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Writing medium's impact on memory: A comparison of paper vs. tablet

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Abstract

Studies comparing writing media typically compare different modes of writing (e.g., keyboard typing vs. writing, smartphone tapping vs. writing, etc.). The current study sought to investigate the cognitive outcomes of a more direct comparison: tablet- versus paper-based writing. Thirty-two speakers of L1 English were tasked with memorizing 20 Japanese kanji (stroke orders, Japanese readings, and English translations). Ten kanji were practiced (10 times each) on paper; the other 10 were practiced on an iPad. The kanji that were practiced on paper were more likely to be correctly translated into English at both the post- and delayed posttest, though Japanese scores were statistically equal. Of most intrigue was that while both groups were written with equal accuracy at the posttest, only the kanji practiced on paper showed a significant increase at the delayed posttest (after a period of 24 hours). The results of exit questionnaires indicated that the participants were divided on their preference of writing medium but were unanimous in their agreement that tablets should have a place in modern classrooms. One significant finding is that participants acknowledge the difficulty of tablet-based writing but conclude that what is necessary is more practice – not the avoidance or abandonment of the technology.

Keywords: writing, handwriting, digital media, paper, tablets, Apple Pencil, kanji

Introduction

Research into differences between writing media has remained a key area of investigation over the past several years. What investigators are mainly interested in, is how changing the medium used to write affects the writing process, the written product itself (e.g., a composition's length or quality), and the resulting cognitive outcomes (e.g., degree of comprehension or recollection). Particularly in an educational context, some of these factors can make a large difference in a student's development, making an understanding of these relationships vital for students, educators, and institutional

Data Availability Statement: *All relevant data are within this paper.*

policymakers. For example, in a seminal study by Mueller and Oppenheimer (2014), it was suggested that while laptop-based notetakers recorded a greater quantity of notes, a handwriting-based cohort scored better on subsequent questions which tested their conceptual understanding of lecture contents. This led the researchers to posit that the speed advantage afforded to the typists resulted in them transcribing lectures verbatim, whereas the speed limitation forced the longhand writers to condense and synthesize the information, resulting in a greater depth of cognitive processing. Their observation adeptly captures the concept that technology not only affects the physical act of how we write, but also influences how we approach writing from a cognitive or strategical standpoint.

The onset of the global COVID-19 pandemic has brought about a renewed urgency in writing media research, as more students worldwide are now using technology to access their schoolwork than ever before. However, while there has been a large body of research conducted which focused on the dichotomy of handwriting versus computer-based typing, the near universal prevalence of mobile devices has opened the field to new areas of investigation which consider the impact of screen-based writing methods. Even before the pandemic, smartphones were slowly beginning to appear in classrooms (e.g., Anshari *et al.*, 2017; Chen *et al.*, 2017; Norris *et al.*, 2011), but now that students are engaging in remote learning, the number of students using smartphones and tablets to complete assignments has surely grown. Perhaps in acknowledgement of the desire of most students to use mobile devices in school (Lee, 2019; Lee & Al Khateeb, 2021), several school districts have seen the gradual acceptance and official introduction of portable devices into policy. In 2019, the Ministry of Education, Culture, Sports, Science, and Technology (MEXT) in Japan announced the start of a GIGA (Global and Innovation Gateway for All) School Program, which aimed to provide every primary and secondary student in the country with their own tablet by March 2021 (MEXT, 2019).

The attraction of portable devices is quickly apparent – they allow for the capture and storage of vast amounts of information, with searchability and transfer options far superior to paper documents. However, as Mueller and Oppenheimer (2014) pointed out, it is important that administrators and educators do not assume a false equivalency between writing media, lest their students experience unintended adverse effects. The current study therefore sought to investigate the cognitive implications of writing on a tablet, compared to writing on paper. Specifically, the research questions (RQs) asked were as follows:

1. When learning a new writing system (i.e., Japanese kanji), does practicing on tablet versus paper result in quantitatively different degrees of written production ability?
2. When learning a new writing system (i.e., Japanese kanji), does practicing on tablet versus paper result in quantitatively different degrees of visual recognition ability?
3. What are participants' reactions to the experiment and their feelings regarding paper- versus tablet-based writing practice?

Literature Review

Research on writing media

As Yancey (2009) pointed out, humans have an innate impulse to write, and find ways to utilize whatever materials and technologies are afforded to them at the time. However, changing the medium by which one writes has been shown to have several implications which are not often immediately apparent. In perhaps the most well-documented comparison, paper-based handwriting has been shown to have more cognitive benefits than keyboard-based typing, perhaps owing to the advantage in graphomotor, tactile, and visual feedback that a pen has over a keyboard. Learners of a new writing system (pre-literate children in their native language: James & Engelhardt, 2012; Kiefer *et al.*, 2015, and adults learning a second language: Longcamp *et al.*, 2006) have been found to recognize letters better after training by drawing/writing than by typing. This advantage in letter recognition has also been explored in neural imaging studies which found that the regions of the brain responsible for reading and writing are linked – a writer simultaneously reads what is being written, and reading handwritten text alone triggers sensory motor-control regions as the brain simulates writing (James & Gauthier, 2006). In addition to letter recognition, some studies have suggested that people have better memory/recall of items which they have written, as opposed to typed (Frangou *et al.*, 2018; Frangou *et al.*, 2019; Smoker *et al.*, 2009) or *tapped* (i.e., on a smartphone screen: Lee, 2021).

Naturally, the previous studies comparing writing media also entailed different modes of writing: longhand writing, typing, and tapping. The current study focuses on a more direct comparison – the difference between writing on paper or on a tablet screen. This comparison controls for several independent variables that existed with previous studies of writing media, as handwriting is known as a *unified action*. In other words, a writer's visual attention is fixed on the same point as the motor action, unlike typing in which a typist's gaze is often on the screen while the hands and fingers operate the keyboard on the periphery of the visual field. (The case of a smartphone tapper is somewhat more ambiguous as a tapper's visual attention often flickers back and forth between the screen and the fingers.) This unification of attention has been postulated to be a source of the advantage writers show over typists/tappers as a writer simultaneously monitors both letter production and textual context (Caporossi & Alamargot, 2014). The individual variation of handwritten script has also been suggested to be a significant factor in unifying writing and cognition through the framework of embodied cognition (Mangen & Balsvik, 2016), which posits that sensory perception and motor systems assist in managing cognitive loads. Despite there being a standard form of each letter which everyone learns, each person develops an original handwriting style of viable exemplars which is unique and personal to the writer. As handwriting is graphically free from constraints, contextual cues are also often naturally embedded in handwritten script (e.g., neatness, deliberateness, alignment, thickness/strength of stroke, etc.) which can relay nonlinguistic messages to the reader (Kim *et al.*, 2019).

The efficacy of tablets as a writing tool has been supported by studies such as Berninger *et al.*, (2015), which reported that students with learning disabilities showed significant improvements in their writing skills after training on iPads in a series of 18 two-hour sessions. This result supports the notion that digital technologies may facilitate learning as students tend to have higher motivation and spend longer on task than with traditional paper-and-pen assignments (e.g., Clark & Dugdale, 2009; Rogers & Graham, 2008). Nevertheless, there are some noteable physical differences between writing on paper versus a tablet. Perhaps most importantly, there is a noticeable difference in friction between graphite or metal on paper and a plastic stylus sliding on a glass screen. Typically, handwriting skills develop over several years, beginning at around age 5 and achieving full automatization at around age 15 (Accardo *et al.*, 2013; Rueckriegel *et al.*, 2008). This developmental process is conceptualized by the gradual formation of central motor programs for each letter and is marked by frequent pen pauses as the writer coordinates visual and propriokinesthetic feedback in a reactive manner. The quantity and length of these pauses gradually decreases as the writer depends less on feedback and more on the mastered motor programs. However, Alamargot and Morin (2015) found significant differences in writers' pen movements and pauses when writing on tablets, indicating that the unfamiliarity of a tablet screen's slick sensory feedback causes writers to become more retroactive, a sign of reversion to an earlier stage of writing proficiency. Conceptually, these findings are similar to those which have suggested that paper texture has a significant effect on writing speed (Chan & Lee, 2005). However, researchers have provided evidence that writers constantly show adaptation in their writing dynamics, with more experienced writers adapting more quickly and adeptly to disruptions than beginner writers who have yet to achieve full automatization (Gerth, Dolk *et al.*, 2016; Gerth, Klassert, *et al.*, 2016).

The Japanese writing system

Writing systems can very broadly be divided into two main systems: phonographic scripts and logographic characters. English is an example of the former, as each letter in the alphabet represents a certain sound. In contrast, logographic writing systems (such as Chinese) have different characters which carry meaning. Therefore, while it is generally possible for a speaker of English to read a word that they had never encountered before, to do so would be impossible for a speaker of Chinese when faced with an unfamiliar character. Japanese makes use of both of these writing systems in combination; it uses both Chinese characters, called *kanji*, and phonographic letters known as *kana*. Kana are relatively straightforward as there are a limited number of them and each one maps directly to a single sound with high consistency. Kanji, on the other hand, are extremely complex, as a single kanji sometimes has multiple meanings, and most have multiple readings, which must be determined based on context. For example, even the basic kanji of 月can mean either *moon* [tsuki] or *month* [getsu] or [gatsu]. In addition, when writing kanji (and also kana), the order in which the various strokes are drawn is prescribed – each person writes every character in the exact same way. This is helpful when attempting to disambiguate calligraphic, cursive, or merely sloppy handwriting, as the reader can often infer the writer's intent by retracing and extrapolating the path of the pen. However, this implies that in order to master kanji, a person must memorize the overall forms, the individual stroke orders, the semantic values, and all of the possible pronunciations of each character. Anatomically, it has been suggested that since kanji discernment depends on multiple dimensions, each of which affect different regions of the brain, that "(r)eading, writing, and semantic comprehension could thus be suggested as likely components of Japanese kanji abilities, distinct from each other but also interacting" (Otsuka & Murai, 2020, p. 2).

It can be unequivocally stated that the predominant method of learning kanji is that of rote repetition (i.e., repeated writing). Not only is the method commonly employed in Japan for children learning kanji (Mori & Shimizu, 2008, 2007; Shimizu & Green, 2002; Sato, 1988), but is also the primary method for learners of L2 (second language) Japanese as well (Gamage, 2003; Okita, 1995). Due to the necessity of memorizing the correct writing sequence of each kanji, this kind of rote drilling is the only viable way to develop the muscle memory required. In fact, kanji-culture individuals are often observed miming in the air with their fingers (i.e., *kusho* [air writing]) when trying to recall the shape of a character. It has been suggested that this motor behavior assists with cognitive processing as a result of visual and kinetic feedback eliciting motoric representations of the kanji in memory (i.e., muscle memory; Itagaki *et al.*, 2015; Matsuo *et al.*, 2003; Sasaki, 1987). The current study will therefore compare the performance of inexperienced learners of L2 Japanese on kanji writing and recognition tests after training on either paper, or on a tablet.

Materials and Methods

Participants

The participants consisted of a total of 32 adults (14 males, 18 females), all speakers of L1 English and employed in Japan as EFL (English as a foreign language) instructors (M_{age} = 25.3 years, *Range* = 22-32 years). Biographical data was collected at the beginning of the study which showed that none of the participants had formal proficiency ratings in the JLPT (Japanese-Language Proficiency Test) and self-reported themselves to be at a novice level in terms of Japanese language and kanji reading/writing ability. According to IRB (internal review board) requirements, all participants were volunteers and informed that they would be contributing to research involving technology's intersection with language learning. No monetary remunerations were distributed, and all participants agreed to join the study voluntarily, in exchange for the opportunity to learn kanji.

Materials and methods

In Japan, students systematically learn prescribed kanji beginning in 1st grade, with a total of 1,026 kanji to be learnt by the end of elementary school (i.e., 6th grade). According to the Ministry of Education guidelines, kanji are presented to students in order of a) frequency of use, b) relevance to children's lives, c) basic radicals (i.e., components) and phonetics, and d) ease of acquisition (Sato, 1988). Of the 191 kanji prescribed for 6th graders, the 24 ten-stroke kanji were selected for the experimental materials (see Appendix A). These kanji were selected as they were considered to be of medium difficulty (as they are introduced in the 6th year of kanji education) and complexity (the kanji that 6th graders learn range from three to 19 strokes). A set of practice flashcards was created for each kanji, which included diagrams indicating the correct stroke order, up to two possible readings of the kanji in roman characters (kanji with more possible readings were reduced to just two; five kanji had only one possible reading), and a single English translation. A second set of assessment flashcards was created – one set of only kanji (with no stroke diagrams) and one set of Japanese readings with English translations.

The researcher met with each participant individually on two consecutive days due to COVID-19 related restrictions on mass gatherings. To control for potential prior knowledge effects, each member was first asked to look at a list of all target kanji and indicate if they knew any of the words. Items #1 (値 - value), #5 (座 - seat), and #10 (秘 - secret) were identified by a single participant each as being somewhat familiar; these kanji were eliminated from the treatment and assessment items for those members, regardless of if they knew the readings/meanings or not. The participants thus reported having zero knowledge of the remaining kanji. Each participant then received 20 kanji flashcards at random, a 10 x 10 sheet of kanji practice paper, and an iPad mini with a first-generation Apple Pencil. The iPad's native Notes app was loaded with a graphic of the kanji practice paper so that participants could use the Apple Pencil to write directly onto it. The size of the iPad mini display and the paper version of the practice sheet (B5-size) were roughly equivalent. The participants followed the stroke order diagrams as described on the flashcards and practiced writing their 20 characters, 10 times each, while attempting to memorize the English translations and Japanese readings. Ten kanji were done on paper, and the other 10 on the iPad mini. While the kanji combinations were randomized, and thus different for each participant, the order of either paper practice first or iPad practice first was controlled by the researcher and appropriately counterbalanced.

Once the practice session was completed, participants submitted all the materials, and an immediate posttest was conducted. The researcher laid out the 20 flashcards with phonetic readings and English meanings that correlated with each person's practice session kanji in a 4 x 5 pattern on the table; they were then tasked with drawing the appropriate kanji on a corresponding answer sheet. There was no time limit for this task. Once the participants indicated that they were finished, the flashcards and answer sheets were collected, and the appropriate 20 kanji assessment flashcards were put out in a similar fashion with a new, blank answer sheet. This time, the participants were asked to write down the Japanese reading of each kanji, along with the correct English translations. At the second session on the following day, the same assessment procedures were conducted without a practice period as a delayed posttest. It should be noted that the participants had not been informed of the delayed posttest (i.e., they did not know that they had to remember the kanji overnight). The participants were not allowed to take any materials from the venue and were not told their scores of either assessment.

Once the delayed posttest was complete, participants completed an original exit questionnaire designed for the study (Appendix C) which sought to elicit their writing medium preferences and identify where participants felt any specific differences existed (if any) between the two. The final item of the survey asked the participants their opinion on whether tablets should be used in the classroom or not.

Results

The practice sheets and answer sheets of each participant were examined and marked to indicate which 10 kanji had been practiced on paper, and which had been on the iPads. For the kanji submissions, each correctly placed stroke was counted as one point (even if the written order was mistaken). As each practice mode (i.e., paper vs. iPad) was comprised of ten kanji with ten strokes each, the maximum score for this section was 100 points per mode. For the English translations, in addition to exact matches, synonyms, or technically accurate responses were counted as correct. For example, Item #19 (降) was taught as [to descend] on the flashcards, but responses such as [go down] were also accepted. This section had a maximum of 10 points. For kanji which had multiple readings, either of the designated responses were accepted (maximum of 10 points), as long as the readings were an exact phonetic match.

All scores were tabulated in IBM's SPSS v.24 (Statistical Package for the Social Sciences) dataset, from which all statistical calculations were performed. Descriptive statistics for both assessments are first presented in Table 1.

Table 1 *Descriptive statistics for posttest and delayed posttest results*

	Paper-based *M (SD)*	**iPad-based** *M (SD)*
Posttest		
Kanji Drawing	39.69 (18.24)	40.81 (16.87)
Japanese Readings	3.88 (2.76)	3.63 (2.73)
English Translation	5.53 (1.78)	4.34 (2.30)
Delayed Posttest		
Kanji Drawing	49.19 (14.35)	39.53 (15.38)
Japanese Readings	3.78 (2.43)	3.47 (2.54)
English Translation	5.38 (1.83)	4.06 (2.30)

Note: Scoring scales - Kanji: (0-100); Reading: (0-10); English: (0-10)

Research Questions 1 & 2

Non-parametric Mann-Whitney U-tests (Tables 2 and 3) were chosen to determine whether the differences between the means shown in Table 1 were of statistical significance as the results of Shapiro-Wilk tests indicated that some of the variables were in non-normal distribution (see Appendix B). While *t*-tests are typically considered to be robust enough to resist violations of normality, the sample size of the current study was beneath the recommended threshold in such situations (i.e., $N < 50$; Lix *et al.*, 1996).

Table 2 *Mann-Whitney U-test output comparing posttest scores (paper vs. iPad)*

Variable	Z	p	η^2
Kanji Drawing	.48	.62	.01
Japanese Readings	.27	.79	< .01
English Translation	2.15*	.03	.15

Note. * indicates significance at the < .05 level

Table 3 *Mann-Whitney U-test output comparing delayed posttest scores (paper vs. iPad)*

Variable	Z	p	η^2
Kanji Drawing	2.50*	.01	.20
Japanese Readings	.48	.63	.01
English Translation	2.35*	.02	.18

Note. * indicates significance at the < .05 level

As shown in Table 2, the only significant difference in means at the posttest between the paper-based and iPad-based kanji was detected in the English translation category. In this metric, the participants were able to recall the English translations of kanji that were practiced on paper by a significantly higher degree than those practiced on iPad ($z = 2.15$, $p = .03$, $\eta^2 = .15$). This eta-squared effect size indicates that 15% of the variability in the English translation scores is accounted for by the medium in which they were practiced. The output of the Mann-Whitney tests for the delayed posttest, however (Table 3), indicated significant differences in both the kanji drawing and English translation scores ($z = 2.150$, $p = .01$, $\eta^2 = .20$; $z = 2.35$, $p = .02$, $\eta^2 = .18$, respectively). In both cases, the participants scored significantly higher on the kanji that were practiced on paper. These results provide the basis to answer the research questions, which asked if the writing medium of practice affected written production (RQ1) or visual recognition (RQ2) abilities, in the affirmative, though with some notable caveats. For visual recognition (in English), paper-based practice resulted in significantly higher results both immediately after training, and after a period of 24 hours. However, visual recognition in Japanese did not show significant differences at either assessment. Similarly, written production ability did not show any statistical differences at the immediate posttest but rose to significance after a 24-hour period. It is worth mentioning that *only* written production of paper-based kanji showed an increase between post- and delayed posttest (see Table 4); all other metrics showed non-significant declines.

Table 4 *Mann-Whitney U-test output comparing posttest-to-delayed posttest scores*

Variable	Z	p	η^2
Paper – Kanji	-2.59*	.01	.22
Paper – Readings	.07	.95	< .001
Paper – English	.26	.80	< .01
iPad – Kanji	.19	.85	< .01
iPad – Readings	.18	.86	< .01
iPad – English	.41	.68	.01

Note. * indicates significance at the < .05 level

Research Question 3

The quantitative results from the exit questionnaire items (Q1 - Q3) are presented in Tables 5 in terms of frequencies; statistical significance and effect sizes are expressed in one-way Chi-square and Cohen's *w* values. Responses to the open-ended questions were coded based on emergent themes, with each comment being deemed *positive* or *negative* for that theme. Statements which contained multiple themes were coded as a single instance of each, as were compound utterances which explicitly indicated positive or negative dispositions (e.g., *I like the feel of writing on paper better because an iPad is too bulky* = one positive for paper haptics and one negative for iPad haptics). These themes and their frequencies are reported in Table 6.

Table 5 *Quantitative responses to exit questionnaires*

Q1 Did you feel that there was any difference between practicing on paper vs. the iPad?						
n	Yes [Freq.]		No [Freq.]	Chi-Square	*p*	*w*
32	29 [90.63%]		3 [9.38%]	21.13***	< .001	.81
Q1a Which medium did you prefer?						
n	Paper [Freq.]		iPad [Freq.]	Chi-Square	*p*	*w*
29	17 [58.62%]		12 [41.38]	.86	.35	.17
Q2 If you could choose, which writing medium would you use to study kanji?						
n	Paper	iPad	Both	Chi-Square	*p*	*w*
32	10 [31.25%]	3 [9.38%]	19 [59.38%]	12.06**	.002	.61
Q3 Do you think schools should allow students to use tablets in the classroom?						
n	Yes	No	No Opinion	Chi-Square	*p*	*w*
32	32 [100%]	0	0	-	-	-

Note: ** indicates significance at the < .01 level
*** indicates significance at the < .001 level

The results of the exit questionnaires indicated that a significant portion of the participants felt that practicing on paper was somehow different from practicing on an iPad ($\chi^2 = 21.13$, $p < .001$, $w = .81$; Table 5). However, participants were statistically evenly divided as to which medium they preferred for practicing (i.e., $p = .35$; Table 5). The reasons given for these preferences varied widely, though major themes which emerged from the open-ended responses were *enjoyment*, *environmental impact*, and *modernity* in support of iPad-based learning, and *cognitive efficacy* and *haptics* in favor of paper-based learning (Table 6). The theme of enjoyment refers to the joy/novelty of using an electric device, while comments on modernity reflected the participants' view that mobile devices are an integral part of daily life in modern times; class time should be no different. Regarding environmental impact, participants lauded the ability to move towards a paper-free classroom to save paper and trees (though the increased need for electricity to power the iPads was notably overlooked). In support of paper-based writing, many participants felt that they learned better/faster on paper. Haptics refers to the perceptual feedback of the Apple Pencil's plastic tip sliding across the iPad's glass screen, as mentioned in Section 2.1. Among the other less numerous comments, *accuracy* (mentioned six times) was raised in terms of both drawing and erasing accuracy. *Ergonomics* was mentioned five times, with some participants stating that they had difficulty resting their wrist/hand on the table while writing on the iPad due the height difference between it and the table. This was perhaps unfortunately exacerbated due to the protective case that the iPad was in, which added another millimeter or so of thickness. However, this was perhaps unavoidable, as even the government-issued tablets under the GIGA School Program are in protective cases, reflecting how tablets are typically used in a practical context. Finally, while *cost* was not a factor in the current study, four participants indicated that as it would be an issue for learners in a classroom, they favored traditional pen-and-paper for studying.

Table 6 *Emergent themes in open-ended responses and their frequencies (Q1 & Q2)*

	Paper (Frequency: *n*)	iPad (Frequency: *n*)
Q1 & Q2 (combined)		
Positive Responses	Cognitive Efficacy (34)	Enjoyment (26)
	Haptics (28)	Environmental Impact (12)
		Modernity (7)
Negative Responses	Environmental Impact (12)	Haptics (28)
		Accuracy (6)
		Ergonomics (5)
		Cost (4)
Q3		
Positive Responses	-	Freedom (27)
		Modernity (18)
		Environmental Impact (12)
		COVID-related (8)
Negative Responses	-	-

Note: Responses with multiple themes were coded as one instance of each.
Responses to Q1 and Q2 are combined, resulting in a larger *n*

While Q1 asked the participants to choose only one medium, Q2 allowed for the option to choose *both* as the medium they would select for kanji practice. In response, a significant portion of the sample indicated that they would use both media if available ($\chi^2 = 12.06$, $p = .002$, $w = .61$; Table 5). The reasons given mostly often mirrored those of Q1; it should be noted that if a student responded with *same as above*, the response was coded as a second instance of the same theme in Table 6. Finally, the responses for Q3 showed unanimous support for schools allowing iPads in the classroom. Major reasons given for this preference were *freedom*, *modernity*, and *environmental impact*. Freedom refers to the participants' belief that students should be permitted to use whatever works best for them and not be forced to limit themselves or their potential. It is worth mentioning that the fourth theme which was observed was that of *COVID-related* factors. In other words, some participants suggested that digital methods of submitting/receiving homework were preferable as being more sanitary – they eliminated the need of physically passing objects around the classroom in order to maintain social distancing.

Discussion

The current study sought to elucidate what effect writing medium (i.e., paper vs. tablet) had on the written production (RQ1) and visual recognition abilities (RQ2) of naïve learners of Japanese kanji. In addition, the subjective opinions of the participants towards the different writing media (RQ3) were explored via a survey of fixed and open-ended questions. This resulted in several notable findings which both extend our understanding of the cognitive impacts of writing media and help inform policy implementations at educational institutions.

First, the finding that written production of kanji was not significantly impacted by the medium of practice at the posttest was surprising. Due to the background research that the different haptics and perceptual feedback of a plastic stylus on a glass tablet was thought to hamper the implementation of automatized writing processes (e.g., Alamargot & Morin, 2015), it was hypothesized that iPad users would show less ability to memorize the strokes of new kanji than their paper-based peers. One possible explanation for this parity is that, as naïve learners, none of the participants had yet automatized kanji writing to any degree. The participants were all L1 English speakers, having no prior experience in logographic writing systems, thus putting them on a level playing field of zero proficiency. However, this hypothesis is unable to explain the significant *increase* in written production ability at the delayed posttest for paper-based writers, while all other metrics for both groups decreased. This result could possibly be seen as implying that there is a differential impact of writing media on the transition of knowledge from working memory to procedural memory, with paper-based practice offering quicker or more effective development of the latter. This is a tantalizing possibility which should be developed by further empirical studies.

With regard to visual recognition of the newly learnt kanji, the results are somewhat ambiguous. While paper-based writers showed greater recollection of the English translation of the kanji at both post- and delayed posttests, neither medium offered a performative advantage when it came to recalling the Japanese vocabulary. However, it is important to note that these two assessments are not perfectly analogous. As naïve learners of L2 Japanese, learning kanji involves both mastering the form and stroke order of kanji itself, along with memorizing an entirely foreign lexical item. In comparison, as speakers of L1 English, it was not necessary to memorize the vocabulary of English translation but merely to link it with the appropriate logographical representation. Essentially, the task of reading the kanji in English was 'easier' than providing the Japanese readings, an assertion that is supported by the data in Table 1 which shows that the participants performed better on the English tasks under all conditions. As such, with the current information available, it is only possible to speculate that the increased difficulties the participants reported with writing on the iPad (i.e., haptics, accuracy, and ergonomics; see Table 6) somehow impeded the mapping of newly learnt visual cues with existing cognitive representations, but not with newly formed ones. Conversely, it might be that writing on paper simply offered an advantage in forming such form-function connections.

Finally, RQ3 brought out several factors which the participants felt helped or hampered their writing processes. It was interesting to observe that while many participants believed that they learnt better on paper, and 17 participants explicitly stated that they preferred the experience of writing on paper, the majority of the sample indicated that they would use both media for studying, if possible (n =19; Table 5, Q2). While not perfectly comparable, this result coincides with precursor research (Lee & Al Khateeb, 2021), which compared paper- versus smartphone-based writing. In that study, paper-based writing was shown to be superior to smartphone input over a number of factors. However, the participants of that study (Saudi Arabian students of L2 English) did not take that conclusion to mean that smartphones in schools should be abandoned, but merely as evidence that more practice time was clearly needed. To be sure, while the development of handwriting occurs gradually over a period of around 10 years (Accardo *et al.*, 2013; Rueckriegel *et al.*, 2008), the participants in both the current and precursor studies did not have nearly that much practice with the relevant digital devices. Future studies clearly need to take this into consideration when developing their study designs and theoretical positions, as digital writers may not have yet reached their full stage of procedural development.

Pedagogical implications

The participants of the current study, all adult practitioners of TESOL (teaching English to speakers of other languages), unanimously agreed with the idea of using tablets in the classroom. While this may have been influenced by the current policy in Japan, in which every student already has a tablet issued by the government, it is nonetheless a vote in support of the concept. As previously mentioned, what this study strongly implies is that writing practice on the tablet is now what is most needed. Given enough practice, students can most likely achieve the same level of motor program automatization as paper-based writing, thus eliminating the largest independent variable which separates the two. Likewise, the participants indicated that they enjoyed using a tablet in the current study, though it should be remembered that the average age of the participants was 25.3 years old (see Section 3.1). It is not clear whether the novelty of digital devices still holds for younger children who have been exposed to tablets since birth, though it is presumably so. Schools might seek to capitalize on this inherent interest and engagement factor (e.g., Clark & Dugdale, 2009) by perhaps transitioning more tedious tasks, such as rote kanji drills, to digital devices.

Limitations and future directions

As mentioned at various points throughout this article, the current study was limited in several ways. Some of the issues are related to the population sample, all TESOL instructors who currently reside in Japan, which gives them a slight bias in terms of their professional interest in the topic and varying degrees of incidental exposure to kanji in their daily lives. However, the major limitation of the current study must be the current inability of researchers to rate a participant's current stage of writing proficiency. On paper, it can be assumed that any participant over the age of 15 has reached the final developmental stage of motor program automatization in their native language. However, as the current study asked alphabetic-based L1 speakers to write in a logographic L2, it is unclear whether the factor of writing proficiency was sufficiently controlled for. Future studies could possibly improve in this area by keeping the two writing systems the same, for example, L1 English and L2 Arabic (both alphabetic) or L1 Japanese and L2 Chinese (both logographic). While this would level the field in terms of writing system, the slight regression to a lower level of writing proficiency on a tablet (see Section 2.1) needs to be fully quantified before it can be controlled for.

One of the most interesting results of the current study was that kanji written production ability increased significantly from the posttest to delayed posttest for paper-based kanji only. This is certainly an avenue which deserves further study. As the delayed posttest was only 24 hours after the posttest, it would be interesting to see how the factor of time interacted with performance. With the current data available, it is not clear whether the formation of procedural memory for tablet-based kanji was limited, or merely needed a bit more time to develop. Similarly, it is unclear to what degree the increased performance for paper-based kanji is able to be retained over time. Future studies should therefore consider adding additional delayed posttests at various intervals to map the decay in performance memory for both groups.

Conclusion

For decades, comparisons between writing media have been narrowly restricted to the dichotomy of keyboard-based typing and paper-based handwriting. However, with digital devices such as tablets and smartphones achieving massive levels of penetration in both homes and schools worldwide, it is imperative that we understand how the adoption of these devices impacts students' learning outcomes. The current study sought to contribute to the knowledge base in two ways: a) by quantitatively investigating how writing medium affected the written production and recognition abilities of Japanese kanji among naïve speakers of L1 English, and b) by qualitatively investigating learners' emotive dispositions towards the use of tablets for language-learning drills. The results suggested that paper-based practice confers some degree of advantage to learners in recognition ability, with an advantage in production ability arising over time. Nevertheless, the participants of the study indicated their interest and willingness to use tablets for studying activities, unanimously agreeing that schools should allow tablets to be used in the classroom. The takeaway from this study should be that students may be willing to put in the time and effort to become proficient at tablet-based writing, just as every child currently practices handwriting over a period of ten years before becoming fully adept.

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Appendices

Appendix A – List of tested kanji (Grade 6, 10-stroke)

1. 値 – value, chi, atai
2. 射 – shoot, sha, i
3. 将 – commander, shou, hata
4. 展 – expand, ten, no
5. 座 – seat, za, suwa
6. 従 – to accompany, jyu, shitaga
7. 朗 – bright, rou, hoga
8. 株 – stock, shu, kabu
9. 班 – group, han, wa
10. 秘 – secret, hi
11. 納 – to receive, nou, osa
12. 純 – innocent, jyun, kiito
13. 胸 – chest, kyou, mune
14. 蚕 – silkworm, san, kaiko
15. 討 – to chastise, tou, u
16. 針 – needle, shin, hari
17. 骨 – bone, kotsu, hone
18. 除 – remove, jo, nozo
19. 降 – to descend, kou, o
20. 恩 – grace, on
21. 党 – political party, tou
22. 俳 – actor, hai
23. 俵 – straw bag, hyou, tawara
24. 陛 – majesty, hei

Appendix B – Shapiro-Wilk Test Output

Table 7 *Shapiro-Wilk normality of distribution output*

	Paper			iPad		
Variable	**Statistic**	***df***	***p***	**Statistic**	***df***	***p***
Posttest						
Kanji	.90*	31	.005	.95	31	.19
Reading	.90*	31	.007	.90*	31	.007
English	.88*	31	.002	.93*	31	.03
Delayed Posttest						
Kanji	.95	31	.20	.93	31	.05
Reading	.90*	31	.008	.92*	31	.02
English	.90*	31	.005	.93	31	.05

Note. ** Indicates significance at the < .001 level

Appendix C – Exit Questionnaires

1) Did you feel that there was any difference between practicing on paper vs. the iPad?
   a. Yes b. No
   i. (Only if you answered YES) Which writing medium did you prefer?
      a. Paper b. iPad
   ii. Why?
      ____

2) If you could choose, which writing medium would you use to study kanji?
   a. Paper b. iPad c. Both
   i. Why?
      ____

3) Do you think schools should allow students to use tablets in the classroom?
   a. Yes b. No c. No opinion
   i. Why?
      ____