Castledown

OPEN ACCESS

Technology in Language Teaching & Learning
ISSN 2652-1687
https://www.castledown.com/journals/tltl/

Technology in Language Teaching & Learning, 6(1), 1–14 (2024)
https://doi.org/10.29140/tltl.v6n1.1067

Transitioning from Paper to Touch Interface: Phoneme-Grapheme Recognition Testing and Gamification in Primary School Classrooms

LISHI LIANG[a]

W. L. QUINT OGA-BALDWIN[b]

KAORI NAKAO[c]

LUKE K. FRYER[d]

ALEX SHUM[e]

[a]*University of Hong Kong, Hong Kong*
lsliang131@gmail.com

[b]*Waseda University, Japan*
quint@waseda.jp

[c]*Seinan Gakuin University, Japan*
k-nakao@seinan-gu.ac.jp

[d]*University of Hong Kong, Hong Kong*
fryer@hku.hk

[e]*University of Hong Kong, Hong Kong*
alexshum@hku.hk

Abstract

Phonological processing of written characters has been recognized as a crucial element in acquiring literacy in any language, both native and foreign. This study aimed to assess Japanese primary school students' phoneme-grapheme recognition skills using both paper-based and touch-interface tests. Differences between the two test formats and the relationship between phoneme-grapheme recognition skills and interaction with digital tests were investigated. We hypothesized a relationship between paper test performance and digital item performance. Participants were sixth-grade students from two public schools. The results of comparison tests indicated that the touch-interface test had lower success rates compared to the paper-based test for most items, suggesting a difference in performance patterns. A consistent relationship between phoneme-grapheme knowledge tested on paper and successful digital

interaction was found. Findings highlight the potential of touch-interface assessments for assessing phoneme-grapheme recognition skills in primary school classrooms and suggest incorporating more digital tasks to enhance student adaptation.

Keywords: digital testing, elementary school, phoneme-grapheme recognition, decoding

Introduction

Acquiring literacy in a foreign language requires an understanding of the new language's phonology (Melby-Lervåg & Lervåg, 2014). Children who have already developed literacy skills in one language may experience interference from their prior linguistic expectations, hindering their acquisition of the new language (van Daal & Wass, 2017). Thus, learning to read in an alphasyllabic language after a non-alphasyllabic language requires connecting the sounds to the written symbols (McBride-Chang et al., 2013). Children who struggle with connecting the sounds to the letters in the new language will continue to have difficulties with literacy (Moll et al., 2014). As a necessary precursor to mastering sound-letter correspondence (Bedewy, 2020), phonological awareness is a crucial aspect of learning to read in a foreign language, specifically English, although it is not enough to ensure literacy (Moll et al., 2014).

Research has identified some universal elements in learning to read an alphasyllabic language such as English (Nag & Snowling, 2012). The act of reading in any language requires some degree of phonological processing (Leinenger, 2014). One main aspect of phonological processing is storing and retrieving sound-based information (Dally, 2006), which could not be achieved without associating sounds with their written forms. The connection between sounds and letters is essential in most European languages using an alphasyllabic system (Moll et al., 2014). Thus, the process of learning to read in a new language can be seen as mapping a new set of phonemic principles to written characters (Moll et al., 2014).

One complicating issue in the modern world is the question of how learners interact with written texts in digital formats. The increasing frequency with which children interact with digital materials, accelerated by interventions to provide continued learning opportunities during the COVID-19 pandemic, creates a natural question as to the effect of interacting with written versus digital texts and activities. Though some claim physical materials offer apparent cognitive benefits (cf. Mueller & Oppenheimer, 2014), better evidence shows no meaningful differences in mode of presentation and interaction (Voyer et al., 2022). Without existing hypotheses for the superiority of one modality over the other, we suppose that there are measurable performance effects when transitioning activities for teaching phoneme-grapheme correspondence from the physical to digital worlds, as have been found in other differentiated modalities of tests (cf. Roediger et al., 2017; Tulving & Thomson, 1973). This paper addresses the question of differences in learners‘ experience of paper-based and tablet-based materials for assessing phoneme-grapheme recognition in English.

Background

Phonological Processing

The development of literacy in any language involves a balance of skills that are specific to the language being learned. When learning an alphabetic language, one critical component of developing literacy is phonological awareness, which refers to an understanding of how speech is broken down

into individual sounds and how those sounds can be combined to form words (Bedewy, 2020; Kahn-Horwitz et al., 2012). A second step is the acquisition of sound-letter correspondences (Siegelman et al., 2020), which is regarded as a universal element in learning to read alphabetic scripts (Shankweiler & Fowler, 2019). Young learners first develop some level of phonological awareness (Melby-Lervåg et al., 2012), and then use that knowledge to create phoneme-grapheme correspondences, such as associating the sound [d] with the letter "d" in English.

The process of acquiring literacy in a foreign language may involve recognizing and decoding individual sound units and connecting them to visual representations in transparent phoneme-grapheme languages like Finnish and Korean (e.g., Silinskas et al., 2020; Wang et al., 2009), or mapping sounds onto logograms in opaque logographic languages like Chinese (e.g., Inoue et al., 2023). As an alphabetic language, English falls somewhere in between, with elements of mapping sound through memorization of lexical units as well as decoding words through semi-regular sound units (McBride et al., 2022). First (L1) and second (L2)/foreign language phonological abilities are highly correlated in alphabetic languages (Melby-Lervåg & Lervåg, 2014). L1 reading has been shown to significantly predict L2 reading performance in children learning to read (Caravolas et al., 2019), with some transfer of skills across languages (Arfé & Danzak, 2020). These skills are considered teachable (Castles et al., 2018), with children responding positively to instruction across diverse L1s (McArthur et al., 2018).

Elementary school foreign language curricula are designed to develop the foundational skills that later lead to literacy and other language abilities (Shin & Crandall, 2013). Despite the general agreement on the central role of phonology in developing literacy in foreign language learning (Koda & Yamashita, 2019; Yamashita, 2022), the process of acquiring phoneme-grapheme correspondence in foreign language learning environments remains an under-researched issue (Arfé & Danzak, 2020; Castles et al., 2009). Further research is necessary to clarify the process of letter-sound recognition in young foreign language learners and to improve curricula to support it effectively.

Digital vs. Paper Based Modalities for Learning Materials

Studies have shown varied results regarding the effects of digital and paper-based learning materials. Some studies found that different learning modalities do not influence students' learning outcomes. Most recently, meta-analytic findings have revealed that reading and note-taking from either digital or paper-based modalities showed very little difference in promoting or preventing student retention of information (Voyer et al., 2022). Empirical evidence has found no differences in reading comprehension and reading speed between digital and paper-based materials, in both academic and non-academic reading (Margolin et al., 2013). On the other hand, many other studies found that digital and paper-based modalities could lead to different learning outcomes. Most researchers claim that paper-based learning outperforms digital learning. Advantages for reading comprehension (Kong et al., 2018; Mueller & Oppenheimer, 2014), retention and recall of materials (Mangen et al., 2013), and metacognition (Clinton, 2019) when reading from paper compared to reading from a screen were revealed. At the same time, digital learning has its advantages. It increases the availability and flexibility to assess learning resources (Valentine et al., 2017), as well as motivation, self-regulation, and self-efficacy (Halamish & Elias, 2022; Xodabande et al., 2023). Meanwhile, digital materials have pedagogical affordances that paper-based materials do not. A paper-based task can hide a degree of guessing that students might do, leaving out false starts and mistaken answers to common traps, while digital materials can log each click and error in real time (Mayer, 2002; Piper & Hollan, 2009). Students with greater ability may thus perform better on less forgiving multimedia tasks that record each error, while students with lower ability scores may be able to hide this on paper tasks.

More recent work has indicated that the effectiveness of paper-based versus digital materials may depend on the tasks being performed and the preferences of the individual. Bernard et al. (2018) found that reading on paper led to better comprehension for narrative texts, while reading on a screen led to better comprehension for expository texts. Another study by Margolin et al. (2013) found that individual preferences played a role in whether paper or digital materials were more effective for a given task. As previous research on the topic of digital and paper-based materials remains controversial, it is necessary to continuously examine whether alternative digital materials allow students to learn as effectively as traditional paper versions.

Aims

This study aimed to assess Japanese primary school students‘ phoneme-grapheme recognition skills as they perform on paper and using a bespoke touch-interface web platform. In this study, students completed two tests of phoneme-grapheme awareness: one paper-based and one digital. The initial paper-based test is intended to provide a baseline result to look at performance differences and similarities in the implementation of digital materials. The study was designed to address two research questions and test one hypothesis.

Research Question 1 (RQ1): What pattern of differences is there between students’ prior paper-based and the current touch-interface-based assessment of their phoneme-grapheme recognition skills?

Research Question 2 (RQ2): What is the relationship between students’ paper-based phoneme-grapheme recognition skills and their digital modality interaction with the same phoneme-graphemes?

Hypothesis 1 (H1): Students with higher prior phoneme-grapheme recognition skills were expected to perform better on digitally assessed phoneme-grapheme items than those presenting lower skills previously.

Recognizing that though test-retest performance is best predicted by a similar modality of testing (Roediger et al., 2017; Tulving & Thomson, 1973), we should still expect similarity in performance on linked items testing a similar phenomenon (Carr, 2011).

Methods

Participants

Participants were sixth-year students (n = 153) at two public primary schools: one in the Fukuoka region (n = 105) and one in Tokyo (n = 48). All students were between the ages of 11 and 12. Gender and student names were not recorded as a part of the study. Students were tracked using an anonymized system provided by the schools/boards of education. The Tokyo sample was used for paper/touch interface comparisons, while the combined sample was used for descriptive statistics, tests, and gamification correlations.

Both schools were located in urban areas, primarily serving residential districts. The racial and ethnic demographics of the students followed the national pattern in Japan, with over 98% being ethnically Japanese and Japanese being their home language. None of the students included in the sample indicated English as their home language.

This current study employed a convenience sample obtained through meetings with the school principal and teachers. Research permission was granted by the boards of education. Student participation in the

study was voluntary. Ethical oversight was included in the review process for the JSPS Grant-in-aid for Scientific Research. All procedures were in accordance with the ethical standards of the national research committee.

Procedures

Paper tests. During a guest lesson conducted by the second author, students in Tokyo participated in a test assessing their ability to recognize initial sound-letter correspondence. The test employed a paper-based format and included fifteen items sourced from the Ministry of Education, Culture, Sports, Science and Technology (MEXT) assigned textbook for third-grade students (MEXT, 2017). Test items were selected from a list of items rated from easy to difficult by the participating native Japanese teachers and researchers. The list of test items is presented in Appendix 1. To record their responses, students utilized an optical mark reader (OMR) sheet, which featured options A to Z for selecting the corresponding letters and "?" to indicate "I don't know." The decision to present the choices in capital letters aimed to enhance students' recognition and facilitate their reporting process. Previous studies (Nakao et al., 2022) have corroborated the efficacy of employing this testing format in similar educational settings.

In Fukuoka, the paper test was administered by the native Japanese teacher of English who taught at the elementary school where the study took place. The participating teacher played a standardized recording of each item. The students selected the letter on the test sheet after hearing each of the fifteen target words. The teachers and researchers distributed and collected test papers for all classes. The test took between six to nine minutes to complete. The paper test in Fukuoka was the same as the paper test delivered in Tokyo.

Digital tests. Students in Tokyo were presented with the digital test during their morning classroom activities. Students logged in anonymously using tablet computers provided by the school (MEXT, 2021). After logging in, students were given 10 minutes to complete the game tasks, review their results, and log out.

As with paper-based tests, the digital tasks involved identifying initial sounds for 15 test items. Students were presented with an audio-only representation of the word and were then asked to identify the correct starting sound using alphabet characters. Students could listen to the sound up to three times by pushing a button and then select the correct starting sound-letter from a series of choices. Sound files were updated with new voice recordings for the digital tests. Correct and incorrect answers were presented immediately. An example activity is presented in Figure 1.

Figure 1 *A Model of the Digital Tasks Students Completed.*

Analyses

At the first stage, the data was reviewed to address potential missing data. This was followed by the calculation and review of descriptive statistics, including test means, standard deviations, skewness/kurtosis, and reliability (Cronbach's Alpha). Subsequent analysis was undertaken to address each of the two research questions. For RQ1, the probability of success for the same word and the same grapheme-phoneme (paper vs touch interface) was calculated and graphed to present the two patterns of success side by side. For RQ2, the pairwise relationship between students' initial performance on the touch interactive grapheme-phoneme test and their subsequent digital-medium performance with the same words or the same grapheme-phonemes was examined.

Results

Touch Interactive Test Mean, SD, Normality, Reliability

Due to the online administration of the test and gamification, no missing data were present in the data from the phoneme-grapheme study software platform. The mean score on the 15-item touch interactive test was relatively high, demonstrating a reasonable standard deviation and normal distribution (Table 1). Given the test's short length, it showed relatively high reliability.

Research Question 1

Addressing research question one, Tables 1 and 2 present the probability of success for students on the paper versus the touch interactive test of the same words (Table 1) and the same grapheme-phonemes but different words (Table 2). With the exception of the words "want" and "egg," the students' probability of success was lower, and in many cases, much lower for the touch interactive test than for the paper test. Figures 2 and 3 indicate the changes in performance visually. Figure 2 shows the drop in performance for the same items, while Figure 3 shows the drop in performance with the differing sounds.

Research Question 2 and Hypotheses 1

As can be observed in Table 2, there were small to moderate relationships between students' success on the digital-medium phoneme-grapheme items and the previously tested paper test. Overall, these results confirm a reasonable and consistent relationship between previously tested phoneme-grapheme knowledge on paper and successful digital-medium interaction.

Table 1 *Descriptive Statistics and Reliability for Touch Interactive Test*

Descriptive Statistics and Reliability	Paper Test	Touch Interactive Test
Mean	11.98	11.34
Standard Deviation	3.78	3.77
Skew	–.51	–0.51
Kurtosis	2.65	–0.9
Cronbach's Alpha	0.77	0.86

Table 2 *Correlation Between 8 Digital Word Phoneme-Graphemes and Paper Test of Phoneme-Grapheme Matching*

Digital Word	By Variable	Correlation	Lower 95%	Upper 95%	Signif Prob
Hot	Paper Test	0.21	0.05	0.36	0.0127*
Office	Paper Test	0.26	0.09	0.41	0.0023*
Inside	Paper Test	0.27	0.10	0.42	0.0017*
Bag	Paper Test	0.36	0.21	0.50	<.0001*
Wash	Paper Test	0.40	0.25	0.54	<.0001*
Jam	Paper Test	0.42	0.28	0.55	<.0001*
Down	Paper Test	0.52	0.38	0.63	<.0001*

Note. *$p < .05$.

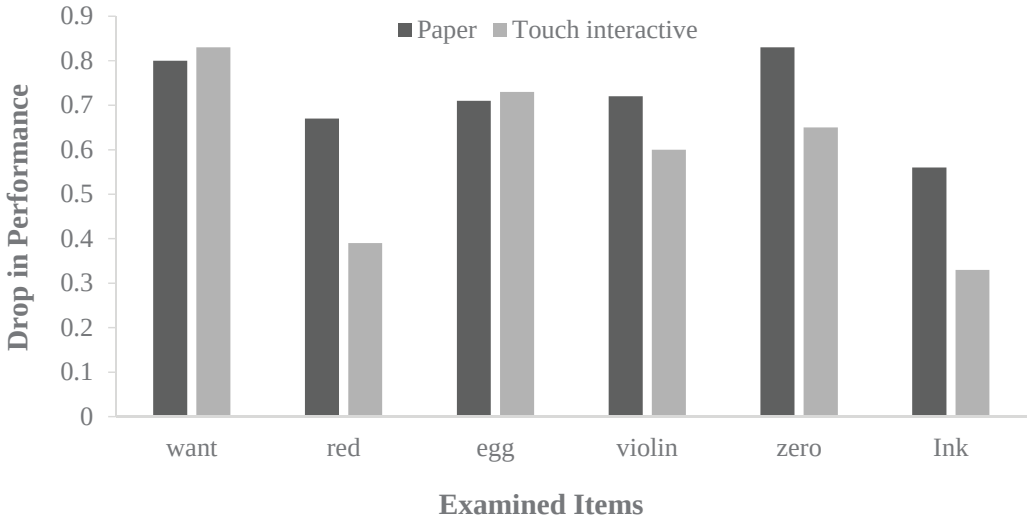

Figure 2 *Overlapping Words on Paper and Touch Interactive Tests.*

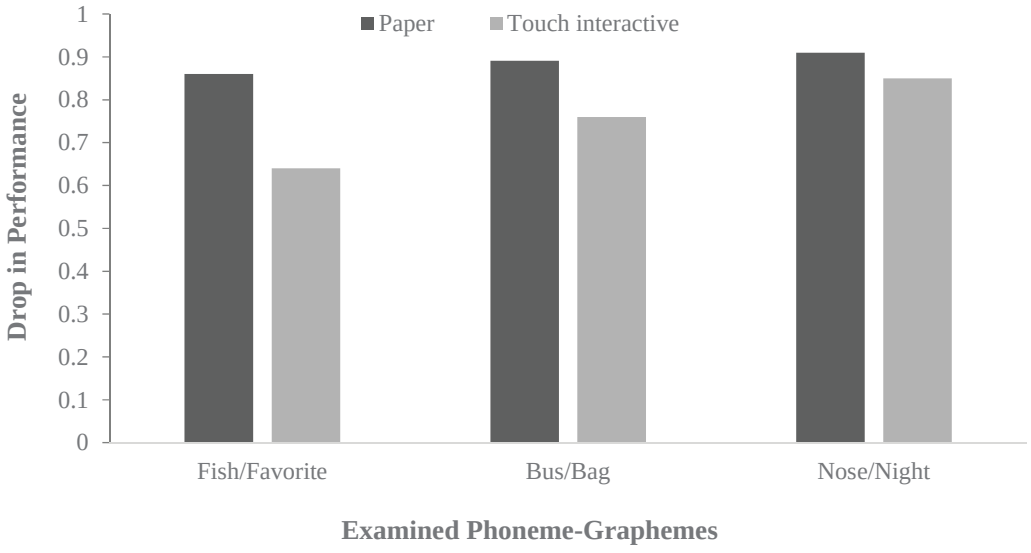

Figure 3 *Overlapping Phoneme-Graphemes on Paper and Touch Interactive Tests.*

Discussion

Japanese elementary school students' phoneme-grapheme recognition was assessed using a touch-interface web platform in the current study. The study aimed to explore the differences and connections between previous paper-based tests and the current touch interactive test. Descriptive statistics indicated a reasonable standard deviation and normal distribution, suggesting high reliability of the touch interactive test. The study focused on two research questions and proposed one hypothesis.

The first research question (RQ1) aimed to identify the pattern of differences between students' performance in the previous paper-based test and the current touch-interface-based assessment of their phoneme-grapheme recognition skills. Analyses were conducted to examine the probability of success for the same word and same phoneme-grapheme in both paper-based and touch interactive tests. The results revealed that, in most cases, students had a lower probability of success in the touch interactive test compared to the paper test, regardless of whether it was the same word or the same phoneme-grapheme. However, two exceptions were observed: the words "want" and "egg" showed higher probabilities of success in the touch interactive test.

The second research question (RQ2) explored the relationship between students' phoneme-grapheme recognition skills and their digital interaction with the same phoneme-graphemes. Hypothesis one (H1) proposed that students with higher overall phoneme-grapheme recognition skills would perform better on digital phoneme-grapheme items. The pairwise correlation analysis between students' phoneme-grapheme knowledge and successful digital interaction yielded statistically significant and positive results, confirming H1.

Theoretical Implications

Can simple touch interactive tests assess students' phoneme-grapheme recognition skills?

The current study confirms that even a very short touch interactive test conducted by teachers in primary school classrooms can effectively assess the phoneme-grapheme recognition skills of sixth-grade students. The touch interface demonstrates reliability for standard classroom applications. This finding aligns with the ongoing trend of transitioning to digital modalities in education (Halamish & Elias, 2022). As educators strive to find more efficient and convenient ways to capture students' language learning progress, the touch interface is likely to play an increasingly significant role. These study findings can contribute to the broader implementation of mobile-assisted learning, where researchers can further explore the potential benefits of using touch interface technology.

Does the touch interface yield equivalent results to paper when assessing students' phoneme-grapheme recognition skills?

The results reveal that, in most cases, a paper-based assessment still outperforms its digital counterpart, which is consistent with previous research (e.g., Kong et al., 2018). One possible explanation for the disparity between paper and touch interface assessments found in this study is the less forgiving nature of digital tasks. A digital task records each press and error in real-time, whereas a paper-based task can mask certain guessing behaviors that students might engage in (Piper & Hollan, 2009). When encountering less frequently encountered initial sounds in Japanese, such as /r/ and /l/ (So & Best, 2010), students with lower learning abilities may struggle more in digital tasks that track all errors. However, as students gradually become more familiar with digital devices (Björngrim et al., 2019), the touch interface has the potential to revolutionize the way teachers assess students' linguistic skills by providing a more detailed understanding of their learning process.

Practical Implications

What could be a simple and effective way to assess students' phoneme-grapheme recognition skills in Japanese primary school classrooms?

The present study suggests that a touch interface could serve as a reliable tool for assessing primary school students' phoneme-grapheme recognition skills. Since 2020, the Japanese government has provided personal tablets to all public elementary and junior high school students to support their learning (MEXT, 2021). The accessibility of touch interfaces makes it feasible to incorporate them into the existing curriculum. However, it is important to be cautious about the potential challenges a touch interface may introduce. Students may experience difficulties and increased cognitive load when using a touch interface (Jeong, 2014; Kong et al., 2018). Educators should provide adequate introductions and instructions to students when implementing touch interfaces in classrooms.

Another possible explanation is that digital tests are more sensitive to errors in the moment, both in terms of comprehension and interaction with the tablets. In this digital test, answers were recorded as soon as students touched a letter, while students had the opportunity to go back, erase, and correct answers on the paper-based test. Consequently, any difficulties in understanding that students encountered during their initial interaction with a test item were more likely to be captured with digital materials, whereas paper-based materials might allow students to present their "best performance." In other words, students may conceal their mistakes and misunderstandings on paper but provide a more accurate real-time indication of their skills using digital materials.

How can we address students' weaker performance on specific phoneme-graphemes?

One crucial finding from the current study is that students tend to perform worse on touch interactive tasks for certain phoneme-graphemes, such as /r/ and /l/. Building upon the cross-language perception of non-native tonal contrasts, previous studies have confirmed that some phoneme-graphemes are more challenging for native Japanese speakers to master (So & Best, 2010). For example, perceiving the English /r/ – /l/ distinction is more difficult for them because these phonemes are not contrastive in Japanese phonology (Best & Strange, 1992). For second language educators in Japan, it is crucial to identify those phoneme-graphemes that are more challenging for Japanese learners and consider using visually or spatially distinct methods to reinforce the differentiation between them. The touch interface could be a powerful teaching tool as it combines both acoustic and visual information.

When implementing touch interactive assessments in classrooms, what can teachers do to help students adapt to the new assessment format more quickly?

One key implication for teachers arising from the current study is the congruency between the study phase and the test phase. The differences in results between paper-based and touch interactive tests found in the current study could be attributed to the incongruity between the study materials and the test format. Currently, students do not acquire phoneme-grapheme knowledge through digital modalities. Previous research has demonstrated that there is better retention of learning content when the learning context is similar to the testing context, known as the encoding-specific principle (Roediger et al., 2017; Tulving & Thomson, 1973). For instance, people tend to remember the content they have studied better when the background properties are present during learning. Consistent with the encoding-specific principle, teachers could incorporate more digital tasks into their lessons to promote students' adaptation to touch interactive tests.

Limitations and Future Directions

While the results indicate potential differences in performance when transitioning from a traditional paper-based test format to online digital tools, it is important to consider the sample size. The comparisons in the pre-post analysis only involved two classes from a single school, so caution must be exercised when assessing the generalizability of these findings. However, the consistency of the digital results across two different cities in different regions of Japan suggests that similar performance can be expected when using digital materials. The variable that remains unknown is the comparison with prior performance using paper tests. Future comparative studies will be necessary to validate and explore the differences and similarities between students' performance on paper and digital tests.

Conclusions

Phonological processing skills form a fundamental part of literacy training. Japanese students in this study showed differences in performance on certain phonological items between paper-based and digital learning modalities. The study confirms that short touch interactive tests conducted by teachers can effectively assess sixth graders' phoneme-grapheme recognition skills in primary school classrooms. Digital tests provide a more detailed picture of students' learning but may impede performance and require additional attention and cognitive load. The accessibility of touch interfaces in Japanese classrooms can offer significant instructional benefits, provided teachers offer sufficient introductions and instructions when using touch interfaces. To help students adapt to touch interactive assessments, teachers should ensure congruency between study and test formats when incorporating digital assessments in the classroom.

Acknowledgement

This work was supported by a JSPS Grant-in-Aid for Scientific Research (Activity Start-up, No.19K23093). We thank the students and teachers of the school that participated in this research and thank Toshiaki Ichii and Hisako Yamaguchi for their assistance with testing. This work was also partially supported by a JSPS International Fellowship grant (S20135) and JSPS Grants-in-Aid for Scientific Research (21K00777 and 23H00647)).

References

Arfé, B., & Danzak, R. L. (2020). The influence of first language spelling and response inhibition skills on English-as-an-additional-language spelling. *Cognitive Development, 56*, 100952. https://doi.org/10.1016/j.cogdev.2020.100952

Bedewy, D. (2020). The effect of phonemic awareness on EFL word recognition in a sample of Arabic native preschool children speakers. *Psychology and Education, 57*(2), 137–142. http://psychologyandeducation.net/pae/index.php/pae/article/view/128/81

Bernard, M., Mills, C., Swanson, T., & Storrer, K. (2018). The effects of screen vs. print reading on reading comprehension: A meta-analysis. *Journal of Educational Research, 111*(5), 569–580. https://doi.org/10.1080/00220671.2016.1160995

Best, C. T., & Strange, W. (1992). Effects of phonological and phonetic factors on cross-language perception of approximants. *Journal of Phonetics, 20*(3), 305–330. https://doi.org/10.1016/S0095-4470(19)30637-0

Björngrim, S., van den Hurk, W., Betancort, M., Machado, A., & Lindau, M. (2019). Comparing traditional and digitized cognitive tests used in standard clinical evaluation—A study of the digital application Minnemera. *Frontiers in Psychology, 10*, 2327. https://doi.org/10.3389/fpsyg.2019.02327

Caravolas, M., Lervåg, A., Mikulajová, M., Defior, S., Seidlová-Málková, G., & Hulme, C. (2019). A Cross-linguistic, longitudinal study of the foundations of decoding and reading comprehension ability. *Scientific Studies of Reading, 23*(5), 386–402. https://doi.org/10.1080/10888438.2019.1580284

Carr, N. T. (2011). *Designing and analyzing tests.* Oxford.

Castles, A., Coltheart, M., Wilson, K., Valpied, J., & Wedgwood, J. (2009). The genesis of reading ability: What helps children learn letter–sound correspondences? *Journal of Experimental Child Psychology, 104*(1), 68–88. https://doi.org/10.1016/j.jecp.2008.12.003

Castles, A., Rastle, K., & Nation, K. (2018). Ending the reading wars: Reading acquisition from novice to expert. *Psychological Science in the Public Interest, 19*(1), 5–51. https://doi.org/10.1177/1529100618772271

Clinton, V. (2019). Reading from paper compared to screens: A systematic review and meta-analysis. *Journal of Research in Reading, 42*(2), 288–325. https://doi.org/10.1111/1467-9817.12269

Dally, K. (2006). The influence of phonological processing and inattentive behavior on reading acquisition. *Journal of Educational Psychology, 98*(2), 420–437. https://doi.org/10.1037/0022-0663.98.2.420

Halamish, V., & Elias, D. (2022). Digital versus paper-based foreign-language vocabulary learning and testing: A study-test medium congruency effect. *Computers & Education, 190,* 104606. https://doi.org/10.1016/j.compedu.2022.104606

Inoue, T., Zheng, M., Lui, K. F. H., McBride, C., & Ho, C. S.-H. (2023). Early literacy acquisition in logographic orthographies: Evidence from Chinese and Japanese. *Early Childhood Research Quarterly, 63,* 73–84. https://doi.org/10.1016/j.ecresq.2022.11.009

Jeong, H. (2014). A comparative study of scores on computer-based tests and paper-based tests. *Behaviour & Information Technology, 33*(4), 410–422. https://doi.org/10.1080/0144929X.2012.710647

Kahn-Horwitz, J., Sparks, R. L., & Goldstein, Z. (2012). English as a foreign language spelling development: A longitudinal study. *Applied Psycholinguistics, 33*(2), 343–363. https://doi.org/10.1017/S0142716411000397

Koda, K., & Yamashita, J. (2019). *Reading to learn in a foreign language: An integrated approach to foreign language instruction and assessment.* Routledge.

Kong, Y., Seo, Y. S., & Zhai, L. (2018). Comparison of reading performance on screen and on paper: A meta-analysis. *Computers & Education, 123,* 138–149. https://doi.org/10.1016/j.compedu.2018.05.005

Leinenger, M. (2014). Phonological coding during reading. *Psychological Bulletin, 140*(6), 1534–1555. https://doi.org/10.1037/a0037830

Mangen, A., Walgermo, B. R., & Brønnick, K. (2013). Reading linear texts on paper versus computer screen: Effects on reading comprehension. *International Journal of Educational Research, 58,* 61–68. https://doi.org/10.1016/j.ijer.2012.12.002

Margolin, S. J., Driscoll, C., Toland, M. J., & Kegler, J. L. (2013). E-readers, computer screens, or paper: Does reading comprehension change across media platforms?: E-readers and comprehension. *Applied Cognitive Psychology, 27*(4), 512–519. https://doi.org/10.1002/acp.2930

Mayer, R. E. (2002). Multimedia learning. In B. H. Ross (Ed.), *Psychology of Learning and Motivation, 41,* 85–139. https://doi.org/10.1016/s0079-7421(02)80005-6

McArthur, G., Sheehan, Y., Badcock, N. A., Francis, D. A., Wang, H.-C., Kohnen, S., Banales, E., Anandakumar, T., Marinus, E., & Castles, A. (2018). Phonics training for English-speaking poor readers. *Cochrane Database of Systematic Reviews, 2018*(11). https://doi.org/10.1002/14651858.CD009115.pub3

McBride, C., Pan, D. J., & Mohseni, F. (2022). Reading and writing words: A cross-linguistic perspective. *Scientific Studies of Reading, 26*(2), 125–138. https://doi.org/10.1080/10888438.2021.1920595

McBride-Chang, C., Shu, H., Chan, W., Wong, T., Wong, A. M.-Y., Zhang, Y., Pan, J., & Chan, P. (2013). Poor readers of Chinese and English: Overlap, stability, and longitudinal correlates. *Scientific Studies of Reading, 17*(1), 57–70. https://doi.org/10.1080/10888438.2012.689787

Melby-Lervåg, M., & Lervåg, A. (2014). Reading comprehension and its underlying components in second-language learners: A meta-analysis of studies comparing first- and second-language learners. *Psychological Bulletin, 140*(2), 409–433. https://doi.org/10.1037/a0033890

Melby-Lervåg, M., Lyster, S.-A. H., & Hulme, C. (2012). Phonological skills and their role in learning to read: A meta-analytic review. *Psychological Bulletin, 138*(2), 322–352. https://doi.org/10.1037/a0026744

MEXT. (2017). *Shogakkou gakushuu shidou youryou kaisetu: Gaikokugokatsudou/gaikokugohen [Elementary school curriculum guidelines: Foreign language activities/foreign language]. MEXT.* https://www.mext.go.jp/content/20201029-mxt_kyoiku01-100002607_11.pdf

MEXT. (2021). *GIGA sukuru koso-no jitsugen-ni tsuite [The realization of the GIGA School Concept].* https://www.mext.go.jp/a_menu/other/index_00001.htm

Moll, K., Ramus, F., Bartling, J., Bruder, J., Kunze, S., Neuhoff, N., Streiftau, S., Lyytinen, H., Leppänen, P. H. T., Lohvansuu, K., Tóth, D., Honbolygó, F., Csépe, V., Bogliotti, C., Iannuzzi, S., Démonet, J.-F., Longeras, E., Valdois, S., George, F., … Landerl, K. (2014). Cognitive mechanisms underlying reading and spelling development in five European orthographies. *Learning and Instruction, 29,* 65–77. https://doi.org/10.1016/j.learninstruc.2013.09.003

Mueller, P. A., & Oppenheimer, D. M. (2014). The pen is mightier than the keyboard: Advantages of longhand over laptop note taking. *Psychological Science, 25*(6), 1159–1168. https://doi.org/10.1177/0956797614524581

Nag, S., & Snowling, M. J. (2012). Reading in an alphasyllabary: Implications for a language universal theory of learning to read. *Scientific Studies of Reading, 16*(5), 404–423. https://doi.org/10.1080/10888438.2011.576352

Nakao, K., Oga-Baldwin, W. L. Q., & Fryer, L. K. (2022). Phonemic awareness as fundamental listening skill: A cross-sectional, cohort study of elementary foreign language learners. *The Journal of Asia TEFL, 19*(2), 609–618. http://dx.doi.org/10.18823/asiatefl.2022.19.2.13.609

Piper, A. M., & Hollan, J. D. (2009). Tabletop displays for small group study. *Proceedings of the 27th International Conference on Human Factors in Computing Systems – CHI 09*. https://doi.org/10.1145/1518701.1518885

Roediger, H. L., Tekin, E., & Uner, O. (2017). Encoding–retrieval interactions. In J. H. Byrne (Ed.), *Learning and memory: A comprehensive reference* (2nd ed.) (pp. 5–26). Academic Press. https://doi.org/10.1016/B978-0-12-809324-5.21036-5

Shankweiler, D., & Fowler, C. A. (2019). Relations between reading and speech manifest universal phonological principle. *Annual Review of Linguistics, 5*(1), 109–129. https://doi.org/10.1146/annurev-linguistics-011718-012419

Shin, J. K., & Crandall, J. (2013). *Teaching young learners English: From theory to practice. Cengage Learning.*

Siegelman, N., Rueckl, J. G., Steacy, L. M., Frost, S. J., van den Bunt, M., Zevin, J. D., Seidenberg, M. S., Pugh, K. R., Compton, D. L., & Morris, R. D. (2020). Individual differences in learning the regularities between orthography, phonology and semantics predict early reading skills. *Journal of Memory and Language, 114,* 104145. https://doi.org/10.1016/j.jml.2020.104145

Silinskas, G., Torppa, M., Lerkkanen, M.-K., & Nurmi, J.-E. (2020). The home literacy model in a highly transparent orthography. *School Effectiveness and School Improvement, 31*(1), 80–101. https://doi.org/10.1080/09243453.2019.1642213

So, C. K., & Best, C. T. (2010). Cross-language perception of non-native tonal contrasts: Effects of native phonological and phonetic influences. *Language and Speech, 53*(2), 273–293. https://doi.org/10.1177/0023830909357156

Tulving, E., & Thomson, D. M. (1973). Encoding specificity and retrieval processes in episodic memory. *Psychological Review, 80*(5), 352–373. https://psycnet.apa.org/doi/10.1037/h0020071

Valentine, A., Belski, I., & Hamilton, M. (2017). Developing creativity and problem-solving skills of engineering students: A comparison of web- and pen-and-paper-based approaches. *European Journal of Engineering Education, 42*(6), 1309–1329. https://doi.org/10.1080/03043797.2017.1291584

van Daal, V. H. P., & Wass, M. (2017). First- and second-language learnability explained by orthographic depth and orthographic learning: A "natural" Scandinavian experiment. *Scientific Studies of Reading, 21*(1), 46–59. https://doi.org/10.1080/10888438.2016.1251437

Voyer, D., Ronis, S. T., & Byers, N. (2022). The effect of notetaking method on academic performance: A systematic review and meta-analysis. *Contemporary Educational Psychology, 68*, 102025. https://doi.org/10.1016/j.cedpsych.2021.102025

Wang, M., Ko, I. Y., & Choi, J. (2009). The importance of morphological awareness in Korean–English biliteracy acquisition. *Contemporary Educational Psychology, 34*(2), 132–142. https://doi.org/10.1016/j.cedpsych.2008.12.002

Xodabande, I., Asadi, V., & Valizadeh, M. (2023). Teaching vocabulary items in corpus-based wordlists to university students: Comparing the effectiveness of digital and paper-based flashcards. *Journal of China Computer-Assisted Language Learning, 2*(2), 257–280. https://doi.org/10.1515/jccall-2022-0016

Yamashita, J. (2022). A commentary on four papers in the second language vocabulary learning strand for the JALT Vocabulary SIG. *Vocabulary Learning and Instruction, 11*(2), 101–113. https://doi.org/10.7820/vli.v11.2.yamashita

Appendix 1: Test items

1.1 Paper tests

Test Item	Phoneme — Correct Response
1. Bus	[b] – *b*
2. Fish	[f] – *f*
3. Horse	[h] – *h*
4. King	[k] – *k*
5. Nose	[n] – n
6. Umbrella	[ʌ] – *u*
7. Want	[ʊ] – *w*
8. Zero	[z] – *z*
9. Ink	[ɪ] – *i*
10. Egg	[ɛ] – *e*
11. Red	[r] – *r*
12. Violin	[v] – *v*
13. Cat	[k] – *c*
14. Six	[s] – *s*
15. Circle	[s] – *c*

1.2 Digital tests

Test Item	Phoneme — Correct Response
1. Dog	[d] – *d*
2. Pink	[p] – *p*
3. Monkey	[h] – *m*
4. Night	[n] – *n*
5. Tomato	[t] – *t*
6. Office	[ʌ] – *u*
7. Vegetable	[k] – *k*
8. Like	[l] – *l*
9. Library	[l] – *l*
10. Bag	[b] – *b*
11. Want	[ʊ] – *w*
12. Zero	[z] – *z*
13. Ink	[ɪ] – *i*
14. Egg	[ɛ] – *e*
15. Red	[ɹ] – *r*
16. Down	[d] – *d*
17. Jam	[dʒ] – *j*
18. Hot	[h] – *h*
19. Wash	[ʊ] – *w*
20. Office	[ɒ] – *o*