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Typing to Replace Handwriting: Effectiveness of the Typing-Primary Approach for L2 Chinese Beginners
(打字取代手写——以打字为主的初级中文教学的有效性)

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Abstract: It is a common assumption in the TCFL field that handwriting Chinese characters (Hanzi) is a prerequisite for Hanzi reading and memorization, and that typing instead of handwriting hinders CFL beginners' literacy development. This study provides evidence for the contrary. Pinyin-based typing employs holistic processing of phonological–visual chunks. This fundamentally different cognitive route supports sound-meaning-form mapping and retrieval, thus facilitating Hanzi processing and memory. The performance data of 108 CFL true beginners from a US university were analyzed with 1,440 assessment records. Compared to using handwriting as a primary mode for daily practice, learners using Pinyin-typing and digital tools performed equally well in reading comprehension and Hanzi accuracy in typed essays, and significantly better in essay length, sentence-level word recognition, and program-end cumulative Hanzi retention. The results suggest that the Pinyin-based typing approach with distributed practice throughout the courses enhances Hanzi rehearsal and retrieval at the word and phrase levels, which in effect facilitate word retention and promote Hanzi literacy development.

摘要: 在 L2 中文教学界手写汉字常被认为是汉字认读和记忆的先决条件，而以打字方式取代手写则会不利于初学者的汉字学习，乃至阻碍其读写技能的发展。本研究提出了相反的证据。拼音打字采用的是语音-视觉组块的整体处理方式，属于完全不同于手写的认知途径; 此方式支持"音-义-形"对应连接及其语块提取，有助于汉字的语块处理和记忆。本研究对一所美国大学中文班的 108 名中文初学者共 1440 项成绩记录进行了数据分析。打字为主的学习者在阅读理解和写作汉字准确性这两方面的表现与手写为主的学习者相当，而在写作长度、句子层面的单词识别、以及课程累积汉字记忆这三方面的表现显著强于手写为主的学习者。研究结果表明，将打字练习系统性地分布于全课程可有效地增强汉字在词语层面的演练和提取，从而在实际上促进词语记忆及汉字读写技能的发展。

Keywords: Beginning Chinese, Chinese character recognition, Chinese literacy, Hanzi retention, typing vs. handwriting

关键词：初级中文，汉字认读，中文读写，汉字记忆保持，打字与手写

1. Introduction

The Chinese character writing system (Hanzi) has been regarded as the greatest barrier to learners of Chinese as a foreign language (CFL). The traditional stroke-based handwriting-memorization (HM) method is laborious and time-consuming, demanding tremendous cognitive resources. For CFL beginners who have very limited time for Chinese learning and need to prioritize aural–oral skills, HM is distracting and counter-productive because of its inefficient use of cognitive resources (Allen, 2008; Halliday, 2014; Ke & Everson, 1999; McGinnis, 1999; Moser, 1991). Conceivably, struggling beginners are further demoralized by memorizing new characters that come every day, in addition to repeatedly practicing previously learned ones. Indeed, Hanzi retention is a daunting task for learners.

Over the past few decades, researchers have explored or proposed alternative pedagogical models in CFL settings, such as delayed writing and separate-track models (Packard, 1990; Yin, 2006), learning whole characters without HM (Everson & Ke, 1999; McGinnis, 1999), and Hanzi character learning using digital and multimedia modalities (Jin, 2006; Shen & Liao, 2017; Xu & Jen, 2004; Xu et al., 2013). Nonetheless, the most significant break-through was the advent of the Pinyin-based word processing, a "game-changer" (Z. Zhang, 2009) that affords a fundamentally different style of Hanzi pedagogy for CFL beginners. Not only has the Pinyin-typing approach significantly lowered the hurdle of HM, but it has also facilitated the integration of technology-enhanced Chinese learning (P. Zhang, 2016), and has promoted language use through e-learning activities such as emailing (Xie, 2011) and blogging (P. Zhang, 2012). Since the early 2000s, several typing-primary or mixed models for CFL beginners have been explored with favorable results (Feng & Yang, 2013; He et al., 2008; Xie, 2011; P. Zhang, 2018).

1.1 The Pinyin system and Pinyin Input Method

Pinyin, literally "spelled sounds," is the official romanization system for standard Mandarin Chinese developed in China during the 1950s. Since the 1980s, Pinyin has become the most commonly-used phonetic guide for CFL learners worldwide. Therefore, a Pinyin Input Method (IME) is a sound-based Chinese character input assistance program using Pinyin spellings. It is the only Romanized and cross-platform Chinese IME based on international standards that uses the standard computer keyboard with English letters. There have been several other popular IMEs, such as Cangjie (structure-based), Wu Bi (strokes- and form-based), and Zhuyin (sound-based using a unique set of phonetic symbols). However, these non-Romanized Chinese IMEs were designed mainly for native

Chinese speakers who already have a solid command of Chinese and Hanzi. Before using any of these IMEs, one must also take a substantial training typing course to gain familiarity with its complex coding system.

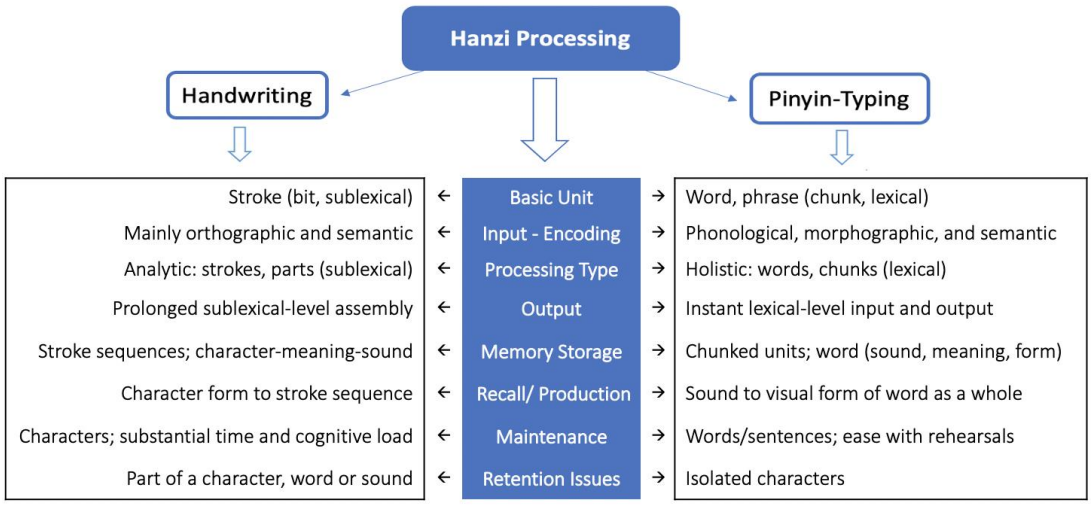
Evidently, learning to output Hanzi via a Pinyin IME is the easiest for CFL beginners. Most learners are not only already skilled in standard computer keyboarding, but also familiar with Pinyin (after 6–8 hours of training in a beginner's course). As a cross-platform system, Pinyin IME is also installed on Windows, macOS, and Linux or other Unix like systems, as well as mobile systems such as iOS and Android. However, one major obstacle is the large quantity of monosyllabic homonyms, i.e., one sound and one spelling is shared by many characters, ranging from a few to over a hundred. For example, typing the sound "yi" will yield over 150 possible characters. Fortunately, multiple input modes are normally available in a Pinyin IME: character, word, or phrase/sentence. Since disyllabic/polysyllabic homonyms for words with two or more characters in Chinese are extremely limited, using the intelligent word/phrase mode can effectively filter unfit homonyms and quickly yield highly accurate Hanzi output. In other words, inputting strings of Pinyin words and phrases instead of monosyllables can significantly improve Hanzi output speed and accuracy.

Despite the successful practice of Pinyin-typing in beginner's courses at American universities, stroke-based HM has remained the primary practice in the CFL field: most U.S. CFL classrooms continue requiring the HM routines (Li et al., 2014; Ye, 2013). Many teachers regard the typing approach as improper for CFL beginners. Jiang (2017) discussed some common presumptions among native Chinese teachers, e.g., handwriting is the only correct way to achieve Hanzi literacy; without handwriting learners cannot recognize and remember Hanzi, and typing can inhibit the learner's reading and literacy development.

1.2 Pinyin-typing: A different cognitive route

Does Hanzi retention depend on handwriting as commonly assumed? Is Pinyin-based typing inferior to handwriting in developing Chinese literacy? This study argues the opposite: Pinyin-typing is a ground-breaking innovation that optimizes CFL beginners' Hanzi learning. It involves a phonologically-supported cognitive process that influences Hanzi acquisition at a deeper level than the seeming convenience. The traditional HM approach was based on the functional need of handwriting since people relied on the pen and paper for written communication. However, as digital technology has enabled e-writing via keyboarding and even speech, the HM routine lacks a scientific basis and a pedagogical rationale. Specifically, the stroke-based HM is founded on prolonged procedures of sublexical input/output devoid of phonological input. Typical HM steps include: (1) follow a writing guide to learn the strokes and the stroke order of the character; (2) assemble the character stroke by stroke for an initial familiarization; (3) repeat the assembly steps until the character's composition, components, and exact stroke order are committed to memory, and (4) maintain learned characters by repeated handwriting practice of characters (see Appendix A1). Obviously, for CFL beginners, memorizing 8-10 new characters a day in addition to maintaining ever-increasing learned items is not only time-consuming but also cognitively draining. In contrast, Pinyin-based typing

employs a fundamentally different cognitive route. Rather than bits and pieces (sublexical), the learner focuses on meaningful units in words and phrases (lexical). The phonetic- to-Hanzi conversion during typing entails instant phonological–visual processing: inputting and outputting meaningful chunks of words and phrases (see Appendix A2). Clearly, the two modalities involve distinctly different processes in learning and represent two cognitive routes (Figure 1).



Note. This chart was created by Phyllis Ni Zhang (2021), contrasting the characteristics of Hanzi handwriting and Pinyin-based typing in cognitive processing.

Figure 1 Pinyin-typing vs. handwriting: Differences in cognitive processing

As can be seen, Pinyin-typing transforms the Hanzi processing from a sublexical-based visual-motor procedure into a lexical-based phonological–visual chunking procedure, which can substantively impact learning outcomes. Conceivably, the typing/digital route opens a new and promising path to Hanzi literacy for CFL learners. This study seeks to explore the effectiveness of typing/digital approach on CFL beginners' Hanzi learning concerning their reading and e-writing development.

2. Literature review

This review draws on theories from cognitive psychology and discusses related CFL studies. Pertinent cognitive aspects include information processing (encoding, storage, and retrieval), working memory (WM), long-term memory (LTM), and depth of processing. The discussion of CFL research centers on Pinyin-based typing and its related processing, practice, and issues.

2.1 Information processing and memory: Theories and key concepts

Phonological Loop (PL). PL plays a key role in language processing. According to Baddeley (2003), PL is an active sub-system of WM that interact with LTM. It processes verbal content, including sound and visual text: (1) storing and refreshing the sound of

language in rehearsal loops, and (2) transferring visual information (words and sentences) to a phonological code through subvocalization so that meaning can be extracted. In other words, to read a written word, people first convert it to a spoken/acoustic code to be processed in WM and then transferred to LTM. Thus, PL "can be a useful aid in learning new words" and facilitates the acquisition of language (Baddeley, 2003, p. 194; also see Baddeley at al., 1998). Based on the PL mechanism, a morphographic language such as Chinese will take an extra step for the visual acoustic conversion. The learner must first make a sound-meaning-form link of the word and store the package as a mental representation, allowing for subsequent PL retrieval. Conversely, missing the sound coding can inhibit effective retention in LTM.

Chunking. Chunking refers to grouping or organizing bits of information into larger or meaningful wholes to facilitate WM and memory consolidation. According to Miller (1956), the human immediate memory span can only hold approximately seven items of information. To effectively aid information processing and LTM, small bits should be *recoded*: grouped or organized into larger chunks. As a psycholinguist, Ellis (1996, 2012) viewed chunking (i.e., learning and memorizing phonological and written sequences or formulaic expressions) as an essential process of second language acquisition (SLA) because it promotes the development of automaticity and fluency (1996, p. 107). Ellis further explained how language sequences/chunks in WM transfer and evolve in LTM:

> Short-term representation and rehearsal allow the eventual establishment of long-term sequence information for language. In turn, there are reciprocal interactions between long-term sequence representations and short-term storage whereby long-term sequence information allows the chunking of working memory contents that accord with these consolidated patterns, thus extending the span of short-term storage for chunkable materials. (1996, p. 115)

Holistic vs. analytic processing. Chunking entails holistic processing (HP) in language processing, i.e., taking a chunk (e.g., a word or a phrase) as whole without analyzing its parts. By contrast, analytic processing (AP) focuses on the parts of a word/phrase. HP is associated with higher efficiency in word recognition and text reading (Ventura et al., 2020). However, the processing of Chinese written text may require the use of both holistic and analytical strategies. For example, Chinese children tended to use HP to identify two-character compound words but switched to AP to judge characters when in isolation (Liu et al., 2010). Nonetheless, a learner's tendency to analyze Chinese character parts in each encounter is "detrimental to efficient reading" (Jiang et al., 2020, p.9)

Depth of processing and retrieval. According to Craik and Tulving (1975), information processing with encoding elaboration (e.g., semantic categories and meaning cues) can increase the depth of processing, enhancing LTM. More importantly, retrieval affects retention, rather than the amount of attention and effort, because "deeper encodings are associated with greater retrieval potential in an environment conducive to recall" (Craik, 2002, p. 309). Tulving emphasized that retrieval is "the key process of memory" (Guzzaniga, 1991, p. 91) as encoded and stored information can be useful only if it can be

retrieved. Despite some criticism on the depth framework, psychologists generally agree that the process involving *meaning* facilitates retrieval and retention.

2.2 The phonological factor in Hanzi learning

Previous CFL research has recognized the strong relationship between phonology and Hanzi learning and reading (Everson, 1998; Everson & Ke, 1997; Yin, 2006; T. Zhang & Ke, 2018). Characters presented with sound have been found to be better retained than those without it (Zhu & Hong, 2005). Everson (1998) observed, that learners tend to systematically resort to phonological resources in Hanzi learning, i.e., taking sound and visual forms as "a packaged deal" (p. 200), which effectively facilitates their reading. Other studies (Jin, 2017; Shen & Jiang, 2013; Z. Zhang, 2009) have emphasized the importance of phonological awareness, e.g., syllables, segmentation, phonetic components in literacy development. Z. Zhang (2009) asserted that the phonetic components of characters should be given a central place in Hanzi instruction since their phonological information plays a key role in Hanzi learning and recognition. Therefore, sound-based typing supports Hanzi literacy development efficiently with enhanced sound-meaning connections, better awareness of phonetic components in Hanzi, contextualized Hanzi recognition/ differentiation practice (vs. isolated characters by handwriting), and better meta-linguistic awareness of the word/polysyllabic word (vs. character) as a basic unit in Chinese (Z. Zhang, 2009, p. 86-87).

Clearly, for CFL beginners, "the memorization of the large amounts of characters needed for beginning literacy seems doomed to failure without firm spoken language support" (Everson, 1998, p. 201). The Pinyin-based typing approach makes sense both cognitively and pedagogically: bypassing the meaningless stroke-based sublexical practice enables the learner to focus on and benefit from the phonological-based processing of meaningful units. The Pinyin-typing mode synchronizes with and reinforces the learner's aural-oral practice, thereby promoting Chinese acquisition through an integrated approach (Allen, 2008; Xie, 2005, 2011; Z. Zhang, 2009).

2.3 Chunking as a solution to the Hanzi reading barrier

The absence of explicit word boundaries in Chinese written text is generally recognized as the greatest barrier to reading comprehension (Everson & Ke, 1997; Moser, 1991; Shen & Jiang, 2013). Learners struggle to decipher the meaning of an evenly spaced line of text without any clues to word boundaries (e.g., 昨天我和朋友一起从上海坐飞机到广州去). To read Chinese sentences efficiently with accuracy, the chunking training based on meaningful units (e.g., words, phrases, collocations, and idiomatic expressions) is essential. CFL professionals have suggested ways to foster learners' ability to parse words/phrases through speech-based training (e.g., awareness of strings of phonemic units, chunk-based recitation and reading aloud; Jin, 2017; Shen & Jiang, 2013; Yin, 2006). It follows that Pinyin-based typing can also lend significant support to such rudimentary training with phonological–visual mapping (Xie, 2005), because inputting-outputting chunks (in words and phrases) naturally develops the learner's ability to process Hanzi by meaningful units, facilitating word parsing and sentence segmentation. Given that handwriting learners tend to analyze parts of a character, intervention is necessary to

develop holistic reading to improve reading efficiency (Jiang et al., 2020), and chunk-based typing may serve as a suitable instrument for this purpose.

2.4 Hanzi retention

Some longitudinal empirical studies have revealed that the intensive HM routine for CSL beginners does not facilitate Hanzi retention. Studying a 3-month beginner's program, Jiang (2007) found that the reduced-handwriting group performed significantly better in both character recognition and handwriting tests than the control group that had more HM practice. Similar findings were reported by Wang (2015) that as learners progressed to new Hanzi items during a year-long program, both their overall performance on character recognition and handwriting declined considerably, with only 50% of handwriting retention at the end (p. 23). These findings contradict the presumption that the more handwriting practice, the better L2 learners can recognize and remember Hanzi.

A few studies have compared the effect of typing versus handwriting on retention with varied findings. Guan et al. (2013) found that handwriting supports character-meaning memory but not sound, and typing strengthens character-sound memory but not meaning, whereas Jiang (2017) found no differences in sound or meaning recall between handwriting and typing learners. However, these findings based on character-level tests are inadequate to explain learners' word-level performance. Lu et al. (2019) reported a word-level experiment based on a CFL setting, arguing that "[w]hen considering communication, words (rather than characters) are the basic unit of a sentence" (p.3). This study compared the effects of a digital-only without handwriting condition (NH) versus a with-handwriting condition (WH) that used a third of the allowed practice time on handwriting. The results show that NH performed significantly better than WH, suggesting that handwriting practice is not as efficient as that with digital tools for learning and retaining Hanzi. Lu et al. argued that efficiency should also be considered as an important CFL learning criterion. The key findings demonstrate two important things: (1) handwriting's effect on character-meaning memory is only limited to a short period of time, and (2) typing practice with words (lexical units), different from discrete characters (sub-lexical units), effectively enhances morphographic-semantic mapping—even better than handwriting.

2.5 Typing-primary models: Practice, issues, and benefits

Several typing-primary models using a regular Pinyin IME have been explored in some CFL beginning Chinese programs, such as typing Hanzi from Day 1 (Feng & Yang, 2013); typing Hanzi regularly supplemented with a gradual handwriting program (He et al., 2008); typing Hanzi proceeded with a basic handwriting training (Xie, 2011; P. Zhang, 2015b, 2018). While these programs reported overall success, learners' weaker character-level performance due to word/phrase processing has also been noted. Feng and Yang (2013) argued that it is natural for CFL learners to first focus on words/phrases before attending to characters—a similar course that Chinese children develop their character knowledge over time as their word bank expands (p. 36). This view aligns with Ke (1996) that in-depth orthographic and character information can be acquired after obtaining adequate knowledge of basic words. Allen (2008) shared the same view: "[o]nce the pronunciation, speaking, and electronic reading/writing skills are solidified, handwriting

then could be introduced more effectively" (p. 245). Furthermore, the typing-primary approach provides additional pedagogical benefits. Z. Zhang (2009) noted that Pinyin-typing develops better sound-meaning connections for learners, greater awareness of phonetic components, intensified recognition/differentiation as well as contextualized practice, and greater meta-linguistic awareness of Chinese word (p. 86-87).

2.6 The gap in research and current studies

Previous research has been heavily centered on HM-based character learning; studies on Pinyin-based typing versus handwriting are scarce. Lyu et al. (2021) found only 16 published quantitative empirical studies on this topic from 2009 to 2019, of which only one examined word learning and retention. Moreover, there have been few studies on learning outcomes pertaining to level-related practical reading and writing skills, such as those described in ACTFL Proficiency Guidelines (2012). It is, therefore, compelling for the CFL field to be informed of empirical evidence on learners' actual learning outcomes in the classroom setting, including pre- or semi-functional levels beyond characters and words. For example, research is required to determine whether learners can achieve Hanzi literacy without handwriting (Allen, 2008), or how learners' Hanzi skills contribute to their reading comprehension performance (T. Zhang & Ke, 2018). From a pedagogical point of view, evidence of the effects of typing on the beginner's Hanzi proficiency development is essential for restructuring CFL instruction for the digital age. It also calls for a shift of research focus from the character-centered orthographic knowledge to proficiency-oriented skills and literacy development.

Given the need for closing the gap, this study seeks to investigate the long-term effect of the Pinyin-based typing-primary approach on learners' actual performance. It argues that as phonology plays a key role in human memory, typing via phonological-visual chunking of words and phrases can optimize Hanzi processing (encoding, storage, and retrieval). Therefore, sound-based typing using Pinyin is in effect superior in supporting beginners' Hanzi learning and literacy development. Contrastively, HM for beginners is inefficient and counter-productive due to its cognitive overload and the lack of phonological support. The study attempts to answer these research questions: Can the Pinyin-typing approach achieve expected Hanzi learning outcomes in place of the traditional HM routine? To what extent do typing-primary learners differ from their handwriting-primary counterparts in target performance? The following four aspects are to be determined:

1. Reading comprehension as measured by periodic assessments
2. Hanzi production and output accuracy in e-writing as measured by term-end impromptu essay-writing assessments
3. Contextualized word recognition as measured by periodic assessments
4. Long-term word retention as measured by course-end and program-end Hanzi assessments.

3. Methods

3.1 Instructional context

This study was based on existing records of students in a two-semester beginning Chinese program (Course 1 and 2, with 14 weeks per course/semester) at a private university in the US where this researcher works; Courses 1 and 2 each lasted for 14 teaching-weeks with a 4-week break in between. A regular week had two 75-minute lectures and two 50-minute oral sessions. Course materials were published textbooks developed by this researcher: the textbook, Volumes 1 and 2 (P. Zhang, 2015a), and the literacy workbook, Volumes 1 and 2 (P. Zhang, 2015b), as well as a companion website with interactive online exercises. Each course introduced approximately 350 characters and 500 word/phrase items.

Hanzi instruction: Initial training and general requirements

Course 1 started with a two-week (6 hours) foundation unit on Pinyin and Hanzi basics. Hanzi training included character strokes, radicals, and four 20-minute in-class tracing practice sessions. During the first two weeks, students also completed a 50-minute homework assignment on Pinyin and Hanzi exercises following each session. At the end of the foundation unit, students received a 30-minute training on typing Chinese using a commonly available Pinyin IME program (e.g., the Pinyin IME installed on Windows or Mac). The training emphasized strategies for output efficiency and accuracy, e.g., inputting chunks of words and phrases instead of monosyllables. Throughout Course 1 (14 weeks) and Course 2 (14 weeks) of this beginning Chinese program, students were expected to: (1) spend a minimum of 40 minutes a day on Hanzi learning/practice as part of the routine homework, and (2) do weekly sentence reading–typing exercises or grammar exercises requiring sentence reading and typing.

Hanzi treatment: Changes of handwriting requirements

This program transitioned from a primarily handwriting approach to a primarily typing one: Stage 1 (before 2016) adopted HM with a rigorous daily load with Pinyin-typing being used as the secondary mode; Stage 2 (2016-17) adopted a moderate and more balanced HM approach (HM-b) that reduced handwriting by 50%. While some students found moderate handwriting helpful, others regarded handwriting as unnecessary. Another change was made (Stage 3, 2017-2019) to accommodate different learning needs and to test out the effectiveness of the typing-digital approach. Pinyin-typing was adopted as the primary mode for Hanzi requirements: after the initial handwriting training, Course 1 only required minimal hand-copying (without the stroke-memorization) and Course 2 no longer required handwriting in daily work and quizzes. Although students were free to choose their own practice method, e.g., handwriting, mixed/balanced, or typing/digital, all students were still required to complete typing-assignments and use only the typing mode for all tests.

Hanzi-related assessments

The direct measures included four main types:

- Reading. Three periodical and six unit-based reading comprehension tests consisting of narrative passages of 300–600 characters with true/false or multiple-choice questions in English (Course 1) and in Chinese (Course 2).
- E-writing. Three term-end typed essays (timed impromptu writing on provided topics/prompts).
- Word recognition (since 2016-17). Six unit-based and timed reading–typing tests.
- Cumulative word recognition (since 2016-17). Term-end Hanzi recognition tests (word recognition and sentence reading-typing).

The indirect measures included three surveys: an entrance questionnaire on language experience followed by testing items (Pinyin, typing, and passage reading) and two term-end surveys with reflections on Hanzi learning and practice, among others.

3.2 Research design

To examine the effectiveness of the typing-primary approach compared to the HM-primary approach, this study used a quasi-experimental design with retrospective cohort comparison groups with students enrolled in the beginning-level courses taught by this researcher (Spring 2015–Spring 2019). The conditions of the all the cohorts were consistent: the head instructor, textbooks, lesson plans, and assessments remained mostly the same throughout. Data mainly included the digital performance records of these cohorts. While the early HM cohorts using pen and paper for written tests had limited digital records, the available data still provided valuable information on reading and e-writing and was therefore included. Other data analyses (sentence reading-typing and Hanzi recognition/ retention) were made only between the typing-digital and HM-b modalities. The following retrospective cohorts formed the three comparison groups based on their practice modalities according to course requirements:

- HM (2015 spring, fall): Daily handwriting and memorization (8-10 characters); weekly sentence reading–typing or other typed exercises.
- HM-b (2016–17): Balanced with reduced daily handwriting and memorization (4-5 characters) and weekly sentence reading–typing or other typed exercises.
- Typing–digital (2017-2019): Daily practice with Hanzi word lists and/or Quizlet (audio-enabled e-flashcards with words and phrases); minimal hand copying in Course 1 and no regular handwriting required in Course 2; weekly sentence reading–typing or other typed exercises.

(See details in Appendix B.)

Inclusion/Exclusion rules

(1) To ensure baseline equivalence and to avoid confounding variables, this study included only true beginners as determined by an entrance test and a survey administered during Course 1 in each cohort. (2) Beginners who spoke Chinese or had Hanzi writing

experience were not included here. (3) Only those with complete assessment records in Courses 1 or 2 were included. Course 2 students who did not take Course 1 of this program were excluded. (4) True beginners who enrolled between 2017 and 2019 but did not use typing–digital consistently as the primary mode were not chosen for the typing–digital group. Given these restrictions, the present sample can only be considered representative of true CFL beginners enrolled in a rigorous college program, with regular attendance, who have adopted a consistent Hanzi practice mode as defined above.

Sample size and data sources

Sample Size. 108 students were included, aged 18–20 years (47% male and 53% female). The HM group included 54 students: Course 1 had 27 students who enrolled in Fall 2015, and Course 2 had 27 from Spring 2015 who completed Course 1 in 2014 (a different cohort). To match the number of the HM group, HM-b and typing-digital groups each had 27 for Course 1; from this, 26 of HM-b and 25 of typing-digital learners continuing in Course 2 were included for paired-sample analysis.

Data. A total of 1440 records (1,200 records of tests with identical items and format and 240 records of entrance/exit surveys) were collected and analyzed. All data were collected from the existing digital records of the two courses from 2015–2019. Although much of the 2015 cohorts' handwritten data were unavailable, the limited digital data from these early HM cohorts still provided valuable information and were therefore included (see Appendix B).

Measures and instruments

To evaluate learners' Hanzi reading and Pinyin-based typing performance, the averages of reading comprehension scores, reading–typing test scores, and essay word count and typing error count were computed for each group using the same set of criteria. The mean, median, and standard deviation scores were summarized. The Hanzi count in the essays was character-based using the Word Count feature in Microsoft Word and English words were excluded. Repeated typographical errors were not double-counted. Given the multifaceted nature of L2 writing and limited scope of this study, learners' grammar errors were not included in the analysis.

Comparisons of means (or medians where appropriate) between or across the groups were performed using parametric tests (analysis of variance [ANOVA] and t-test) and non-parametric tests for non-normally distributed data (Wilcoxon signed-rank, Mann-Whitney U, and Kruskal-Wallis H tests). Paired-sample tests for the available HM-b and typing-digital data of Courses 1 and 2 were also conducted to measure learners' Hanzi retention and progressive development.

4. Results

4.1 Reading comprehension performance

Course 1 periodical assessments

Each reading task contained one or two passages, each with 300–600 characters followed by 8–12 true/false or multiple-choice questions in English. The summary of the three reading tests is presented in Table 1. An ANOVA found no statistically significant differences across the three groups (N = 81, F (2, 78) = 1.26, p = .29).

Course 2 unit assessments

Due to a lack of available data for the HM cohorts, only two groups were analyzed: HM-b (n = 26) and typing–digital (n = 25). Each reading passage contained a narrative story of 420–550 characters followed by seven to eight true/false or multiple-choice questions in Chinese. The performance of the two groups was consistent with their performance in Course 1, indicated by the similar average scores (Table 2) and a t-test found that the two groups did not differ (N = 51, t (49) = -0.518, p = 0.61).

Table 1 Course 1 reading comprehension scores (based on three periodical tests)

Group	N	Mean (%)	Median (%)	SD (%)
HM	27	82	85	11
HM-b	27	86	88	10
Typing-Digital	27	84	88	10
Total	81	84	88	11

Table 2 Course 2 reading comprehension scores (based on six unit tests)

Mode/Group	N	Mean (%)	Median (%)	SD (%)
HM-b	26	78	79	8
Typing-Digital	25	79	79	11
Total	51	78	79	10

4.2 Writing production and Hanzi output accuracy

Course 1 term-end timed impromptu essays

Essay length was measured by the Hanzi count of typed essays, and the Hanzi accuracy rate was based on the character count. The data included two short typed essays completed in class without support, and all examined cohorts were given the same topics, prompts, and time limits.

Essay length/Hanzi count. The total Hanzi (by characters) produced in the two essays were tabulated and group averages were computed. Typing–digital learners on average produced more Hanzi (*M* = 496, SD = 124) than HM (*M* = 425, SD = 116) and HM-b (*M* = 465, SD = 100) learners. The difference between typing–digital and HM was statistically significant (*N* = 54, *t (52) = -2.18*, *p* = .034). The Hanzi-count frequencies further revealed that 11% of typing–digital learners produced 700+ characters, whereas none from the other two groups did. The upper ranges (501 up) showed that typing–digital had a total of 40%, compared to 33% for HM-b and 26% for HM (see Figure 2-a).

Hanzi typing errors. These included typographical errors due to homonyms (e.g., 晚 for 完) and other misspelled or misused words (e.g., 中文 for 中国, 比 for 不). The average error rates of the three groups were all below one percent (0.4–0.6%), with an accuracy rate of 99.4–99.6% for each group. Since the distributions were skewed (non-normal), a Kruskal-Wallis H (ANOVA) test was conducted; no significant differences were found across the groups (*Mdn* = .004, *N* = 81, *H* (2) = 2.79, *p* = .248). However, the frequency distributions of each group showed that the proportion of learners who achieved 100% accuracy (zero errors) was 37% in typing–digital, which was considerably higher than that in HM (19%) and HM-b (26%) (see Figure 2-b).

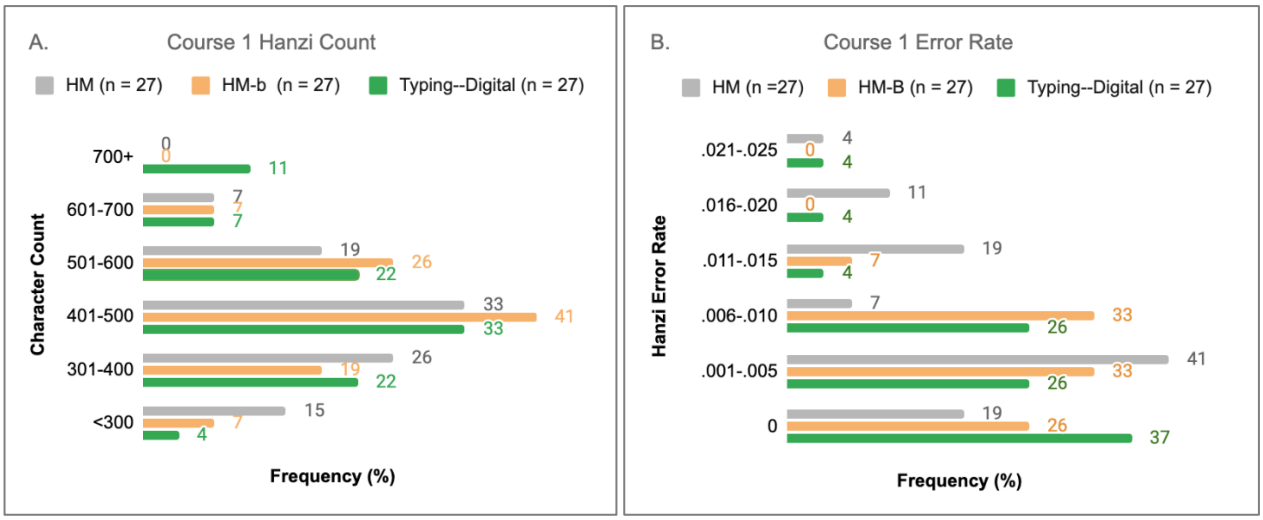


Figure 2-A. Course 1 essay length was based on the total Chinese (Hanzi) character production of two typed essays. The frequency represents the percentage of a group for each range.
Figure 2-B. Course 1 essay Hanzi error rate was based on the Chinese character count. .001 indicates 1 error in 1,000 characters. The frequency represents the percentage of a group for each range.

Figure 2 Course 1 Hanzi count and error rate frequencies across groups (two essays)

Course 2 term-end timed impromptu essay

Length/Hanzi count and Hanzi output accuracy rate were measured in the same way as in Course 1. To control the variables, only one of the two essays in Course 2, identical across all cohorts, was analyzed. All groups had the same essay prompts and used the same platform (Quia), however, the HM cohort completed the task outside of class with a longer

timeframe and permission to refer to resource materials. In contrast, the HM-b and typing-digital cohorts completed the essay in class without the support of any resources.

Essay length/Hanzi count. The total Hanzi produced in one typed essay was averaged for each group. As the results were skewed (non-normal distributions), the data were analyzed using non-parametric tests (Kruskal-Wallis H and Mann-Whitney U). Consistent with Course 1, typing–digital produced significantly more Hanzi (*Mdn* = 303) than HM (*Mdn* = 271; *N* = 52, *U* = 226, *z* = -2.051, *p* = .04). As shown in the frequency distributions (Figure 3-a), only 12% of typing–digital was in the below-250 range, compared to 32% (HM) and 30% (HM-b); and for the upper ranges (351 up), typing–digital was 24 %, compared to 8% (HM) and 20% (HM-b).

Hanzi typing errors. The results of typing errors in the Course 2 essay were highly consistent with those in Course 1, with similar median error rates: 0.3% (or 99.7% accuracy) for HM and HM-b learners, and 0.4% (or 99.6% accuracy) for typing–digital learners. A Kruskal-Wallis H (ANOVA) test found no significant differences across the groups (*N* = 78, *H* (2) = 1.26, *p* = .533). The error frequencies, shown in Figure 3-b, revealed that only 8% of typing–digital learners had a higher error rate (0.01 up), which was remarkably lower than that in HM (30%) and HM-b (12%).

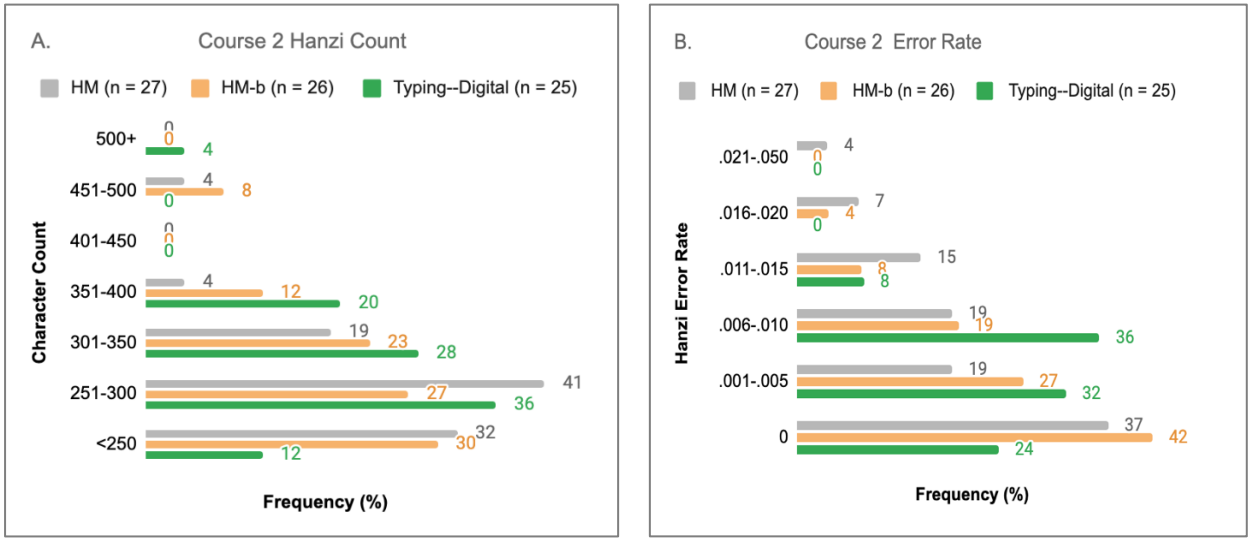


Figure 3-A. Course 2 essay length was based on the total Chinse (Hanzi) character production of one typed essay. The frequency represents the percentage of a group for each range.
Figure 3-B. Course 1 essay Hanzi error rate was based on the Chinese character count; .001 indicates 1 error in 1,000 characters. The frequency represents the percentage of a group for each range.

Figure 3 Course 2 Hanzi count and error rate frequencies across groups (one essay)

4.3 Contextualized word recognition (Hanzi and sound)

Course 2 reading–typing performance (five out of six unit-based tests)

Sentence reading-typing items were only used in the unit tests of Course 2 after 2016, therefore only two groups were compared: HM-b and typing-digital. In each reading-

typing task, students read 10–16 sentences from a paper sheet and typed the sentences verbatim on an online answer sheet within a set time limit. One of the six R-T records did not set a time limit and was excluded. Table 3 presents the score summary. A *t*-test determined that typing–digital did significantly better than HM-b (t (40.9) = -2.2, p = .034).

Table 3 Course 2 sentence reading–typing performance scores (based on five unit tests)

Group	N	Mean (%)	Median (%)	SD (%)
HM-b	26	76	77	17
Typing--Digital	25	84	86	10
Total	51	80	82	15

4.4 Long-term word retention (Course-end Hanzi assessments)

The Hanzi assessments available in digital form included 2016 to 2019 cohorts to examine learners' cumulative Hanzi retention through word recognition and sentence reading-typing tasks. Data were collected for these three tests: Course 1 Exit (Test 1); Course 2 Entrance (Test 2, a posttest of Test 1 after a 4-week interval), and; Course 2 Exit (Test 3). Paired samples were analyzed based on the available records of 26 HM-b and 25 typing–digital learners. The following items were measured: (a) identifying inappropriate words from word groups, and (b) typing out the sentences verbatim (20 in total) from a paper question sheet. HM cohorts had different written tests and the data were unavailable.

Results of Hanzi Tests 1 and 2: cumulative and retention tests (matched samples)

Records of HM-b and typing–digital learners in Course 2 (n = 51) were analyzed to determine the score difference between Test 1 and Test 2 (posttest) within each learner. The score summary is presented in Table 4. A Wilcoxon Signed–Ranks (WSR) matched samples test indicated that the Test 2 (posttest) scores were significantly lower than those of Test 1: (N = 51, Mdn = 65, T = 240, z = -3.3, p = .001).

Table 4 Cumulative word recognition and retention in matched pairs (Course 1 exit and Course 2 entrance)

	N	Mean (%)	SD (%)	Percentiles (%)		
				25th	50th (Median)	75th
Test 1 (Course 1 Exit)	51	74	20	62	81	88
Test 2 (Course 2 Entrance)	51	66	25	42	65	88

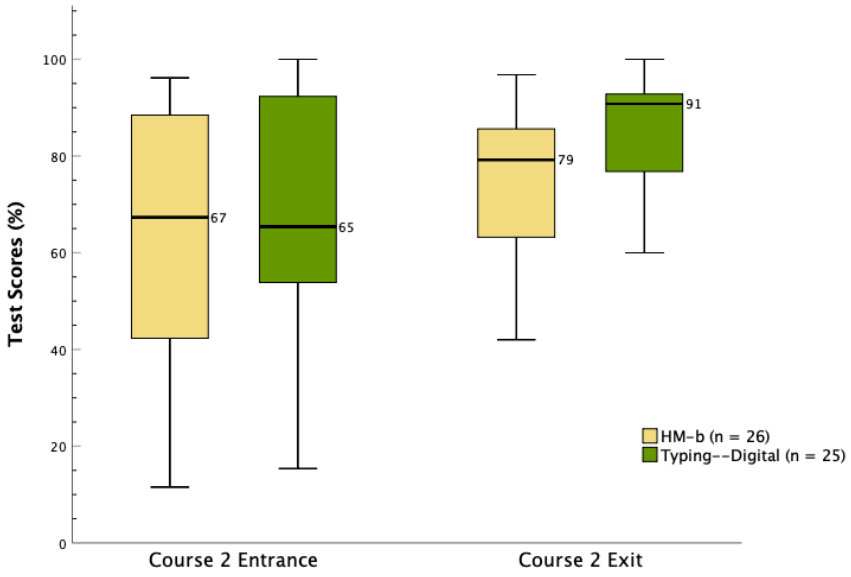
Results of Hanzi Tests 1 and 2: Cumulative retention tests (independent samples)

Mann–Whitney U tests were used to compare the differences in performance between the HM-b and typing–digital groups. For Test 1, no significant difference was

found (N = 51, *Mdn* = 81, U = 384, p = .26). In Test 2, the average performance regressed (as shown in Table 4 above); however, no significant difference was found between the two groups (N = 51, *Mdn* = 65, U = 344, p = .73).

Results of Hanzi Test 3: Cumulative word recognition (independent samples)

The program-end Hanzi test included words taught in both courses. The same groups for Test 2 were examined for Test 3. As can be seen in Figure 4, at the beginning of the course, there was no difference between the two groups. However, after a 14-week study period in Course 2, typing–digital (n = 25, *Mdn* = 91) did significantly better than HM-b (n = 26, *Mdn* = 79) in word recognition and sentence reading–typing (U = 460, p = .011).



Boxplot showing score distribution of the two Hanzi tests across the groups. Medians are labeled.

Figure 4 Cumulative word recognition performance (Course 2 entrance and exit tests)

5. Discussion

5.1 Summary of main findings

This study aimed to determine the difference in Hanzi learning outcomes in terms of reading, e-writing, and retention between typing-primary and handwriting-primary approaches. Reading comprehension and e-writing were compared between the typing–digital, HM, and HM-b groups. No significant differences were found in reading comprehension across the groups. However, typing–digital learners did significantly better in e-writing (essay length) and word recognition/retention than their HM/HM-b counterparts. These results confirm previous classroom-based observations that the typing-primary approach with a well-structured training program leads to better reading efficiency and e-writing production (Feng & Yang, 2013; Xie, 2011; P. Zhang, 2018). The outcomes of handwriting learners align with those of the previous studies on CSL beginners (Jiang,

2007; Wang, 2015) that more handwriting for beginners does not lead to better reading and writing performance over time.

5.2 Writing production and Hanzi accuracy

This study seeks to find out whether Pinyin-typing learners can achieve the same expected learning outcomes as handwriting learners, as measured by e-writing length and Hanzi output accuracy. As shown, the typing–digital learners produced significantly longer typed essays than their HM counterparts, while maintaining an equal level of Hanzi accuracy (99.95–100%). The HM cohort's e-writing production was significantly lower. At the end of Course 2, 73% of HM learners produced less than 300 Hanzi characters (low ranges) in one typed essay, compared to 48% of typing–digital learners. These outcomes were surprising given that the handwriting learners were allowed more time and resources during the writing task. These learners should not be considered as disadvantaged for typing since they had also practiced Pinyin-typing routinely; besides, typing is an easier task than handwriting as generally assumed by CFL teachers and students. It is possible that their shorter production resulted from the intensive daily orthographic practice: i.e., writing and memorizing the strokes of 10 characters a day had inevitably forced learners to slow down to focus on sublexical units. Presumably, this orthographic-based analytical routine may negatively impact the development of meaning-focused production that requires lexical-level and holistic processing. As a student reflected on Hanzi learning in the 2019 course survey, the handwriting process is indeed a hindrance to Hanzi learning and productive writing:

> [H]and-writing isn't integral to learning Hanzi. What I've found is that whenever I hand-write Hanzi, I end up mindlessly writing without really thinking. Even if I actively concentrate on what the word is, I get so caught up on making sure the word is written perfect[ly] that instead of learning how to recognize the word, I learn the task of writing instead. Typing, on the other hand, allows me to learn sentence structures and how to view and recognize Hanzi in relation to other words rather than individual words or the act of writing.

This also explains the typing–digital learner's impressive performance in e-writing. It is true that the intelligent Pinyin IME affords typing efficiency and accuracy. However, for a Pinyin IME to produce accurate Hanzi text, the input must first contain meaningful strings of syllables in acceptable Pinyin spellings. In this regard, the typing–primary learners benefited from the effect of phonological–visual encoding (Baddeley, 2003) and chunking (Ellis, 1996). Despite their issues with isolated characters (话 vs.说 or 语), they were able to quickly read Hanzi strings, and in most cases, differentiate target words from their homonyms (e.g., 吃完饭 vs 吃晚饭; 室友 vs 是有 or 师友). Evidently, for most learners, reducing or eliminating handwriting did not inhibit their Hanzi reading development. Rather, it promoted Hanzi learning since learners must constantly identify and match Hanzi words /phrases to their phonetic input. The outcomes also support Z. Zhang's (2009) assertion that sound-based typing can effectively raise the learner's meta-linguistic

awareness of: (a) Hanzi homonyms, and; (b) of the word/polysyllabic word, rather than a character, as a basic unit.

5.3 New evidence on learners' word retention

Typing-digital learners' successful word-level retention

Despite an anticipated decline in their word recognition at the beginning of Course 2 (after a four-week interval), typing–digital learners recovered quickly and did significantly better than HM-b learners in all sentence reading–typing tasks in Course 2, including the one in the final program-end assessment. These results contradict previously reported findings that handwriting led to stronger word recognition whereas typing only supported character-sound memory, not meaning (e.g., Guan et al., 2011). However, the findings align with the word-level observations (Lu et al., 2019) that the digital (without handwriting) condition resulted in better word recognition, offering new evidence that typing–digital learners were able to recall words (sound, form, and meaning) over a long period when typing practice was maintained. Clearly, the ease of using typing–digital tools helped sustain Hanzi maintenance as learners progressed to new materials, thus allowing for advancement in Course 2.

Baddeley's (2003) argument regarding the phonological loop as a useful aid for language learning also applies to written Chinese. The program-end learning outcomes suggest that recursive typing practice enhanced sound–meaning-form mapping, effectively facilitating word recall. It also suggests that the lack of phonological encoding and word rehearsal can impede word-level processing and retrieval. In addition, given the learners' relatively weak character knowledge, the existence of meaning cues that support word retrieval (e.g., Craik, 2002; Shen, 2004) also played an important role in successful word recognition performance, especially in the sentence reading-typing tasks.

Handwriting learners' weaker word-level retention

The inferior performance of HM-b learners in the Course 2 cumulative test indicates that regular character-level handwriting, even if with reduced load, does not enhance word-level memory. Three factors associated with handwriting may contribute to unsuccessful word retrievals. First, handwriting learners focus on visual stroke assembling without word–sound input. Despite a stronger character-level memory, the lack of phonological encoding and lexical-level rehearsal may lead to the word-recall failure, especially for typing tasks when the sound information is essential. Second, word-level memory may fade if learners dechunk words—writing only new or hard characters instead of whole words. Third, learners must keep up with new items as they progress, thus, exhausting their cognitive resources for maintaining old character and learning new items at the same time. These factors may also explain the previous findings from longitudinal studies on CSL beginners that rigorous handwriting practice led to declined word recognition and hand-reproduction performance (Jiang, 2007; Wang, 2015). Thus, besides the demanding cognitive load and limited Hanzi retention effect, an added caveat for prolonged handwriting practice is that it may weaken word recognition if the learner tends to practice characters rather than whole words.

5.4 Pedagogical implications and suggestions

The current findings offer the following considerations for CFL beginner-level Hanzi instruction.

1. The typing-primary approach optimizes beginners' learning outcomes. Although many factors can influence learning outcomes, a well-structured typing-primary model (e.g., Pinyin-typing coupled with Quizlet) is efficient and sustainable for most CFL beginners.

2. Handwriting can still provide additional assistance and satisfy beginners' curiosity. An initial familiarization of the basics of handwriting is necessary for all beginners to gain prerequisite knowledge, which also helps support the self-motivated handwriting needs of some learners. Nonetheless, the prolonged stroke-by-stroke memorization routine is counter-productive for most beginners and should be avoided.

3. For a typing-primary approach, structured Pinyin-typing training (e.g., input words and phrases instead of characters) and distributed practice (e.g., routine typing assignments throughout the course) are *essential* for learners to develop Hanzi fluency and accuracy. Distributed practice also provides repeated rehearsals necessary for Hanzi reading and retention. For example, weekly exercises, such as typing of words/phrases from audio and written cues and self-quizzing using audio-supported applications (e.g., Quizlet), increase learners' frequency of exposure to Hanzi text and enable effective word retrievals. Without such as systematic practice in place, the typing-primary approach may not achieve expected learning outcomes.

4. Would a balanced approach be better? Some teachers may prefer an integrated or a dual/mixed method for the benefits of both handwriting and typing. However, which modality takes the precedence can make a difference in learning outcomes. The key issue is the initial *encoding* mode and memory structure involved in the process (i.e., stroke- and part-based vs. phonological–visual, chunk-based). Therefore, it is suggested that a balanced/mix mode should put Pinyin-typing practice before handwriting, and make handwriting as secondary and use it selectively.

5. Radicals and components. For beginners, except for easily confused characters (e.g., 请 vs. 情, 问 vs. 闻), it is unnecessary to over-emphasize radicals and components of characters. In-depth orthographic and character information can be acquired after obtaining adequate basic words to help learners advance their knowledge of Hanzi. (See Ke, 1996 for an orthographic awareness model, and see Z. Zhang, 2009 for a phonic approach to character learning.)

5.5 Limitations of the study and future research

This study has several limitations. (1) It examined records of true beginners sampled from retrospective cohorts without randomization. The generalizability of the results is limited by the small sample size of each group and by the exclusion of learners with partial records and with Chinese or Hanzi experience. (2) The original assessments

were not specifically designed for experiments and, hence, confounding factors might exist. (3) The HM learners' performance analysis was only partially complete owing to a lack of comparable records (e.g., sentence reading-typing tasks). (4) The analyses for essay writing performance were limited to e-writing records due to a lack of handwritten data. In addition, the e-writing analysis was limited to the essay length and Hanzi output accuracy, which answered the research question pertaining to e-writing production in terms of efficiency and Hanzi accuracy. However, as L2 beginners' writing is multifaceted, learners' writing quality, grammar, and communicative appropriateness should be further investigated. (5) Being beyond the scope of this study, learner differences (e.g., auditory vs. visual learners) and other proficiency levels than beginners were not examined. Some learners may depend on handwriting to recognize and remember Hanzi. Therefore, the pedagogical suggestions provided above may not apply to all learner types and levels, especially those who are handwriting-reliant. Future research may delve deeper to gain more insights into these areas and explore learner-specific pedagogical solutions.

6. Conclusion

Since Pinyin-based typing-primary models were introduced in the CFL field in the early 2000s (e.g., He et al., 2008; Xie, 2005; Xu & Jen, 2004), the crucial role of Pinyin-based typing in L2 Hanzi learning has long been ignored, mainly owing to the misassumption that typing leads to poor Hanzi recognition and literacy development. This longitudinal study based on 1,440 records of true beginners' assessments has provided new evidence supporting the typing-primary approach: rather than hindering it, Pinyin-typing promotes Hanzi learning and use. Compared to their intensive or balanced handwriting counterparts, the typing-primary learners demonstrated: (1) comparable reading comprehension, (2) longer typed essays with comparable high Hanzi accuracy (averaged 99.6%), (3) better word- and sentence-level word recognition, and; (4) better cumulative word/phrase retention in course- and program-end assessments. Additionally, in the four-week interval between the two courses, typing-primary learners did not have more Hanzi attrition than balanced-handwriting learners. Evidently, most beginners receiving a structured typing-primary Hanzi training can achieve expected learning outcomes for reading, e-writing, and maintenance without handwriting. The results on reading and writing efficiency are consistent with previous preliminary reports on typing-primary practice (Feng & Yang, 2013; He et al, 2008, Xie, 2005, 2011; P. Zhang, 2018). Despite weakness in recognizing isolated characters, typing-primary learners can successfully read, retrieve, and retain Hanzi in meaningful chunks of words/phrases, if typing rehearsal is regularly maintained. In contrast, handwriting learners, who are generally stronger in character recognition, may fail in word-level performance, possibly owing to a lack of phonological and/or meaning support due to focus on sublexical learning (strokes and isolated characters). This observation is consistent with Lu et al's (2020) results on word-level retention with and without handwriting and extends previous findings that were based mainly on character-level experiments (e.g., Guan et al, 2011; Jiang, 2007; Xu et al, 2013).

To help fill in the gap in the literature, this study has examined CFL Hanzi instruction from cognitive and functional perspectives. Evidently, the typing-primary learners' success can be largely attributed to the phonological–visual route. Pinyin typing

affords sound-meaning-form mapping in meaningful chunks of words/phrases, while recursive typing rehearsals can consolidate and enhance the meaningful chunks in learner's long-term memory, which in turn facilitate the chunk retrieval and learning-use transfer. The effectiveness of this typing approach suggests that chunked phonological–visual processing, a key process for language acquisition (Baddeley 2003; Ellis, 1996, 2012) also applies to a morphological language like Chinese. As demonstrated in this study, the typing-primary approach with structured typing practice optimizes the speaking-reading integrated (语文同步) model and provides a logical, feasible, and sustainable solution to CFL beginners' literacy development.

While offering a preliminary look at a new and promising path, this study is nonetheless limited in scope and qualitative analysis. Future research is necessary to also examine the typing—digital learners' production (e.g., grammar, word usage, error types) to gain in-depth insights into the learners' learning outcomes as impacted by the transformation of Hanzi learning and assessment in digitally enabled procedures. Clearly, to perfect the typing—digital pedagogy across different proficiency levels, more design-based studies are needed to determine when and how CFL learners should acquire more Hanzi orthographic and character knowledge to further their literacy.

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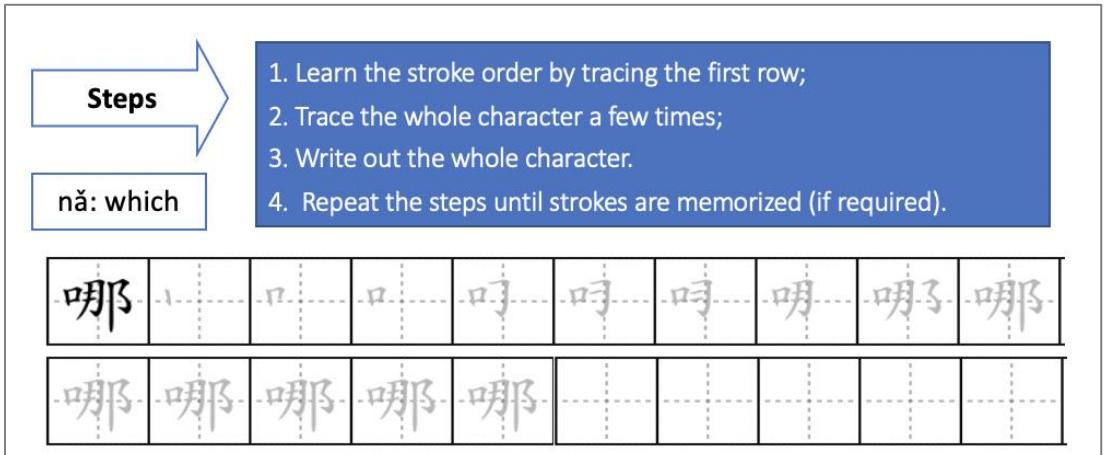
Appendix A

Figure A1

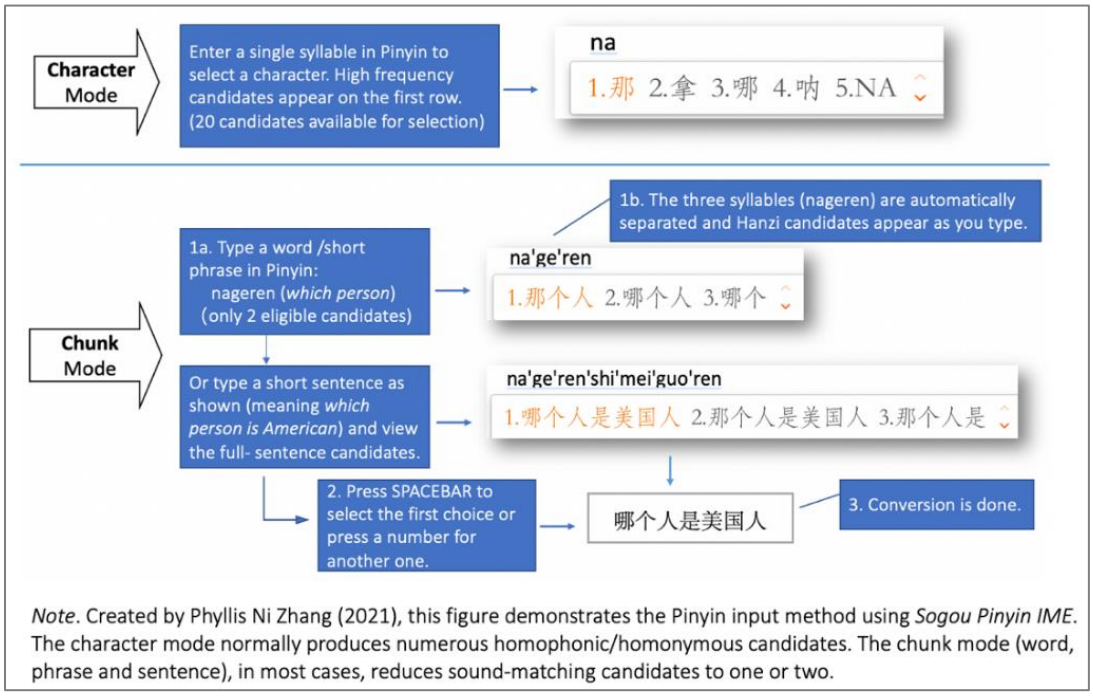
Typical Steps for Learning Chinese Characters (Hanzi) by Handwriting



Note. This example demonstrates typical initial steps for L2 Chinese beginners to learn Chinese characters (Hanzi) based on the traditional handwriting method.

Figure A2

Chinese Word Processing with a Pinyin-based Input Method



Note. Created by Phyllis Ni Zhang (2021), this figure demonstrates the Pinyin input method using *Sogou Pinyin IME*. The character mode normally produces numerous homophonic/homonymous candidates. The chunk mode (word, phrase and sentence), in most cases, reduces sound-matching candidates to one or two.

Appendix B

Table B1

Hanzi Practice and Requirement for Each Cohort

	General Hanzi Practice/Requirement	Daily Hanzi Practice/Quiz			Routine Assignments		Unit Tests	Final Essays
Cohort and Modality	**Course 1** (14 Weeks x 5 hrs)	New characters	Quiz/ handwrite	Quiz/ reading	Grammar exercises	Weekly exercises	Reading, grammar, vocab.	Timed
[Fall 2015] HM-primary (HM)	a. Daily handwriting and memorization; b. Regular typing for assignments	8-10	dictation 5 items	3 phrases	online, type	handwrite; type	handwrite; type	type
[Fall 2016] HM-moderate (HM-b)	a. Daily handwriting and memorization; b. Regular typing for assignments	4-5	copy 4 items	3 phrases	online, type	handwrite; type	type	type
[Fall 2017, 2018] Typing-primary	a. Daily audio-aided/Quizlet practice; w/minimal hand-copying/tracing; b. Regular tryping for assignments	10-15	copy 4 items	3 phrases	online, type	type	type	type
Cohort and Modality	**Course 2** (14 Weeks x 5 hrs)	New characters	Quiz/ handwrite	Quiz/ reading	Grammar exercises	Weekly exercises	Reading, grammar, vocab.	Timed
[Spring 2015] HM-primary (HM)	a. Daily handwriting and memorization; b. Regular typing for assignments	8-10	produce 5 items	2 phrases	online, type	handwrite; type	handwrite; type	handwrite; type
[Spring 2017] HM-moderate (HM-b)	a. Daily handwriting and memorization; b. Regular typing for assignments	4-5	produce 4 items	2 phrases	online, type	handwrite; type	type	type
[Spring 2018, 2019] Typing–Digital	a. Daily audio-aided/Quizlet practice; handwriting not required b. Regular tryping for assignments	10-15	none	2 phrases	online, type	type	type	type

Table B2

Grouping of Data

Records	Course 1 (true beginners)	N (81)	Tests Total	Surveys Total	3 Reading Tests	2 Typed-Essays	1 Hanzi Test	1 Entrance Test/Survey	1 Exit Survey
Fall '15	HM-primary (HM)	27	135	54	81	54	N/A	27	27
Fall '16	HM-moderate (HM-b)	27	162	54	81	54	27	27	27
Fall '17, 18	Typing-Digital	27	162	54	81	54	27	27	27
	Course 1 analyzed records (621)		459	162	243	162	54	81	81
Records	Course 2 (continuing beginners)	N (78)	Tests Total	Surveys Total	6 Reading Tests	5 Typing tests	1 Typed-essay	2 Hanzi Tests	1 Exit Survey
Spring '15	HM-primary (HM)*	27*	27	27	N/A	N/A	27	N/A	27
Spring '17	HM-moderate (HM-b)	26	364	26	156	130	26	52	26
Spring '18,19	Typing-Digital	25	350	25	150	125	25	50	25
	Course 2 analyzed records (819)		741	78	306	255	78	102	78
	Total analyzed records (1440)		1200	240					

* marked cases in Course 2, Spring '15 (N=27) indicates unpaired samples.

