Sub-study I

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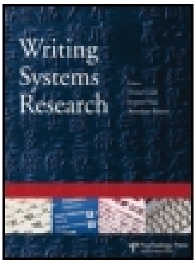

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Can you put your finger on it? The effects of writing modality on Finnish students' recollection

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ABSTRACT

Digitalisation has changed and broadened the ways people write. In higher education, typing is a common practice both for note-taking and for completing written assignments, relegating pen and paper to the last millennium. The cognitive and educational implications of this change, however, require further investigation. We assessed how three different methods of writing short stories affect students' subsequent memory retrieval. In a within-subjects design, Finnish students ($n = 31$) from the University of Lapland transcribed dictated stories using a pencil, a computer keyboard and a virtual touchscreen keyboard. The degree of recollection for each writing task was analysed 30 min after the session and then one week later. The main result is that handwriting led to significantly better recollection after both time delays. This corroborates and extends the findings reported in previous studies, and it calls for further research on writing methods and long-term memory. Additionally, as writing modality seems to affect recollection, reconsideration of instruction practices in higher education is suggested. Typing is the students' main method of writing and better typing competence can yield multiple benefits for them, including facilitating their academic work and enhancing the recollection of their own work.

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Writing; handwriting; typing; memory; long-term memory; recollection

Introduction

Learning to write, and developing the ability to deal with abstract symbols and concepts by combining and rearranging them, requires logic, critical thinking and mathematical ability (Tynjälä, Mason, & Lonka, 2001). In the process of learning to write by hand, the different shapes of letters and their perceptual properties are gradually recognised, identified and categorised into uppercase and lowercase letters, and the need for visual feedback decreases while the speed of writing increases (James & Engelhardt, 2012). In typing, one must first learn the position of the keys, become fluent in movement patterns, increase the speed and rely less on visual feedback as the process becomes automated (Sormunen & Wickersham, 1991; Weigelt Marom & Weintraub, 2015).

It has been postulated that, in comparison to typing, handwriting relies more strongly on fine-motor control, fine-motor movements and kinaesthetic sense. Moreover, in contrast to typing, it has been hypothesised that handwriting requires more fine-grained motor coordination to construct each letter (Mangen, 2013; Webb, 2013) and has controlled processes for output monitoring and automated motor processes for the production of letters (Tucha, Mecklinger, Walitza, & Lange, 2006).

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For the production of handwriting, Van Galen (1991) proposed a model of hierarchical and parallel functional stages. This model shows the complex biophysical, psychomotor and cognitive components that function simultaneously at different levels to produce the final product, which is written text. In the model, the higher-level components are considered to involve the processing of the abstract features of writing, such as spelling. At the same time, the lower-level components are occupied with motor output to produce the letters. The process starts from the intention to write and the retrieval of the letter form; it then continues to letter strokes whilst controlling the shape and size of the text by adjusting muscle movement. The model points to the significance of the processing speeds at the different levels as well as to the temporary memory storage that co-operates in real time for the harmonious result of written text (Van Galen, 1990, 1991; Van Galen, Meulenbrock, & Hylkema, 1986).

From a kinaesthetic perspective, typing on a computer keyboard or a touch screen keyboard is different from handwriting; skilled typing is bimanual and it uses all 10 fingers. When using a touchscreen, the process of writing follows the same principles as those used for a keyboard, albeit with a less clearly demarcated interface. Thus, the writing speed is slower, at least on a large surface with dimensions that are similar to those of a conventional keyboard. In this case, writing accuracy also suffers (Kim, Aulck, Bartha, Harper, & Johnson, 2014). However, the typing speed can be faster on the smaller screen of a mobile phone than on a computer keyboard (Kai, Tsukamoto, & Iio, 2018), even when using fewer fingers to write.

In typewriting, the transformation from motor to linguistic units relies on movement-based spatial coding and a different kinaesthetic sense than that used in handwriting, since the motoric action of choosing a letter to tap is always the same (Webb, 2013). Because technology generates the outcome of the typed text on a screen, it is assumed that, to the writer, the motoric action of typing is more detached from its visually perceived outcome than it is in handwriting (Mangen, 2013). Logan and Crump (2011) suggested a hierarchical two-loop theory for the process of typewriting. The inner and outer loops co-operate harmoniously, even though they have different responsibilities. The outer loop generates, monitors and encodes series of words to be typed and commands the inner loop to produce the appropriate keystrokes to construct the words. The process in the outer loop is explicit, and the typist is conscious of the word he/she is typing. However, the process in the inner loop is implicit as the competent typist is not conscious of the exact letter he/she is typing (Liu, Crump, & Logan, 2010; Logan & Crump, 2011; Snyder, Logan, & Yamaguchi, 2015).

Kinaesthesia and proprioception—meaning the movement, storing, updating and maintaining of writing skills—are fundamentally different for handwriting and typing (Hepp-Reymond, Chakarov, Schulte-Mönting, Huethe, & Kristeva, 2009). Van Galen's (1991) model of hierarchical and parallel functional stages for the production of handwriting and Logan and Crump's (2011) hierarchical two-loop theory for the process of typing indicate a clear difference in the motor output of letter and word production for each writing method. Since the processes and haptics of writing methods differ, it is possible that they contribute to memory trace formation and provide encoding assistance in different ways; thus, they have an impact on cognition (Bui, Myerson, & Hale, 2013; James & Engelhardt, 2012; Mangen, Anda, Oxborough, & Brønnick, 2015). Some theoretical accounts, such as the action perception theory of cognition and communication (Boulenger et al., 2008; Jacob & Jeannerod, 2005; Jeannerod, 1994, 2001, 2006; Jeannerod, Arbib, Rizzolatti, & Sakata, 1995; Pulvermüller & Fadiga, 2010; Pulvermüller, Moseley, Egorova, Shebani, & Boulenger, 2014), emphasise the role of self-performed actions in cognition and they support the reciprocal connection of motor and sensory brain mechanisms. In this view, actions are not perceived as pure motor processes; they are seen as the sum of motor and sensory properties. At the same time, perceptions are not processed as purely sensory information; they also involve the activation of motor processes. This co-operation facilitates the processing of information and the consolidation of active memories, thereby providing a theoretical link to the cognitive properties of writing. Action-word processing and language comprehension have also been shown to have the potential to activate motor regions (Boulenger et al., 2008; Jacob & Jeannerod, 2005; Pulvermüller et al., 2014; Pulvermüller & Fadiga, 2010). If this is the case, writing modality should influence cognitive performance, extending even to memory and recollection.

Prior research

Few studies have focused on handwriting and typing in connection to long-term retention and/or the retention of longer texts. However, the recollection or recognition of single letters has been investigated in behavioural and functional imaging studies in children (James & Engelhardt, 2012; Longcamp, Zerbato-Poudou, & Velay, 2005) and adults (Longcamp et al., 2008; Longcamp, Anton, Roth, & Velay, 2003, 2005; Longcamp, Boucard, Gilhodes, & Velay, 2006). While these studies have demonstrated the contributing effect of handwriting on recollection, it should be noted that earlier studies by Longcamp et al. (2003, 2005) used letters and pseudo letters, whereas later studies by Longcamp et al. (2006, 2008) used unknown characters that had been modified from Bengali and Guanjarati alphabets. To date, studies investigating writing methods and words have only been conducted on adults (Mangen et al., 2015; Smoker, Murphy, & Rockwell, 2009).

Only three of the aforementioned studies measured long-term retention. Longcamp et al. (2005) focused on children's letter recognition; in that study, two tests were conducted, one immediately after writing and another one week later. In a study on adults' letter recognition, Longcamp et al. (2006) tested the participants immediately after the writing sessions, then one week and three weeks later. In another study on adults' letter recognition, Longcamp et al. (2008) conducted the tests immediately after the writing sessions, and then one week, three weeks and five weeks later. In these three studies, the participants learned 10 to 12 different characters through typing and handwriting over a three-week period in one weekly session lasting 30 min for children and one hour for adults. The similar outcomes of these three subsequent behavioural studies are interesting. In recognition tests, the letters that were learned through handwriting were identified more accurately than those that were learned through typing. Notably, older children obtained better recognition scores than younger children, which points to the development of the sensorimotor and memory skills of older children (Longcamp et al., 2005). These studies indicate that handwriting may enhance memory for linguistic items in a way not seen with typewriting. However, it is unclear whether the results concerning single items (i.e. words and letters) can be generalised for longer text, which would have greater relevance for teaching instruction practices.

In a more realistic setting, Mueller and Oppenheimer (2014) compared university students' memory of factual and conceptual facts after they had used handwriting and typing on a laptop to take their lecture notes. The students were free to write in their own words. In particular, sub-study 3 is interesting, since the participants were tested one week after the lecture. The results indicated that handwriting promotes deeper subject comprehension. Typing the lecture notes resulted in more text but poorer subject understanding; this suggests that typing results in shallower information processing and surface-level encoding. In terms of academic performance, Mueller and Oppenheimer's (2014) findings indicate that handwriting notes with one's own words is beneficial for new conceptual knowledge construction, aided by prior knowledge and logical thinking. This corroborates the earlier findings of Igo, Bruning, and McCrudden (2005), where the verbatim transcription of notes resulted in poorer conceptual knowledge than non-verbatim note-taking. However, Bui et al. (2013) investigated the relationship between recall (immediately and 24 h later) and the note-taking strategies of undergraduate students during an 11-minute lecture. The findings revealed that good and organised note-taking strategies are crucial for recollection. In contrast to other research findings (Igo et al., 2005; Kiewra, 1989; Mueller & Oppenheimer, 2014; Van Meter, Yokoi, & Pressley, 1994), Bui et al. (2013) suggested that laptop verbatim note-taking resulted in greater recall in comparison to handwriting.

However, the short length of the test, as well as the short delay of 24 h, makes the results not directly comparable with the results of the present study. Nevertheless, Bui et al.'s (2013) findings suggest that writing modality has an effect on recollection.

Overall, behavioural and functional imaging studies appear to favour handwriting and they show a positive association between handwriting and recollection, even if only for single letters and words immediately or shortly after writing sessions. However, the long-term retention of longer texts written with different writing methods has not been examined in a controlled setting. Hence, the present experimental study investigates the effect of writing methods on long-term recollection with longer dictated texts that were written by hand, typed on a computer keyboard and typed on a touch screen keyboard.

Aim of the present research study

This study addresses the research gap regarding long-term recollection and the writing methods used for longer texts that contain a logical story. To highlight the specific cognitive processes that underlie the effect of writing modalities, three writing modalities were tested in reduced experimental settings by comparing the recollection of short dictated stories that were handwritten, typed on a conventional computer keyboard and typed on a tablet computer's touchscreen keyboard. This enabled us to study the retention of longer logical stories that paralleled academic demands but that had no specific significance in regard to the subjects and did not require any prior knowledge. The time required for each writing task was documented. We also tested the time course of consolidation for the different writing modes—recollection was tested at both 30 min after the writing session and one week later. The current study was designed to answer the following research question: Does the writing modality influence students' recollection of dictated stories?

Method

Participants and design

The 31 voluntary participants (21 women and 10 men) were all Finnish students from the University of Lapland, and their first language was Finnish. They ranged in age between 21 and 51 (mean age 29.5, SD = 8.6), and they were recruited from six different university courses. Sixteen participants were from the Faculty of Education, two were from the Faculty of Law, and 13 were from the Faculty of Social Sciences. Thirty participants were right-handed, and one was left-handed. Table 1 presents descriptive statistics for the participants' ages, the age at which they began typing, the years of experience with conventional and touchscreen keyboards and the number of fingers used in typing. An experimental within-subjects research design was used, where all the participants were subjected to specific varied conditions, and the effects of the different conditions were measured (Mertens, 2010). In this study, each participant was subjected to the same three writing conditions: handwriting with a pencil, typing on a conventional keyboard and typing on a tablet computer's touchscreen keyboard.

Table 1. Demographics, participants' ages, and typing experience.

	Mean	*SD*	Min	Max
Age	29.5	8.6	21	51
Age started typing	10.2	3.5	4	20
Years of experience with conventional keyboard	16.7	4.7	10	26
Number of fingers used in typing	8.2	2.2	2	10
Years of experience with touchscreen keyboard	4.8	1.7	1	9

Materials

Three short stories were dictated to the participants. Two of the stories (Story A and Story B) were from the Finnish version of the Wechsler Memory Scale-Revised (WMS-R) logical memory subtest (Wechsler, 1987); therefore, they cannot be disclosed. This particular sub-test is designed to test episodic memory (the so-called 'story memory'). Because three writing methods were investigated in this study, an additional story (Story C) was created; its length was similar to the two other stories and it was equally difficult to remember. The mean values scored for the three stories are presented in Table 2. Each story included 25 details that the participants had to recall. These details were key elements, such as animals, modes of transport and incidents in the story. Participants earned one point for each recalled detail; the maximum score was 25.

To ensure that the stories were roughly equally difficult to remember, we performed a Bayesian repeated measures ANOVA (JASP 0.8.6) for the recollection scores after a 30-minute delay. The default JASP multivariate Cauchy priors were used: the scale parameters were 1 and 0.5 for the fixed and random effects, respectively. Thus, the obtained Bayesian factor (BF01) was 3.07, indicating that the null model (stories are equally difficult) is roughly three-times more favoured than the alternative model, given the data.

Procedure

Prior to the data collection, the participants signed a consent form and completed a questionnaire to provide basic demographic details. They were also required to make themselves available for re-measurements one week after the initial memory test. The participants performed the tasks individually. All participants were informed about the aims of the study and what the data would be used for. None of the participants were familiar with this kind of testing; hence, the effects of prior experiences on the study were minimal. They were also informed that their participation was confidential and that the research data would not contain any identifiers that could link them to the study.

After being informed about the study and completing the questionnaire, the stories A, B and C were dictated one to three words at a time by the first author to each participant once, in a random order. The participants wrote down the three stories, using a different writing modality for each. In other words, the participants wrote down, verbatim, what they heard using each writing method, consecutively. The writing method sequence was also randomised. This was done in an effort to ensure that the same modality would not always be used first and that the story written with each modality would differ between participants. In this manner, the reliability of the test results was enhanced and any expected effects were ruled out, as much as possible. Each of the stories contained 54 to 62 words (421 to 444 characters), and the dictation speed was adjusted according to each individual participant's writing speed. This enabled the participants to complete all three parts of the test sequentially without a break, at their own pace. The time taken to complete each task was documented. The participants were allowed to read the texts once immediately after completing the writing task. After writing all three stories, the participants' retention was measured following a 30-minute delay and a one-week delay using a free verbal recall test in which they orally related the written stories in their own words to the first author. During the

Table 2. Distribution of scores for stories A, B, and C after 30-minute delay and 1-week delay.

	Min	Max	Mean	*SD*
Story A 30 min	12	21	15.0	2.4
Story B 30 min	7	24	15.6	3.9
Story C 30 min	8	22	14.5	3.2
Story A 1 week	8	19	13.3	2.7
Story B 1 week	7	24	14.7	4.7
Story C 1 week	7	20	13.0	3.5

30-minute delay, the participants were allowed to leave the room and take a break. The participants were not given any cues about the stories before recounting them, and they were allowed to use as much time as they needed to recount the stories. Lists of the 25 details from each story were used to mark and calculate the remembered details.

To enhance the validity of the testing environment, the data acquisition was conducted in one office provided for this purpose at the Centre for Media Pedagogy at the University of Lapland. Thus, the same setting was used for all participants. For the typing task, a Dell OptiPlex 990 desktop computer and a Dell P2412H 24-inch LCD display with 1920×1080-pixel resolution together with a Dell KB212-B keyboard were used. All participants wrote in a Microsoft Office Word document using Calibri Body 11-point font. For the touchscreen task, a third-generation iPad running IOS 9.2.1 was used, and all the participants wrote in a Microsoft Office Word document with Calibri 11-point font. For the handwriting task, the participants were provided with A4-sized white paper and pencils.

Statistical analysis

The main statistical approach was repeated measures ANOVA carried out with IBM's Statistical Package for the Social Sciences (SPSS) version 22.0 (SPSS Inc., Chicago, IL, USA). Greenhouse-Geisser corrected degrees of freedom were used if the sphericity assumption was violated. Bonferroni corrected adjustments for multiple comparisons were used in follow-up pairwise comparisons.

Results

Does the writing modality influence students' recollection of dictated stories?

First, we examined whether writing modality and delay (30 min after the session and one week later) affected the recollection scores. The mean recollection score for handwriting after a 30-minute delay was 16.39 (SD 3.42); after a one-week delay the score was 14.90 (SD 4.15). The mean recollection scores for typing on a conventional keyboard and touchscreen keyboard after a 30-minute delay were nearly equivalent 14.32 (SD 3.23) and 14.39 (SD 2.67), respectively; after a one-week delay the scores were 13.13 (SD 3.57) and 12.94 (SD 3.29), respectively. The mean scores for both delay times are presented in Figure 1. The combined mean score for both delay times for handwriting was 15.65 ($SD = 0.66$); for typing on a conventional keyboard the mean score was 13.73 ($SD = 0.58$) and for typing on a touchscreen keyboard the mean score was 13.66 ($SD = 0.50$).

The repeated measures ANOVA, with writing mode (handwriting, keyboard, tablet) and delay (30-minute, one-week) as the within-subjects factors, yielded statistically significant main effects for both factors on recollection. The analysis revealed a main effect of writing modality (F [2, 60] = 6.95; p = .002); hence, to determine which modality had statistically significantly better recollection scores, we conducted pairwise comparisons between the writing modalities. The results indicated that handwriting yielded significantly greater recall than touchscreen ($p < .001$) and keyboard ($p < .004$) typing. The latter two modalities did not significantly differ from each other. Additionally, the analysis revealed a main effect of delay (F (1, 30) = 24.56; $p < .001$). There was no statistically significant interaction (F (2, 60) = 0.39; p = .76) between writing modality and time delay; this suggests that the writing mode did not affect the rate of memory decay. The eta-squared values for both factors were >0.14, confirming the large effect; the partial eta-squared value was 0.19 for the writing modality and 0.45 for the time delay.

Furthermore, we examined whether the speed of writing and type of writing modality had a combined effect on recollection. As indicated in Figure 2, the time spent writing differed significantly between the writing modes (F[2, 60] = 34.49; $p < .001$). Pairwise comparisons indicated

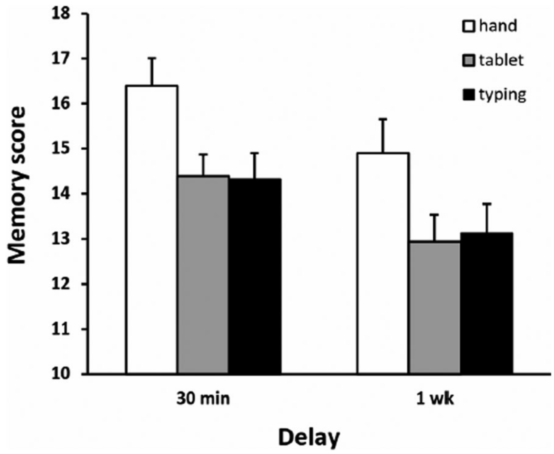

Figure 1. Mean memory scores (+SEM) as a function of writing mode and time delay after writing. Handwriting resulted in significantly better recollection of the dictated story both 30 min and 1 week after the writing event. The decay rate of the memorised items was equal in all conditions.

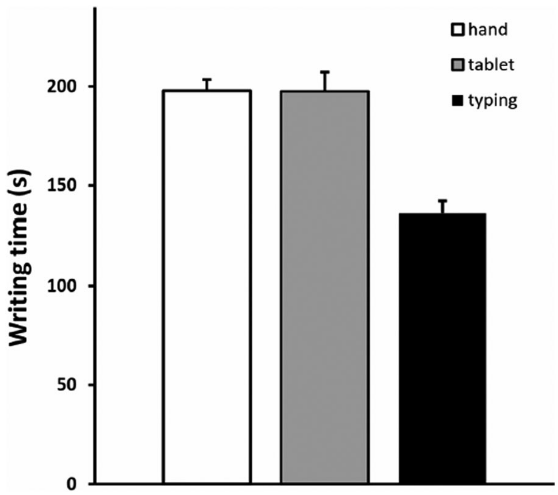

Figure 2. Time (+SEM) spent in writing with each method. Keyboard typing was the least time-consuming method.

that the time spent on writing with the keyboard was significantly less than the time required for both writing by hand and writing on a tablet ($t[30] = 7.72–9.76$; $p < 0.001$). However, the time spent did not differ significantly between handwriting and tablet writing ($t[30] = 0.03$; $p = 0.98$). To assess the contribution of writing time on memory performance, we used writing time as a covariate in an additional univariate ANOVA, assuming that the writing mode and time delay were independent variables; the memory test score was the dependent variable. This analysis still showed that the writing mode had a significant impact ($F[2, 18] = 5.23$, $p < .05$). The consequent pairwise comparisons indicated that handwriting resulted in better recollection than writing on a tablet ($p < .01$). Interestingly, other significant differences were not found.

We also examined whether the participants' age contributed to the recollection results. The Pearson product-moment correlation coefficient indicated a positive correlation between age and the best methods' recollection scores [$r(31) = .49$, $p = .005$] and the worst methods' recollection scores [$r(31) = .54$, $p = .002$] after a 30-minute delay. Within this group of participants, the recollection scores increased with the participants' age; however, age had no correlation with the number of fingers the participants used for typing or the number of years they had used touchscreen devices.

Lastly, in order to control for individual differences in typing skills and experience, we ran additional repeated measures analyses of covariance (ANCOVAs), with writing mode (handwriting, keyboard, tablet) and delay (30-minute, one-week) as the within-subjects factors, and we entered age to start keyboard typing, years of keyboard typing experience, number of fingers used in typing and years of touchscreen typing experience as covariates, one at a time. None of these analyses indicated that the covariate had a significant main effect on recollection score ($F = 0.685$–3.685; $p = 0.077$–0.415). However, years of keyboard use approached statistical significance. When used as a covariate in separate analyses for each of the writing modes, its main effect approached statistical significance in handwriting ($F = 3.005$; $p = 0.094$), but not for the two other writing modes. To summarise, to some extent, years of experience in keyboard typing might explain the main result but the evidence in this data cannot be considered to be particularly strong.

Discussion

We studied three different writing methods (handwriting, typing on a computer keyboard and typing on the touchscreen keyboard of a tablet computer) and the participants' subsequent short-term and longer-term recollection of written stories that had been dictated to them. The main finding of this study supports the assumption drawn from previous studies concerning letters (James & Engelhardt, 2012; Longcamp et al., 2003; Longcamp et al., 2005; Longcamp et al., 2006, 2008; Longcamp, Anton, Roth, & Velay, 2005) and words (Mangen et al., 2015; Smoker et al., 2009) of the pre-eminence of handwriting in regards to recollection. The results are consistent for both the 30-minute delay after the writing task and one week later, pointing to the moderate cognitive benefits of handwriting.

Three major factors might have contributed to these results. First, writing modalities might vary in the way they engage cognitive resources. For the participants, handwriting was the earliest acquired and possibly the most automatic writing skill, making it possible to allocate more attentional resources to the content of the story (Baddeley, 2010; Cowan, 2005). Typing, and especially tablet typing, are relatively newly acquired proficiencies. They might occupy working memory resources and, thus, interfere with learning (Chi & Ohlsson, 2005; Kane & Engle, 2000; Logie, 2011). Working memory, with its limited capacity in both space and time, has been found to play a crucial role in note-taking (Bui & Myerson, 2014; Piolat, Olive, & Kellogg, 2005).

Second, differences in the sensorimotor requirements between the writing modalities might recruit different degrees of neural resources that are relevant for recollection. It is possible that, in comparison to typing, handwriting activates the motor and sensorimotor networks in the brain to a larger extent, thus facilitating interaction with higher cognitive functions, such as memory, as mentioned in the action perception theory of cognition and communication (Boulenger et al., 2008; Jacob & Jeannerod, 2005; Jeannerod, 1994, 2001, 2006; Jeannerod et al., 1995; Pulvermüller et al., 2014; Pulvermüller & Fadiga, 2010). As noted in the introduction, in terms of biomechanics, the need for kinaesthetic sense and fine-motor control of movements is stronger for handwriting than typewriting. However, because typewriting requires memorising the spatial location uniquely for each letter, it also requires the utilisation of different cognitive functions. Nevertheless, handwriting is typically (still) learned at an earlier age than typewriting, and it is likely to represent more primary coding between the sensorimotor and cognitive brain networks. Indeed, learning to master reading and writing skills during cognitive development is critically linked with a sufficient level of working memory (Baddeley, 2010). This developmental association may result in a stronger integration of handwriting-specific motor patterns with cognitive functions in comparison to the later-learned skills used for typing on a keyboard or a touchscreen.

Spatial dimension is one clear difference between handwriting and both typing modalities. In handwriting, the movements are anchored to the writer's body (hand), and the same letters can be written in many different sizes or forms. For touchpads and keyboards, the movements are anchored to the external spatial arrangement. However, it is not clear whether the memory-enhancing effect of motor action only remains at the perceptual level or whether it generalises memorised things to a higher conceptual level. Mueller and Oppenheimer (2014) confirmed that handwriting lecture notes resulted in better conceptual knowledge than typing the notes. Moreover, previous studies have elaborated on the role of motor function in perception and recognition, for example, in the context of speech perception (Liberman & Mattingly, 1985) and letter recognition (Longcamp, Hlushchuk, & Hari, 2011). Furthermore, reading written text symbols activates the same motor areas of the brain as handwriting the same symbols (Heimann, Umilta, & Gallese, 2013). It has also been proposed that perceptual-motor integration plays a general role in human cognition, especially in short-term memory (Macken, Taylor, & Jones, 2014). While these possibilities could not be addressed in the present data, future neuroimaging studies could shed light on the mechanisms involved.

Third, and finally, writing speed differed between the modalities. Handwriting required more time than using a computer keyboard, and when this difference was considered in the comparison between recollection scores, the observed difference in memory performance remained between handwriting and typing on a touch screen keyboard ($p < .01$), but not between handwriting and typing on a computer keyboard. This indicates that the time used for writing in different modalities cannot fully account for the observed effects. It could be that the time spent forming the letters one-by-one in handwriting allows relatively simple material to be processed more efficiently (McCutchen, 2006; McCutchen, Teske, & Bankston, 2008). Thus, it could be speculated that there is a trade-off between writing speed and recollection, and that the automated action of handwriting leaves more time for processing information. However, the time factor alone cannot explain the enhanced memory performance of handwriting because typing on the tablet took as much time as handwriting but it resulted in poorer recollection. This suggests that time alone, as such, is not a contributor. This further indicates the sensorimotor networks proposed by the action perception theory of cognition and communication (Boulenger et al., 2008; Jacob & Jeannerod, 2005; Jeannerod, 1994, 2001, 2006; Jeannerod et al., 1995; Pulvermüller et al., 2014; Pulvermüller & Fadiga, 2010) do not explain the memory difference. Indeed, this difference could be related to differences in the participants' familiarity with the writing methods.

Limitations

The findings of this study are from a small group of participants, thereby limiting how broadly the results can be generalised. Moreover, on average, the study participants had started typing at the age of 10 (Table 1); by then, handwriting had already more or less become automated since all the participants had attended school and learned the skill of writing at a time when cursive handwriting was still being taught. Thus, these results are not generalisable or transferrable to children that are learning to write.

The participants' age might have impacted the results of this study, since the recollection scores were better for the older participants. Furthermore, the fact that the participants recounted the stories they had written down after a 30-minute delay possibly affected their retention the following week. All of the participants expressed this view. Additionally, even though all the students were provided with similar testing conditions, their individual differences in typing experiences and competences (Table 1) may have affected the results. The experience in any given writing method, regardless of age group, might have an effect on the outcome. With a larger sampling, the effect of the writing method experience could be studied further. In this study, some of the participants started typing at the age of four, whereas others began at the age of 20; overall, the number length of the participants' typing experience fluctuated from 10 to 26 years. Moreover, some of the participants had only one year's experience with a touchscreen keyboard, whilst the most experienced participant had been using touchscreen devices for nine years. Some participants were also very competent typists, using all 10 fingers, while others only used two fingers. In the latter case, typing is not automated, which can affect recollection.

Implications for educational practice, future research directions and conclusion

The findings of this study have some implications that are worth mentioning. Particularly, the results of this study should be reflected upon in an educational context. The inescapable digitalisation of learning environments and the shift from handwriting to typing will have cognitive and educational implications that have not yet been discovered. First, in the cognitive context hand-motor skills, manual dexterity and learning may be altered by not learning or using cursive handwriting. The consequent reduction in manual activity will affect handwriting competence, the implications of which are still unknown. Second, in the educational context the implications may vary between age groups. In higher education, typewriting is a necessity. It is possible that better typewriting competence could enhance student recollection and learning outcomes since the combined effect of the typewriting method and typewriting speed on recollection was not significant in the present study. Furthermore, competent typewriting could facilitate a student's work. Typewriting with two fingers can be laborious; thus, the completed assignments might not represent a student's full potential. Therefore, providing supplementary instruction in typewriting could have multiple benefits for the students. In light of the results of the current study, there is cause for further investigation into writing modalities and recollection in all age groups.

In conclusion, our findings reveal the relevance of writing modality in recollection, and, consequently, in remembering logical stories. Moreover, the decrease in cursive handwriting instruction in school points to the need for further research about children who learn to print, as well as type, in the first grade. Thus, more empirical research on this topic is required for different age groups with varied experiences of different writing methods to understand the possible effects of writing modalities on cognitive performance and to provide educators with the knowledge to guide the new generation of students towards balancing writing practices in an effort to improve learning outcomes. Additionally, further empirical research is needed to investigate the developmental and neural factors associated with different writing modalities.

Conflict of interest statement

The authors whose names are listed immediately above certify that they have NO affiliations with or involvement in any organisation or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements) or non-financial interest (such as personal or professional relationships, affiliations, knowledge, or beliefs) in the subject matter or materials discussed in this manuscript.

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