to extend the previous research scope as well as fulfill this gap. In the first study, we aimed to directly examine the relationship between handwriting fluency and compositional writing measures based on the Simple View of Writing. Instead of simply averaging the effect sizes, we relied on robust variance estimation to control the dependence of effect sizes from one particular sample. Our research questions included:

1. How does handwriting fluency associate with writing?
2. Do any other factors constrain the concurrent relationship between handwriting fluency to writing?

Our second study explored the relationship between handwriting and keyboarding, and compared their associations on students' writing performances. A concern on this comparison was that whether the possible difference was related to the writing modes or extraneous factors, like rater scoring. Accumulative research suggested no statistically significant rater bias, due to the writing and scoring modes (Harrington et al., 2000; King et al., 2008; Zhu, Shum, Tse, & Liu, 2016). In other words, the scoring on a particular composition would not be significantly different, depending on whether the composition was provided and scored by a certain rater through the written format or an online system. Since the studies that simultaneously included both handwriting and keyboarding measures often examined the same group of participants, this study aimed on synthesizing the findings from samples. Therefore, our research questions were:

1. How does handwriting performance associate with keyboarding?
2. Do handwriting and keyboarding differ on their relationships with writing development?

Study 1

Method

Inclusion and exclusion criteria

Studies were searched based on the following criteria: (1) were conducted and published by 2015; (2) implemented quantitative empirical research methods; (3) included measures on both handwriting fluency and compositional writing outcomes; (4) reported sample size and bivariate correlations between handwriting and writing; (5) were printed in English; and (6) were from either peer-reviewed journals or dissertation and thesis. Such searching constrain is used to maintain the quality of the present review as well as public accessibility, either online or in library archives. According to García and Cain (2014), studies regarding correlation generally examined both flips of the coin: hypothesis which supports the significance of the potential relationship among factors and that which yields opposite voices. Therefore, the searching of studies would not be doubted due to concerns on publication bias.

Studies were excluded if the results of the studies provided only means and standard deviations, without any correlational information. Studies with adult participants were excluded, since we focused on school-aged population, from Kindergarten to high school level. Studies including participants with learning disabilities were retained during the preliminary search.

Literature search

Studies for this meta-analysis were identified mainly through electronic searches in four databases: ERIC, PsycINFO, Web of Science, and ProQuest (including dissertations and theses global). The primary search among titles, abstracts, and keywords was conducted using Boolean combinations of terms including *handwriting fluency*, *handwriting speed/rate*, *writing*, and *composition*. We also searched the reference lists of collected documents and other relevant reviews during the coding procedure to identify additional qualified studies.

The initial search resulted in 93 documents, including journal articles, dissertations and theses. Duplicated studies located from different databases were excluded. Qualitative studies and book reviews were also excluded. Utilizing the selection criteria mentioned above, a total of 16 documents were retained for further consideration. Some documents included more than one group of participants and reported their results individually. Therefore, our coding and final calculations consisted of effect sizes from 19 studies.

Coding procedures

Each study was coded for study descriptors and variables which were related to effect size calculation. Study descriptors included: author information, publication year, publication type, participant feature (e.g., English language learner, students with reading/writing difficulty), number of participants, and research design (e.g., longitudinal study). The following moderator variables were coded: type of writing measures (i.e., writing quality, writing fluency, substantive quality, spelling performance, and complexity), type of handwriting measures (i.e., measurement on letter, word, or sentence level), grade level, genre of writing outcomes (i.e., narrative or expository text), and orthographies. We intended to examine the variation of the relationship between handwriting and writing under different circumstances.

All studies were coded by the first author and 60% of them were double coded by the second author independently. The interrater reliability was 0.92, and disagreements were resolved through discussion.

Analytic procedure

The computer program, comprehensive meta-analysis (CMA; Borenstein, Hedges, Higgins, & Rothstein, 2005) was employed for the calculation procedure. Effect sizes of each study were presented by the correlation coefficients (Pearson *r*) between handwriting and writing measures. The 95% confidence interval (CI) for each effect size was calculated to test whether the specific effect size was statistically significantly different from zero.

We used a recently developed statistical technique, robust variance estimation (RVE), to calculate the overall correlation and examine the impacts of moderator variables in meta-regression analyses (Hedges, Tipton, & Johnson, 2010; Tanner-Smith & Tipton, 2014). The majority of the studies included more than one

measurement approach on writing quality (e.g., grammar, structure, ideas, and word choice, in Kent, Wanzek, Petscher, Al Otaiba, & Kim, 2014). Some studies reported results separately based on genres of writing outcomes (e.g., Graham et al., 1997). Some studies also distinguished the correlation coefficients based on the methods of handwriting measures (e.g., word and sentence, in Yan et al., 2012). The RVE technique allows the inclusion of multiple effect sizes from the same study within a given meta-analysis. Without violating the assumption of independence, this approach avoids the loss of information by dropping certain effect sizes, and does not require the covariance information of effect sizes, which would be necessary for the application of other multivariate meta-analysis techniques.

We used a random effect model with two assumptions: the variation between studies uses a random effect model, and the variation between studies relates to how they are drawn from the population and includes random errors. Sensitivity analyses were conducted based on different rho values (e.g., $\rho = 0.1, 0.2,\ldots$) used for estimation in the model. In the current study, we generated the results from the rho value as 0.5 if our estimations did not show much sensitivity along with the change of ρs. López-López, Viechtbauer, Sánchez-Meca, and Marín-Martínez (2010) found that the statistical power was influenced by the number of studies available, rather than the total number of effect sizes. Therefore, they suggested using a t test to assess the statistical significance of the meta-regression coefficients. All RVE analyses were run in SPSS 20 (SPSS, 2011), using macro downloaded from http://peabody.vanderbilt.edu/research/pri/methods_resources.php (Tanner-Smith & Tipton, 2014). According to Tanner-Smith and Tipton (2014), RVE is applicable when the sample size is limited, but produces narrower CIs and smaller p values. In other words, with a small sample size, a reported estimation, which is expected to be statistically significant at $\alpha = 0.05$ level, is actually significant at $\alpha = 0.10$ level. Therefore, a lower α-level should be applied to determine statistical significance (e.g., $\alpha = 0.01$ or 0.001) when estimating a slope and having the number of studies within the range of 10–40. Therefore, we used $\alpha = 0.01$ to determine the significance of the estimation in the current study.

Finally, we conducted the examination of publication bias. Results were displayed using funnel plots and results from Egger's regression test (Egger, Davey Smith, Schneider, & Minder, 1997) and Duval and Tweedie's trim and fill analysis (Duval & Tweedie, 2000) through the analyses using the CMA program.

Inclusion of moderators

As there are many different factors that contribute to overall handwriting skill and writing quality, we coded multiple moderator variables included in this review study. In our analyses, we tested the moderation of the following factors on the relationship between handwriting and writing quality: handwriting measures, writing measures, grade level, writing genre, and orthography.

Handwriting measures The handwriting measures that were included in our analyses are measures on the letter, word, and sentence level. That is, whether the

scorers in each study scored each individual letter for fluency or legibility, or whether the scorers evaluated a word as a whole, or even an entire sentence. Differences on the amount of handwriting that needed to be completed for each score may have varying effects on the relationship between handwriting and writing. For instance, Jones and Christensen (1999) found that orthographic-motor integration, including handwriting, accounted for more than half of the variance in written expression when assessing an entire written text which participants were allotted 15 min to write. Connelly, Gee and Walsh (2007) also examined handwriting based on a text produced by participants in a 15-min time period in their second study. However, in their first study, they also examined handwriting speed and legibility at the letter level, assessing each individual letter formed in a 2-min time period. The authors found that the number of correct letters produced increased with age, and that students with more fluent handwriting produced better quality written texts. As these studies show the use of different handwriting measures, we included handwriting measures as a possible moderator of the relationship between handwriting and writing.

Grade level Due to opposing findings in previous research, it is unclear whether handwriting improves linearly with grade level, or if writers experience period of developmental increases and plateaus (Graham et al., 1998). In a meta-analysis examining the impact of component skills on writing quality, Kent and Wanzek (2016) analyzed grade level as a possible moderator. Whereas the authors found that grade level was not a statistically significant moderator between handwriting and writing quality, the strength of this relationship was greater for younger students (Grades K–3), emphasizing the importance of handwriting fluency for young writers.

Writing genre Two writing genres were analyzed as possible moderators of the relationship between handwriting and writing: narrative and expository. Graham et al. (1997) examined the role of handwriting in relation to both compositional fluency and compositional quality among primary and intermediate children. For both primary and intermediate children, the handwriting copying task was more highly correlated with narrative composition fluency, while for composition quality, handwriting was more highly correlated with expository quality. This study highlights the need to examine writing genres as a possible moderator.

Writing measures Types of writing measures included writing quality, writing fluency, substantive quality, spelling performance, and complexity. Whereas writing quality may refer to the written substance of the paper including factors such as grammar, imagination, organization, and word choice, writing fluency may refer to the generation of written text (Graham et al., 2000). In addition to writing genres, Graham et al.'s (1997) study highlights the need to examine writing measures such as writing quality, writing fluency, and spelling performance as possible moderators. In addition to the finding that the correlation between handwriting and writing quality was higher for expository texts, the correlation between handwriting and

writing fluency was higher for narrative texts for both primary and intermediate children, the authors also found that the correlation between handwriting and spelling was statistically significant for both primary and intermediate children on both the composition fluency and composition quality measures. These findings highlight the need to examine different writing measures as possible moderators.

Orthography We ran moderator analyses to determine whether the orthography of a study impacted the relationship between handwriting and writing. In a study examining component processes of writing skills among Turkish-speaking children in Grades 1 and 2, Babayigit and Stainthorp (2010) found that handwriting speed reliably and significantly predicted writing fluency, or writing productivity ($\beta = .66$). In a study of Dutch-speaking children, Drijbooms, Groen, and Verhoeven (2015) also found that handwriting fluency predicted text length (i.e., writing fluency; $\beta = .24$). Whereas the basis of these findings is similar, the strength of the relationship between handwriting fluency and writing fluency may be different due to different orthographies.

Results

Descriptive statistics

We included 19 studies in this meta-analysis and calculated 59 effect sizes. Meanwhile, an additional 15 effect sizes based on spelling performance of the compositions were identified separately, since some studies included spelling as one of the indices to evaluate children's writing. We separated the effect sizes on spelling performance, because spelling is an independent component of the transcription based on the Simple View of Writing and supports text generation simultaneously. Such effect sizes were extracted from those on writing measures and analyzed separately to avoid inflation of the overall estimation. Besides, some studies also included additional particular spelling measures and reported their correlations with handwriting. However, in the current analyses, we did not include this kind of effect sizes for analysis. Only effect sizes of spelling performance which were derived from the composition processing were included and coded for further consideration. Table 1 shows qualitative descriptions of all the included studies, including the study ID, grade level of participants, total number of participants involved, handwriting measures, writing measures, genres, orthography, and unbiased effect size (correlation coefficient r) between handwriting and writing measures. Table 2 presents a summary of findings for the research questions.

As shown in Table 1, the publication years ranged from 1992 to 2015. Based on information reported in the studies, we first examined whether gender could be an influential factor among the samples. Only the study by Wagner et al. (2011) did not include the gender distribution. For studies with the gender information, the percentage of girls ranged from 13.3 to 59.5% ($M = 0.477$, $SD = 0.099$). The study by Jalbert (2009) was an exception, since the study focused on students with specific

Table 1 Qualitative descriptions of Study 1

Study	*N*	Grade	HW[a]	W[b]	Genre	Orthography	*r*
Babayigit and Stainthorp (2010)	48	2	Copy	Writing fluency	N	Turkish	0.630
				Content			0.080
				Structure			0.120
				Spelling error			−0.350
Berninger et al. (1992)	300	1, 2, and 3	Copy	Writing fluency	N	English	0.790
				Micro organization			0.720
					E		0.690
							0.590
Connelly et al. (2007)	48	5 and 6	Retrieval	Writing quality	N/A	English	0.450
Drijbooms et al. (2015)	102	4	Copy	Writing fluency	N	Dutch	0.300
				Content			0.300
				Syntactic complexity			0.220
Graham et al. (1997)	300	1, 2, and 3	Retrieval	Writing fluency	N	English	0.601
				Writing quality			0.320
				Correct spelling			0.469
					E		0.547
							0.228
							0.323
			Copy	Writing fluency	N		0.743
				Writing quality			0.386
				Correct spelling			0.575
					E		0.687
							0.687
							0.462
	300	4, 5, and 6	Retrieval	Writing fluency	N	English	0.224

Table 1 continued

Study	*N*	Grade	HW[a]	W[b]	Genre	Orthography	*r*
				Writing quality			0.240
				Correct spelling			0.213
					E		0.222
							0.200
							0.240
			Copy	Writing fluency	N		0.412
				Writing quality			0.304
				Correct spelling			0.161
					E		0.343
							0.357
							0.172
Jalbert (2009)	15	Adolescent	Retrieval	Writing quality	E	English	−0.230
				Text generation			−0.120
				Spelling error			−0.190
Jones and Christensen (1999)	114	2	Retrieval	Writing quality	N	English	0.820
Kent et al. (2014)	265	K and 1	Retrieval	Writing fluency	E	English	0.330
				Grammar			0.280
				Ideas			0.240
				Structure			0.200
				Word choice			0.210
Kim et al. (2011)	242	K	Retrieval	Writing quality	N	English	0.460
Kim et al. (2013)	156	5	Combined (Retrieval + Copy)	Writing fluency	N/A	Korean	0.570
				Substantive quality			0.280
Medwell et al. (2009)	198	6	Retrieval	Writing quality	N/A	English	0.464
			Copy				0.321

Table 1 continued

Study	*N*	Grade	HW[a]	W[b]	Genre	Orthography	*r*
Medwell et al. (2013)	186	2	Retrieval	Writing quality	N/A	English	0.581
			Copy				0.440
	198	6	Retrieval	Writing quality	N/A	English	0.464
			Copy				0.321
Olinghouse (2008)	120	3	Copy	Writing fluency	N	English	0.640
				Writing quality			0.420
				Correct spelling			0.200
Olinghouse and Graham (2009)	64	2 and 4	Copy	Writing fluency	N	English	0.630
				Writing quality			0.620
				Word choice			0.570
Wagner et al. (2011)	98	1	Combined (Retrieval + Copy)	Macro organization	E	English	0.320
				Writing fluency			0.400
				Complexity			0.270
				Spelling error			−0.150
	88	4	Combined (Retrieval + Copy)	Macro organization	E	English	0.810
				Writing fluency			0.720
				Complexity			0.070
				Spelling error			−0.030

Table 1 continued

Study	*N*	Grade	HW[a]	W[b]	Genre	Orthography	*r*
Yan et al. (2012)	153	K, 1, 2, and 3	Copy (Word)	Writing fluency	N	Chinese	0.340
				Writing quality			0.240
				Spelling error			−0.110
			Copy (Sentence)	Writing fluency			0.120
				Writing quality			0.340
				Spelling error			−0.060

[a] Types of handwriting measures

[b] Types of writing measures

Table 2 Summary of findings in Study 1

Research question	ES	95% CI	t	τ^2	Q	I^2
What is the general contribution of handwriting fluency on writing?	0.431**	(0.345, 0.517)	10.53	0.049	277.93	0.935
Does the contribution of handwriting vary across writing performances?	−0.048	(−0.143, 0.047)	−1.11	0.060	264.80	0.951
Writing quality ($n = 12$)	0.399**	(0.374, 0.424)				
Writing fluency ($n = 12$)	0.525**	(0.502, 0.546)				
Substantive quality ($n = 9$)	0.408**	(0.373, 0.442)				
Complexity ($n = 3$)	0.193*	(0.077, 0.303)				
Does the contribution of handwriting vary across types of handwriting measures?	0.003	(−0.242, 0.249)	0.03	0.055	237.86	0.945
Does the contribution of handwriting vary across participants' grade levels?	−0.164	(−0.321, −0.007)	−2.21	0.046	245.15	93.3
Does the contribution of handwriting vary across types of writing genres?	−0.114	(−0.331, 0.103)	−1.14	0.057	227.38	0.943
Does the contribution of handwriting vary across written orthographies?	0.152	(0.023, 0.281)	2.48	0.046	249.89	0.928
What is the relationship between handwriting fluency and spelling in writing tasks?						
Correctness ($n = 3$)	0.290	(−0.093, 0.673)				
Spelling errors ($n = 4$)	−0.147	(−0.343, 0.049)				

* $p < .01$; ** $p < .001$

learning disabilities and recruited more males than females. After excluding this sample, a balanced design on gender was found among all the other studies (percentage of girls ranging from 41.9 to 59.5%, $M = 0.499$, $SD = 0.045$). We further examined the participant features. Only the participants ($n = 15$) in Jalbert's study (2009) reported specific learning disabilities. Therefore, the moderator analyses did not consider the potential differences raised by either gender or special needs of participants in the studies.

What is the relationship between handwriting fluency and writing?

Overall, the 19 studies included 3014 participants. According to the RVE method, the effect size of the relationship between handwriting fluency and writing measures was 0.431 (95% CI [0.345, 0.517]). We used a t test to examine the significance and found the effect size was statistically significant ($t_{18} = 10.53$, $p < .001$). The between-study sampling variance (τ^2) was 0.049. The Q test was significant ($Q_e = 277.93$, $df = 18$) and I^2 indicated that 93.5% of variation across studies was due to heterogeneity. Thus, the result suggested a positive and statistically significant association between handwriting fluency and writing measures.

Does the relationship vary across writing performances?

As each study reported a variety of writing measures, we investigated the effect of writing measures on the relationship between handwriting fluency and writing. Hypothetically, we expected to find handwriting fluency and writing measures are consistently related. There are four categories of writing measures: writing quality ($n = 12$), writing fluency ($n = 12$), substantive quality ($n = 9$), and complexity ($n = 3$). Generally, writing quality was presented by overall compositional scores. Writing fluency may also be referred to as writing productivity, which counted the total number of words or characters. Substantive quality was a complex construct suggested by Kim, Park, and Park (2013), which considered content measures (e.g., idea, word choice) as well as organization (e.g., number of key elements, sentence structure). Finally, complexity was measured by T-units in the words and clause density. Based on Borenstein, Gedges, Higgins and Rothstein (2009), the power could be too low when fewer than five studies are included within one category in moderator analyses. Therefore, our calculation only consisted of the first three categories. Results suggested no statistical significance at $\alpha = 0.01$ level ($\beta = -0.048$, 95% CI [−0.143, 0.047], $t_{12} = -1.11$, $p = 0.290$, $\tau^2 = 0.060$, $Q_e = 264.80$, $df = 12$, $I^2 = 95.1\%$).

We further examined the association of handwriting fluency with each writing measure individually. Although the relationship was consistent across types of writing measures, we expected all the effect sizes should be statistically significant. Results showed the relationship of handwriting fluency with writing quality was 0.399 (95% CI [0.374, 0.424], $p < .001$,); with writing fluency was 0.525 (95% CI [0.502, 0.546], $p < .001$); with substantive quality was 0.408 (95% CI [0.373, 0.442], $p < 0.001$); and with complexity was 0.193 (95% CI [0.077, 0.303], $p = 0.001$). All the relationships were significant at $\alpha = 0.01$ level.

Does the relationship vary across types of handwriting measures?

The purpose of the third meta-regression analysis was to determine whether the type of handwriting measures influenced the relationship between handwriting and writing. We expected to see differences between copying and retrieval measures, since more cognitive demands were involved for retrieval measures. Studies in our sample consisted of both copying and retrieval measures on handwriting fluency. In English, the copying measure was related to sentence production (e.g., the sentence containing all of the letters in the alphabet: "The quick brown fox jumps over the lazy dog."). On the other hand, the copying measure was also given as writing the given words as many times as possible during a limited time. This type of measure was generally used for studies whose orthography was other than English. The words usually carried a concrete meaning (e.g., numbers and weekdays) in the specific orthography. Some studies used both approaches when measuring handwriting fluency, but reported them as one construct in their correlation matrix. Overall, we found effect sizes from nine studies on retrieval tasks, ten on copying sentences and three on repeatedly writing words, and used the first two categories for analysis. However, results indicated that retrieval tasks and copying sentences

did not statistically significantly differentiate the relationship between handwriting fluency and writing as the 95% confidence interval included zero point ($\beta = 0.003$, 95% CI [−0.242, 0.249], $t_{12} = 0.03$, $p = 0.977$, $\tau^2 = 0.055$, $Q_e = 237.86$, $df = 12$, $I^2 = 94.5\%$). Therefore, it was concluded that the relationship between handwriting and writing was not statistically significantly influenced by which type of handwriting measures was implemented.

Does the relationship vary across participants' grade levels?

We examined the influence of participants' grade levels on the concurrent relationship and expected that a stronger relationship could be found among primary-level students. The grade level was identified by grouping participants' age or grade reported in the studies. We categorized participants aged from Kindergarten to Grade 3 (i.e., 0 = primary level) and from Grade 4 to adolescents (i.e., 1 = intermediate or upper level) as two groups. The studies were grouped based on the experimental design (Graham et al., 1997; Medwell & Wray, 2014; Wagner et al., 2011), and the differences of the contributors to writing fluency and quality due to influences of grade levels (Abbott & Berninger, 1993). One study (i.e., Olinghouse & Graham, 2009) was excluded for this analysis since it combined second and fourth graders for correlational calculation. However, we found that participants' grade levels did not statistically significantly explain the between-study variance of the relationship between handwriting and writing at $\alpha = 0.01$ level ($\beta = -0.164$, 95% CI [−0.321, −0.007], $t_{16} = -2.21$, $p = 0.042$, $\tau^2 = 0.046$, $Q_e = 254.15$, $df = 16$, $I^2 = 93.3\%$), which indicated that this relationship was consistent across grade levels.

Does the relationship vary across types of writing genres?

As the writing prompts were given in different types, we examined whether the genres of writing outcomes influenced the relationship between handwriting and writing. Most of the studies reported whether their writing prompts expected a narrative or expository composition as an outcome. However, some studies offered no hints to identify this moderator. Therefore, our coding included the genres of writing outcomes as binary (i.e., 1 = narrative, 2 = expository). Results suggested that the genres of writing outcomes did not statistically significantly explain the between-study variance of the relationship between handwriting and writing, and the 95% confidence interval included the zero point ($\beta = -0.114$, 95% CI [−0.331, 0.103], $t_{12} = -1.14$, $p = 0.275$, $\tau^2 = 0.057$, $Q_e = 227.38$, $df = 12$, $I^2 = 94.3\%$). Therefore, we concluded that the genres of writing outcomes did not significantly impact the relationship between handwriting and writing.

Does the relationship vary across written orthographies?

We conducted a meta-regression analysis to examine whether handwriting in different orthographies and writing measures influenced the relationship between handwriting and writing. We generated two groups, English and non-English (i.e.,

Chinese, Dutch, Korean, and Turkish). The majority of the studies (79%, 15 out of 19) were conducted in English. Results showed that the orthography did not statistically significantly explain the between-study variance of the relationship between handwriting and writing ($\beta = 0.152$, 95% CI [0.023, 0.281], $t_{17} = 2.48$, $p = 0.024$, $\tau^2 = 0.046$, $Q_e = 249.89$, $df = 17$, $I^2 = 92.8\%$). However, since the non-English group only consisted of four studies, more such research would be needed to support the consistent correlation between handwriting fluency and writing across orthographies.

What is the relationship between handwriting fluency and spelling in writing tasks?

We investigated the relationship of the two transcription components. There were seven studies reporting the relationship between handwriting and spelling performance, and these spelling measures were conducted within the writing outcomes, rather than individual assessments. The hypothesis was that handwriting fluency and correct spelling should be positively associated, since reducing demands were placed on letter and sound correspondences. Three of these studies reported spelling accuracy, and the average correlation value was 0.290 (95% CI [−0.093, 0.673], $p = 0.083$). The other four studies reported the amount of spelling errors, and the average correlation value was −0.147 (95% CI [−0.343, 0.049], $p = 0.097$). Overall, both 95% confidence intervals regarding the relationship between handwriting and spelling performance included zero point and t tests indicated no statistical significance, which suggested no significant correlation between the two transcription components, when spelling was evaluated along with writing outcomes.

Publication bias

We first explored the publication bias of the studies by the funnel plot of standard error with 95% confidence limits using CMA. There was no obvious asymmetry in the funnel plot while most studies were beyond the range of 95% confidence limits, as is shown in Fig. 1. We also examined the results of Egger's regression test and did not find evidence of publication bias or small study effect ($b = 0.42$, $SE = 2.63$, $p = 0.874$). Furthermore, Duval and Tweedie's trim and fill analyses did not suggest any studies trimmed. Therefore, we concluded that the findings of the studies were not constrained by publication bias.

Study 2

In the second study, we intended to gauge the magnitude of association between handwriting and keyboarding via the meta-analytic review approach and examined whether handwriting and keyboarding differed on their relationships with writing and writing development.

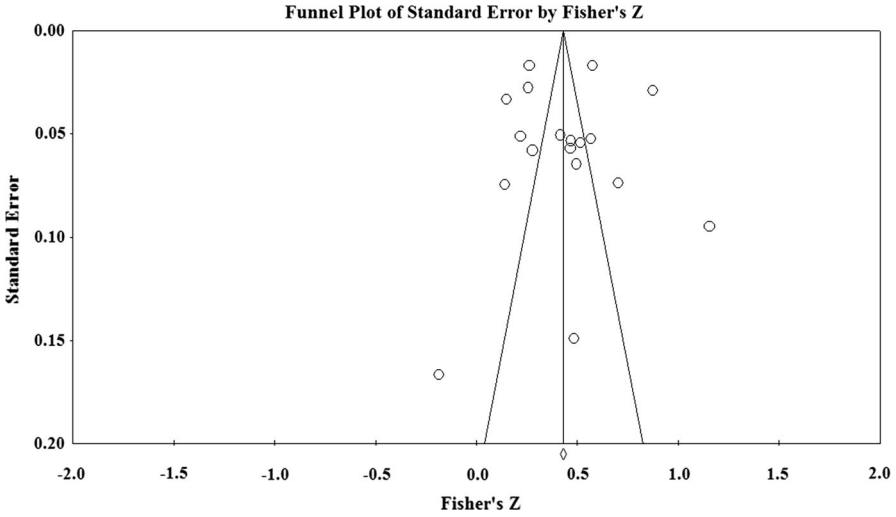

Fig. 1 Funnel plots with 95% confidence limits for the relationship between handwriting and writing

Method

Inclusion criteria

According to prior searching, studies on the comparison and/or relationship of handwriting and keyboarding were limited. Therefore, we included the eligible studies based on the following criteria: (1) the studies were conducted and published by 2015; (2) were designed as quantitative empirical experiments; (3) included measures on handwriting and keyboarding simultaneously; (4) reported sample size and the correlations and/or means (with *SD*) of handwriting, keyboarding, and/or writing measures; (5) were print in English; and (6) are available to the public, either online or in library archives.

Literature search

Studies for this meta-analysis were identified mainly through electronic searches in four databases: ERIC, PsycINFO, Web of Science, and ProQuest (including dissertations and theses global). The primary search among titles, abstracts and keywords was conducted using keywords including *handwriting and keyboarding*, *transcription and keyboard*, *pen and keyboard*, and/or *writing*. We also searched the reference lists of collected documents during the coding procedure to identify additional relevant studies.

The initial search resulted in 20 documents, all of which were journal articles; duplicated studies located from different databases were excluded. Utilizing the selection criteria mentioned above, a total of seven documents were retained for further consideration. Two studies were longitudinal, and each included two cohorts (i.e., Berninger, Abbott, Augsburger, & Garcia, 2009; Berninger et al., 2006).

Coding procedures

Each study was coded for study descriptors and effect sizes which related to the meta-analytic calculation. Study descriptors were same as the first study. Effect sizes included the correlations between handwriting and keyboarding, and the comparison between handwriting and keyboarding on writing measures. Not all the studies included both types of effect sizes, so we coded them separately. All studies were double coded by the first author and a graduate student independently. The interrater reliability was 0.90. Disagreements were resolved through discussion and decisions were revised by the first author.

Analytic procedure

Because of the limited sample size and dependence of participants among samples, we did not honor this study as a meta-analysis. The analytic process, regarding the correlations between handwriting and keyboarding, and their correlations with writing measures, was conducted using CMA. The comparisons of means on writing measures under handwriting and keyboarding modes were reported only in the two longitudinal studies. The results on the patterns regarding these comparisons were analyzed qualitatively and systematically.

Results

Descriptive information of the sample articles is given in Table 3. Although some studies focused their research on students with learning disabilities or special needs, the results of the current analytic study concerned only the general population.

What is the relationship between handwriting and keyboarding performances?

Handwriting and keyboarding fluency

Fluency under both handwriting and keyboarding modes was identified as the total number of correct handwritten or typed letters within a limited period of time. There were four studies (i.e., Berninger et al., 2006; Christensen, 2004; Connelly, Gee, & Walsh, 2007), two of which were from one longitudinal study using two cohorts, reporting effect sizes. For the longitudinal study, we included only the results from the last experimental period to control for the potential effects of grade level, as the participants from the other two studies were from intermediate grade levels. The average weighted effect size was 0.561 (95% CI [0.510, 0.608], $p < .001$).

Handwriting and keyboarding speed

Speed under both modes was identified as the number of handwritten or typed letters per minute. No decision on correctness was made under this condition. There were

Table 3 Qualitative descriptions of Study 2

Study	*N*	Grade	$r_{Fluency}$	r_{Speed}	$r_{Accuracy}$		r_{HW}	r_K		M_{HW} (*SD*)	M_K (*SD*)
Berninger et al. (2006)[a]	92	3	0.30								
	87			0.46							
	91				0.07						
	73	5	0.30								
	76			0.42							
	75				−0.03						
	128	1							Auto letter	3.0 (2.3)	4.3 (3.6)
									Total time	107.3 (25.6)	99.4 (27.4)
	122	3								6.2 (2.4)	8.1 (4.0)
										61.5 (20.0)	68.5 (25.6)
	113	3							Auto letter	5.1 (2.6)	8.9 (4.7)
									Total time	63.8 (23.3)	65.8 (30.9)
	106	5								8.7 (3.6)	14.9 (5.3)
										45.9 (17.0)	35.3 (16.6)
Berninger et al. (2009)[a]	124	2							Auto letter	4.45 (2.20)	6.20 (4.02)
									Total time	81.09 (27.35)	88.25 (35.65)
	229	4								7.18 (3.41)	11.73 (5.35)
										54.47 (22.28)	47.82 (25.17)
	106	6								10.12 (3.44)	18.31 (5.09)
										35.93 (13.93)	25.64 (15.60)
Christensen (2004)	276	8, 9	0.51			Quality	0.44	0.54			
						Length	0.30	0.55			
Connelly et al. (2007)	314	K to 6	0.70								
	48	5, 6				Quality	0.45	0.42			

Table 3 continued

Study	N	Grade	$r_{Fluency}$	r_{Speed}	$r_{Accuracy}$	r_{HW}	r_K	M_{HW} (SD)	M_K (SD)
Perminger et al. (2004)	47	5			0.05				
	52			0.340					
Roger and Case-Smith (2002)	38	6		0.342					
Weintraub et al. (2010)	63			0.52	0.07				

[a] Longitudinal study

five studies included (i.e., Berninger et al., 2006; Perminger et al., 2004; Rogers & Case-Smith, 2002; Weintraub, Gilmour-Grill, & Weiss, 2010). For the two effect sizes from the longitudinal study, the decision of choice was consistent with the previous study. The participants from the other three groups were all in the intermediate grade levels or adults. The average weighted effect size was 0.431 (95% CI [0.335, 0.519], $p < .001$).

Handwriting and keyboarding accuracy

Accuracy under both modes was identified as counting only the number of correct letters or characters through handwriting or keyboarding. No limits on timing were considered under this condition. There were four studies (i.e., Berninger et al., 2006; Perminger et al., 2004; Weintraub, Gilmour-Grill, & Weiss, 2010) including two from the longitudinal study. The average weighted effect size was 0.039 (95% CI [−0.081, 0.159], $p = 0.521$). The 95% confidence interval included the zero point, so we concluded that accuracy of handwriting and keyboarding are not statistically significantly related.

Do handwriting and keyboarding differ on the contributions to writing?

Correlational comparison between handwriting and keyboarding fluency on writing quality

Only two studies (i.e., Christensen, 2004; Connelly et al., 2007) included effect sizes to compare this relationship. The average weighted effect size regarding the handwriting mode was 0.441 (95% CI [0.349, 0.526], $p < .001$). In contrast, the effect size regarding the keyboarding mode was 0.524 (95% CI [0.440, 0.599], $p < .001$).

Correlational comparison between handwriting and keyboarding fluency on writing fluency

Only one study (i.e., Christensen, 2004) reported this type of effect size comparably. The average weighted effect size regarding the handwriting mode was 0.300 (95% CI [0.189, 0.404], $p < .001$), while that of the keyboarding mode was 0.550 (95% CI [0.462, 0.627], $p < .001$). There was no overlap across the 95% confidence intervals under both modes, which may suggest the significant difference between the influences of handwriting and keyboarding fluency on writing fluency. However, the generalizability of this conclusion was limited because we only had one sample study.

Mean comparison between handwriting and keyboarding modes on automatic letter writing

The two longitudinal studies reported the means of automatic letter writing under both modes. Berninger et al. (2006) studied two cohorts, one from Grades 1 to 3,

and the other form Grades 3 to 5. The other article by Berninger et al. (2009) partially combined the results from two cohorts because one was from Grades 2 to 4 and the other was from Grades 4 to 6. Measurements on Grade 4 for both cohorts were considered as one grade level, although the results were recorded longitudinally. Due to the violation of the independence assumption and the mixture of groups, the reported means and *SD*s were not available for further calculation of the weighted effect sizes. However, the overall pattern suggested the students tended to write more letters within a limited period of time (15 s) under the keyboarding mode, and the results of F tests in both studies were statistically significant (both $p = .001$). This finding was consistent across the grade levels.

Mean comparison between handwriting and keyboarding modes on writing time

Another comparison of means made in both longitudinal studies was on the total writing time. The design of reporting the results was the same as previously discussed. However, this comparison of means suggested some discrepancy. Only the group of second graders in Berninger et al. (2009) indicated that the writing time was longer under the keyboarding mode than the handwriting mode, and the result of F test was statistically significant at $\alpha = .05$ level ($p = .03$). Results from all the other groups (i.e., groups of Grades 1, 3, 4, 5, and 6) reported statistically significant priority (all ps $< .01$) of keyboarding mode on the total writing time.

Discussion

According to the presence of presentation and writer effects (Graham et al., 2011), handwriting serves as a critical factor of both the evaluation and development of writing performances. Although the contribution of handwriting instruction on writing has already been cumulatively reported, the findings from the first meta-analysis study provided further support of the beneficial relationship between handwriting and writing. Additionally, the findings from the second meta-analytic review suggested that handwriting contributed to writing as much as keyboarding did, which suggests that students should develop handwriting skills and receive explicit instruction about the technology. Results from the current studies supported the statement by Berninger (2000) and merited the benefits of handwriting as a transcription component.

Integration of the development of handwriting and writing

We proposed that handwriting fluency would correlate to the writing measures significantly. The hypothesis was supported by the significant effect size of 0.423 ($SE = 0.045$). We anticipated that there would be some constraints on this relationship across studies, such as grade levels, handwriting and writing measures, writing genres, and orthographies. However, the contribution of handwriting fluency to writing was relatively robust, because none of the moderator effects were identified with statistical significance. It is critical to be aware of the lower α-level

(i.e., $\alpha = .01$) which we applied on moderator analyses, because of the possible shrink on estimation of confidence intervals through RVE technique when having a limited number of studies.

We further explored the contribution of handwriting fluency to each writing measure. As anticipated, handwriting fluency was identified with significant correlation with most of the writing measures. The only exception was with complexity, which emphasizes syntactic construction and manipulation. The skills of complexity relied more on executive functions, like planning and self-regulation, based on the Simple View of Writing. Besides, previous research with first- and second-language learners has suggested that complexity was further limited due to students' language proficiency levels (Larsen-Freeman, 2006; Vyatkina, 2012), although it could be improved through specific writing instruction on the text structure (Watanabe & Hall-Kenyon, 2011). Other extraneous factors, such as the text genre and the measures used, could impact on the evaluation of complexity (Beers & Nagy, 2009). This might explain why we failed to find a significant relationship between handwriting fluency and complexity.

The meta-analysis by Santangelo and Graham (2015) has already shown that students with handwriting instruction would perform significantly better on writing quality, writing productivity, and writing fluency compared to their peers without handwriting instruction. The practical importance of handwriting instruction is further supported through the current meta-analysis, as we found the consistency of the relationship between handwriting fluency and writing. Although the contribution of handwriting fluency varied across different writing measures, handwriting fluency was identified as a significant factor of students' performance on writing quality, writing fluency, and substantive quality.

The power of our findings from the two studies on handwriting significance was compromised by the limited availability of studies. With more research considering the contributions of handwriting, its importance would be better understood.

Comparative influence of handwriting and keyboarding on writing

While we notice the contribution of handwriting to writing, we are also aware of the challenges from its competitive peer, keyboarding, because both are candidates of the writing modes. If we found the superiority of keyboarding, it is possible that keyboarding should be widely encouraged in classrooms as a substitute for handwriting practices.

In the second study, we found limited studies were designed as having handwriting and keyboarding modes as treatment and control. All of the studies included in the current review had the same group of participants measured under both modes, although some studies intended to compare students' writing performances correspondingly. We found that handwriting fluency was significantly correlated with keyboarding fluency ($r = 0.561$, 95% CI [0.510, 0.608], $p < .001$), especially on the measure of speed ($r = 0.431$, 95% CI [0.335, 0.519], $p < .001$). In other words, students with higher handwriting fluency appeared to have higher keyboarding fluency. As Berninger and Swanson (1994) suggested that transcription consists of handwriting and spelling, the failure of accuracy measures to raise

significant correlation may be due to the influence of spelling and working memory. The automatic spell check capability of keyboarding may lead to bias as well, although no study explicitly mentioned this point.

When we compared the performances of handwriting and keyboarding on writing, we found that students could write faster and produce larger quantities of writing under the keyboarding mode. In other words, students produced more typed words than handwritten ones within the same period of time. They also had to spend more time completing their handwritten composition, although the amount of text written was not more than that under the keyboarding mode. This was not surprising, as previous research consistently suggested that most students could write faster with keyboarding (Brown, 1988). However, the advantage of keyboarding on this aspect was constrained by some limitations. The findings were generated from only two longitudinal studies, and the participants were the same group under both modes. Although these participants had prior experience with keyboarding, their proficiency level under each mode was not explicitly identified. Furthermore, the amount of productivity was not the only major criterion of writing evaluation. The high productivity did not guarantee a structured in-depth planning and then a high writing quality. For example, Mueller and Oppenheimer (2014) investigated students' learning when they took notes under different writing modes. They found that with access to keyboarding, students tended to write verbatim rather than processing information and rewording it under the handwriting condition, which could be detrimental to their learning process. Although the amount of words in a typed manner could be almost three times more than those handwritten ones, students' learning achievement was not significantly promoted with keyboarding. Similarly, when considering writing as a comprehensive practice, choices of writing modes as either handwriting or keyboarding may not lead to a significant discrepancy to evaluate students' writing performance.

We found some overlaps (i.e., correlation ranging from 0.440 to 0.526) on the 95% CIs when comparing the relationships of handwriting and keyboarding fluency on writing quality. Although the non-independent group assignment did not allow further comparison between the two effect sizes, the evidence of overlapping indicated that handwriting and keyboarding are comparable to each other on their contribution to writing quality. Overall, despite the widespread usage of technology in classrooms, handwriting is still critical for students' writing development, and should be explicitly instructed.

Limitations

Admittedly, there are some limitations in our studies. We only included peer-reviewed articles and theses. Excluding other unpublished literature, such as research reports and manuscripts, could lead to insufficient representation of the relationship between handwriting, keyboarding and writing. However, examination on publication bias suggested that the current findings were not limited due to publication bias. Rather, this supported the significance of our findings. Second, although we intended to include studies of all orthographies, limited studies on non-English languages could be located, which constrained the power of moderator

analysis across languages. The insufficient amount of non-English research may influence the significance of the relationship between handwriting and writing in other languages, since studies on English were dominant. More studies on handwriting, keyboarding and writing would be strongly needed for such moderator analyses. Finally, the dependence within studies on handwriting and keyboarding hindered further examination and comparison. Given the result that these two writing modes were moderately positively associated, the significance of handwriting and handwriting instruction was still highlighted, which deserved exploration in future research.

Conclusion

Through the two studies related to the relationship of handwriting, keyboarding and writing measures, we stressed the need for incorporating handwriting as an essential part of instruction in classrooms. Handwriting and keyboarding both significantly positively associated with the development of writing, for a variety of writing measures. This further supports the simple view of writing, which emphasizes the contribution of transcription skills on text generation. Besides, handwriting did no worse than keyboarding on writing quality and actually significantly related to keyboarding performance, particularly on speed. In addition to identifying the significance of handwriting, the current studies also indicated additional research needs on handwriting to explore its implementation and effectiveness.

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