February 2012, Volume 16, Number 1
pp. 110–130

EFFECTS ON LEARNING LOGOGRAPHIC CHARACTER FORMATION IN COMPUTER-ASSISTED HANDWRITING INSTRUCTION

Chen-hui Tsai, University of California, Berkeley, USA

Chin-Hwa Kuo, Tamkang University, Taiwan

Wen-Bing Horng, Tamkang University, Taiwan

Chun-Wen Chen, Taipei National University of the Arts, Taiwan

This paper reports on a study that investigates how different learning methods might affect the learning process of character handwriting among beginning college learners of Chinese, as measured by tests of recognition, approximate production, precise production, and awareness of conventional stroke sequence. Two methodologies were examined during character learning: a worksheet numbering system (the most prevailing workbook method used to learn characters) and a theoretically grounded handwriting system (a multimedia method). A repeated-measures MANOVA showed that under the multimedia treatment, novice learners with no prior character writing experience performed better on all four measures, and first-year learners with six months of character-writing experience only performed better in precise production and awareness of conventional sequence. Variations of character formation produced in both treatments, and learners' perceptions were also analyzed to determine the effects of the two methods. Educational implications in the teaching and learning of character handwriting are provided based on the empirical results.

Keywords: Computer-Assisted Language Learning, Language Teaching Methodology, Multimedia, Writing

INTRODUCTION

Logographic character handwriting, such as *Hanzi* in Chinese, *Kanji* in Japanese, or *Hanja* in Korean, is notoriously difficult for foreign language learners. Fortunately, computer-assisted learning systems for handwriting are being improved to meet the needs of teachers and learners in foreign language education. The use of this developing technology, however, has not been well explored. The aim of this paper is threefold. The first is to draw our readers' attention briefly to first language (L1) handwriting tradition and a common problem in second language (L2) handwriting instruction. The second is to explore the effects of theory-informed multimedia handwriting system compared to the prevailing worksheet method, based on participants' performances in learning handwriting and conventional stroke execution. The third is to provide pedagogical implications from a perspective concerning participants' learning achievements and perceptions, as well as the strengths of the learning tools.

The Role of Character Handwriting in L1 Learning

A character is composed of subset components that are constructed by unique sets of strokes ranging from one to many. The formation and sequence of these components and strokes are not random; the components must fit together internally while the strokes are executed in a conventionally proper manner in L1 handwriting learning. Native beginners are taught to follow established character formation to develop their handwriting skill. The learning of character formation and standard sequencing is reinforced through class instruction and teaching materials throughout elementary education (Taylor & Taylor, 1995), as seen in: China, Taiwan, Hong Kong, Singapore, Japan, and Korea. Unlike the alphabetic system, the logographic character writing system places a high value in the conventional formation for cultural and practical reasons.

From a neuroscience perspective, the skill of logographic handwriting is associated with reading characters. Recent neuroimaging studies discovered that the premotor cortex, a region for handwriting in the brain, is crucially relevant to logographic character reading, and that the execution of finger movements during stroke counting of ideographic characters can lighten the neural loads in recognition of characters (Matsuo, Kato, Okada, Moriya, Glover, & Nakai, 2003). Additionally, the establishment of motor programs is one of the mechanisms that serve and mediate the formation of long-term memory of Chinese characters (Tan, Spinks, Eden, Perfetti, & Siok, 2005). The role of character handwriting in L1 acquisition involves both tactile learning and neural processes.

A Common Problem in L2 Character Handwriting Instruction

Character learning has been considered a challenging aspect for Chinese as a Foreign Language (CFL) students (Everson, 1998; Ke, Wen, & Kotenbeutel, 2001; Shen, 2004). The difficulty lies in the logographic writing system, which constitutes a barrier to memorization. For language learners, sheer rote learning is inevitable (Fan, Tong, & Song, 1987).

Although handwriting is a part of instruction, effective methods to teach this skill have not been given the attention they need. In an L2 setting, instructors usually reinforce it in a much more flexible manner, allowing learners to “draw” a character as a picture to form a similar shape. This, at least partially, is for two practical reasons. The first is that teachers do not want to overwhelm beginning level learners with the obstacles of handwriting that might generally frustrate them. Learning character handwriting consumes a great amount of time for students. A self-evaluation survey study by Allen (2008) reported that, on average, the first-year participants spent a third of their study time on this one skill; however, the time spent usually did not yield productive results. The second reason is because of time constraints related to teaching loads. It is difficult for teachers to evaluate each character and correct the errors that beginners make, even if the stroke errors are discernable simply by judging the appearance of the produced characters. It is very common to see L2 beginners assemble characters together like a puzzle, using small parts to complete the whole.

Learning of Stroke Sequencing Execution in Characters

Some L2 beginners might believe that the sequence and combination of strokes are of little consequence, so long as the final product looks approximately the same. This requires a clarification of the value of conventional stroke sequence. The first rationale is culture-oriented. For centuries, the learning of the conventional character formation has been considered an essential element in handwriting instruction. It is commonly reinforced in early handwriting education in character-using societies and is generally accepted to bring proper proportion to a character. Traditionally, it is argued to be an aid for correct reproduction of the characters, to facilitate better penmanship as well as easy memorization, and to save energy in writing (Shimomura, 1980). Furthermore, because the conventional execution, to a large extent, originates from Chinese calligraphy, it is easier for learners if they would like to further pursue Chinese calligraphy in the future.

The learning of conventional character formation also serves pedagogical needs. The formation of components in a character follows the general basic principle that a character is written: from left to right or from top to bottom. Each specific component is constructed by conventional strokes; that is, when the component appears in another character, its stroke execution remains the same. This knowledge of formation between and within components, once accumulated to a certain level, is transferrable to help beginners reduce their cognitive load when learning new characters, either from the motor aspect of handwriting or from the provision of clue-giving aids, in which a radical component can be utilized to give clues to the meaning or sound of another character that also shares the same component. For example, whenever the component 女 (meaning, *woman*) appears on any position of a character, it is always written with a uniform three-stroke sequence, whether it be in the character 妈 (meaning, *mother*) or in another one 妆 (meaning, *makeup*). In the long run, this helps students to reproduce characters in proper sequence and proportion even if they have never seen the character before.

For L2 learners, the most practical benefit is probably that the knowledge of conventional character formation enables beginners to effectively use a dictionary. When it comes to indexing and retrieving in a dictionary, the logographic script has been noted as being less convenient than a Western (alphabetic) system (Chen, 1999). There are three major ways for learners to look up a character. The fastest one is the indexing of pronunciation, which requires a user to know the exact sound and the corresponding tone of a character. Since a character's sound is not immediately known from its shape for beginners, this method is actually not useful for them. The second one is based on the character's *bushou* (or, radical). A character's radical refers to the aforementioned distinguishing component of a character, and is arranged based on the number of strokes. A stroke is a complete movement of a handwriting action, beginning when a pen touches the paper until it is lifted. Although this sounds straightforward, it might not be as intuitive for beginning learners because of the architectural nature of characters. For example, the radical 弓 (bow) is built with three strokes (㇕, ㇐ and ㇉), not one stroke (弓) as beginners might perceive. The third method is to search for the characters on a computer recognition program, but, in general, learners must know how to write the character correctly for effective recognition results to be obtained.

Computer-assisted Language Learning (CALL) in Character Handwriting

Over the past two decades, many advances have been made in computer-assisted character learning. With the developing technology of touch-screen devices, the design focus of educational software has shifted from simple visual aids to interactive interfaces. Some software has been designed to identify stroke production errors (Tonouchi & Kawamura, 1997; Tsay & Tsai, 1993) and some to analyze the global features of the handwriting (Kim, Kim, & Bang, 1997; Ozaki, Adachi, Ishii, & Koyazu, 1995); however, for the analysis to function well, the systems either required users to write a character in correct stroke sequence or required them to produce it in the correct shape. However, for beginners, these two skills are exactly the targeted abilities that need cultivation. This gap has been bridged by techniques that evaluate character qualities through stroke execution, and spatial relationships, check for multiple errors, and prompt learners with useful automatic feedback (See Tang & Leung, 2006a; Leung & Komura, 2006; Li, Leung, Lam, & Tsang, 2007; Hu, Leung, & Xu, 2008; Hu, Xu, Huang, & Leung, 2009; Kuo, Huang, Horng, Chen, Chen, & Wang, 2009 for more detailed reading on these techniques.)

Although multimedia methods have become more available and accessible for the teaching and learning of orthographic character writing, empirical investigation on the effects of character learning methods is scant. In L1 learning, some studies (Fang, 2000; Wu, 2002; Lin L., 2004) suggest that the multimedia method with interactive exercises and immediate feedback increased accuracy of character writing in elementary-handwriting education. However, C. Lin (2003) examined the effectiveness of a demonstration-only non-interactive multimedia program on character writing and stroke sequence and found that, in spite of the participants' positive perceptions of the demonstration tool, there were no observable statistically significant differences of the achievement test scores among the participants.

Related research on L2 learning is even more limited. Tang, Li, and Leung (2006) reported that it required less time for the multimedia group to learn Chinese handwriting. In a second attempt, Tang and Leung (2006b) suggested that the learning time was shorter in the customized-feedback condition than in the general-feedback condition. There were several commonalities in these CALL studies. For example, learning was sometimes the secondary focus with the technology being the primary point of the studies. The multimedia effects were examined solely on final written production (i.e., the writing process was left out). While the studies were concerned with the learning time and final production, one might wonder how the multimedia method might affect L2 learners' character learning in other areas. Moreover, most of the relevant studies initiated and developed upon practical teaching and learning need without the basis of a second language acquisition (SLA) theory.

Theoretical SLA and Practical Character Handwriting Instruction

Pica (1997) categorized approaches to SLA research based on their interface with teaching. Complementarity is one interface type, in which SLA research complements L2 instruction through the examination of a theory-grounded learning method or of the materials. In the current study, a theoretically motivated handwriting learning system, selected and developed by the researchers, was employed to explore its possible effect on learning character handwriting for L2 learners. In addition to complementarity, we adopted and modified Chapelle's (1998) interactionist model, which is a simplified version of the one outlined by Gass (1997). The multimedia system was designed to operationalize positive conditions for SLA from an interactionist perspective, and Figure 1 illustrates the basic components and corresponding design rationales of the multimedia program.

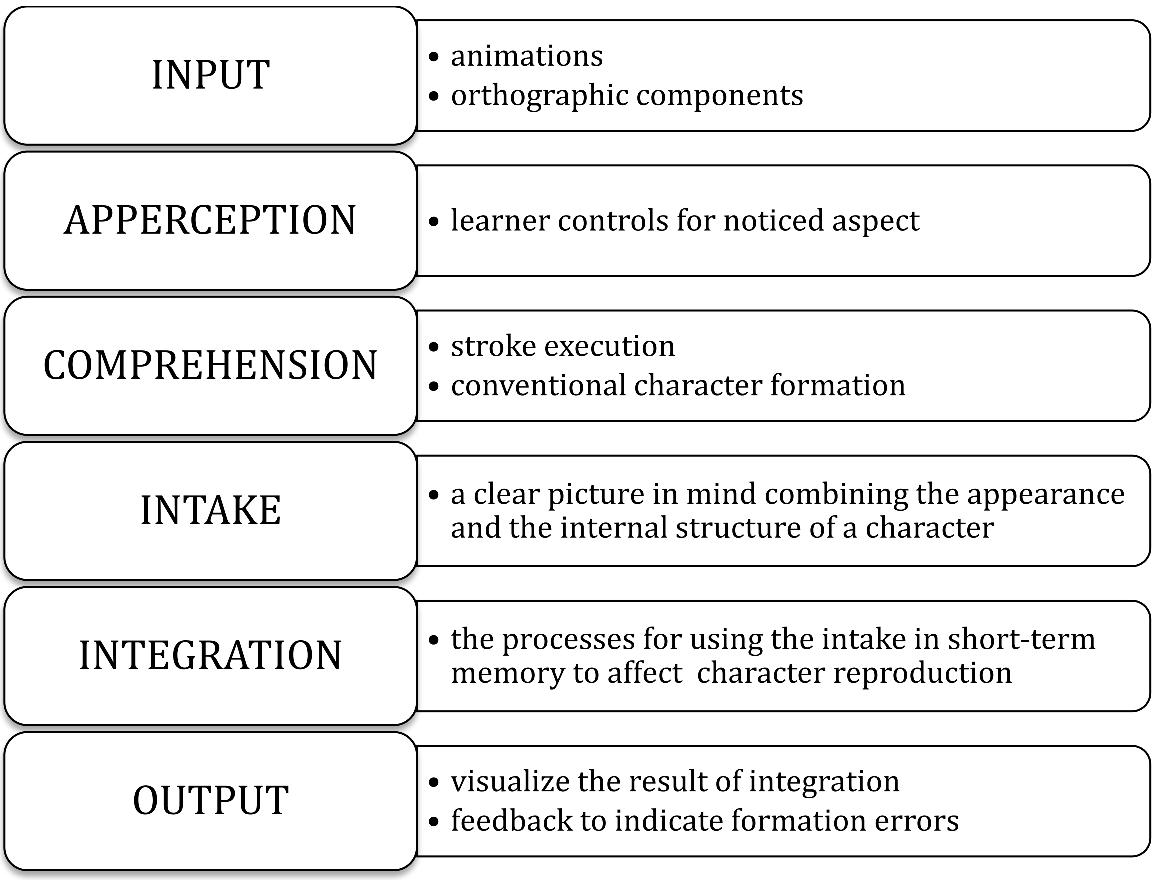


Figure 1. Basic components and corresponding concepts in the design of the interactionist-based multimedia character handwriting program.

In this section, we will address how we apply the constructs of the interactionist model to the learning of character writing. *Input*, located at the top of Figure 1, refers to the character formation a learner is exposed to. Target input is demonstrated to a learner by animations (of the whole character, or by its orthographic subcomponents), but only that which is perceived as having the potential to be acquired. An important aspect of *apperception* is one noticing certain aspects of the input. Learner controls are provided to help a learner to review the noticed aspect of writing.

In learning character handwriting, *comprehension* represents the hypothesis that reproduction of a character can be accomplished either with or without awareness of the conventional formation. However, when comprehension takes place through a combination of authentic stroke execution and conventional character formation, the processing can become *intake*.

Integration is the process of using the intake to influence the development of the character handwriting skills, which in turn affect the character reproduction. The *output* is an observable result of the learning process. It also serves as an aid to develop a specific aspect of a learners' character writing ability. Immediate *feedback* is provided to show indications of problems with the output and that will result in the learner's noticing aspects of the formation, making new integration, and producing more output.

Our particular interest lies in the possible ways in which the designed method assists participants in the learning of conventional formation and character reproduction with the prevailing workbook method serving as the control group. We hope to learn the following: What aspects of handwriting can be improved through either of the learning methods? In addition to that, what are the advantages and disadvantages of the two methods according to the perceptions of the participants? To what extent do novice learners (those with zero experience with orthographic handwriting) and first-year learners (those with prior experience in orthographic handwriting) perceive the two methods differently or similarly? These questions necessitate a research design to integrate quantitative and qualitative features.

METHOD

Operational Definition

In the current study, handwriting refers to the skill of writing Chinese logographic characters by hand. When learning character handwriting, CFL learners need to follow conventional character formation in order to produce a character in its proper shape and proportion among and within sub-components. The conventional character formation indicates the rules about the order and direction in which the strokes and/or sub-components that make up characters should be written. The exercise of character handwriting is usually implemented as self-learning assignments at college level. Thus, self-learning is defined as a learning process done by students themselves outside class. The beginning learners are represented by two groups of students: novice learners with no prior experience and first-year students of Chinese with six-months of experience in character writing. Two methodologies were examined in the present study. The first is the interactionist-based computer-assisted character learning system (hereafter the multimedia method or multimedia task). The other is a popular pen-based workbook approach with aids of numbers marking the stroke sequence along with still images for each stroke (hereafter the prevailing method or prevailing task). The measures of Chinese character handwriting include character recognition, approximate production (judging by the appearance of a character), precise production (judging by conventional formation), and awareness of internal structures. Pronunciation is not emphasized in the measures due to three reasons: 1) this study targets character handwriting skills, 2) Chinese characters do not carry exact phonetic information in general, and 3) this study involves novice learners, whom we would like to focus fully on learning how to write during the assigned tasks.

Research Design

Creswell (2003, p. 215) proposed a mixed-methods sequential explanatory design that consists of two phases: quantitative followed by qualitative. The qualitative data are implemented to help analyze and explain the previous quantitative results. In the current study, we adopted the design strategy and posed a two-phase approach: Phase 1 was a quantitative study that looked at the immediate effects of the two learning methods on character handwriting and character variants. Phase 2 explored the learners' attitudes by administering a survey, which contained Likert scales and corresponding open-ended questions to probe accounts for the learners' perceptions, as well as to examine the Phase 1 results in more explanatory detail from the learners' perspective.

In order to eliminate experimental errors caused by differences among individual participants, the study employs a within-group repeated-measure design (Keppel & Wickens, 1991) to ascertain the effectiveness of performance in the two learning conditions. The order of the two treatment conditions was counterbalanced to reduce possible practice effects.

Research Questions

Performance in Learning Chinese Character Writing

Do statistically significant differences exist among novice and first-year learners of Chinese in terms of character recognition, production, and awareness of conventional formation in character learning between the prevailing learning method and the multimedia method?

Performance in Variations of Character Formation

Do statistically significant differences exist in variations of character formation between the prevailing and the multimedia method?

Learners' Perceptions

1. Are the novice and first-year learners significantly different in their perceptions regarding the stroke demonstration formats of the two learning methods?
2. Do the novice and first-year learners have different degrees of confidence in character reproduction following either of the two learning methods?
3. Do the novice and first-year learners have different preference for either of the learning methods as a means of self-learning?

Participants

Thirty-four native English-speaking college students from a midwestern university in the US participated in the study. Sixteen of the thirty-four participants were recruited from a first-year Chinese class. The remaining eighteen participants were novice learners recruited from a short-term, beginners' Chinese class. At the time of the data collection, the novice learners had some exercises on basic Chinese strokes but had not begun learning characters, while the first-year Chinese group had already studied Chinese characters for approximately six months. A preexperiment background survey showed that none of them had experience in learning an Asian language prior to their Chinese learning. They all considered themselves to have basic computer skills. The participants were compensated for their participation in this study. To avoid a possible Halo effect, participants were recruited from classes that were not taught by the researchers.

Stimulus Characters

Two groups of Chinese characters were selected to implement a with-group design, and were randomly assigned to the two experimental conditions in the study. The two groups were similar in graphic complexity, having similar total stroke counts and stroke turning points and belonging to similar character structure categories. The average number of strokes[1] for each group is 6 and 6.1. Furthermore, the characters in each group represent four character structure categories: left-right structure, top-bottom structure, enclosure structure, and integral structure (see Appendix A for details).

Task Procedure

Participants were asked to learn the selected characters with the two learning conditions, a prevailing task and a multimedia task. A training section was given before each task to help participants familiarize themselves with the format of the tasks in the study. The two groups were randomly designated to the two tasks, and the task order was counterbalanced as well. Each task has three steps.

Step one was a pretest, which confirmed that the target characters were new to all the participants.

Step two was a thirty-minute time-limited writing exercise in which a participant utilized an assigned method to learn how to write the characters.

In a prevailing task, the participants learned character writing by using a worksheet that provided a number marking system and diagram to indicate order of strokes and components within a character (see Appendix B). For each character, the participants were asked to follow the system and reproduce the character five times right next to each provided character on the worksheet. The format of this exercise resembles a popular method that has been adopted by beginning Chinese textbooks.

In the multimedia task, the participants used a computer-assisted program. For each character, participants saw animated demonstration to learn character writing. For each character reproduction, the program provided error-specific feedback for each character entry that a learner submitted. The system checked various error types, such as spatial relationship errors among internal components; stroke production errors including missing, additional, concatenated and/or broken strokes, and so forth. The participants utilized a digital writing tablet to practice writing in the multimedia task. For each character, they had to correctly reproduce five copies in order to move on to the next one.

Step three was an immediate posttest, which consisted of three parts: recognition, production, and awareness of conventional character formation. For the recognition task, the participants were asked to provide a corresponding meaning in English for each character. For the production test, the participants were given English meanings and sounds of the characters and were asked to write the corresponding characters from memory on paper. In the awareness test, the participants were asked to copy each character printed on the awareness task sheet. That is, they handwrote characters one by one with the printed characters on sight. They were also asked to write all of the characters in a correct fashion that they learned during step two. The design of the awareness test is to find out the stroke sequence and execution that the participants learned in step two, and not their ability to remember characters. Fifteen minutes were assigned to the participants to complete step three.

Each participant also took a survey (see Appendix C) at the end of the experiment. The whole experiment was conducted out of class. Each participant took one task per session with both tasks separated by three days. Production and awareness tests were close-up video recorded for further coding.

Coding

Tests in Character Handwriting

The quantitative data were analyzed with SPSS (version 19). The following four aspects of character learning were examined in the posttest:

Recognition. One point was assigned if the English meaning was correct for the stimulus character.

Approximate production. A participant received one point in the production test for writing a character from memory with an approximate shape to the correct form. That is, if a character, judged by examining the character production sheet, was formed in a sense that the rater could recognize easily with or without correct stroke sequence, one point was given.

Precise production. One point was assigned to precise production if a character written from memory in the production test was correctly formed following the standard stroke sequence adopted in this study. This was judged by viewing the corresponding video clips.

Awareness of conventional character formation. One point was given if the on-sight copied character in the awareness test was written in a correct fashion, meaning the appearance was correct, and the internal standard sequence was followed.

Variations of Character Formation

Variation in character formation indicates the incomplete learning of conventional formation in the current study. This was observed by screening the video data of the awareness test. For each character, the variations produced across participants, in either of the learning conditions, were counted.

Qualitative Data Coding

Inductive categorical coding techniques (Teddlie & Tashakkori, 2009) were implemented to analyze open-ended survey responses. In the unitizing process, initial data were reviewed line by line and divided into units of information (UOIs), which are the smallest pieces of meaningful information that are associated with specific themes. These UOIs were again reviewed and provisional categories were generated and attributed to cover similar UOIs, which share potentially meaningful aspects. This categorizing process involves merging and further differentiation of those categories in order to synthesize and conceptualize emerging patterns that surface from the participants' response and to give an idea of the frequencies of each category. Two raters worked on the procedure of classification for three rounds until they reached unanimous consensus of categories.

Performance in Learning Character Writing

Since the two groups of participants are not equal and a within-subjects analysis of variance is very sensitive to violations of the sphericity assumption, we first checked to see if the sphericity assumption is met (Mauchly's Test of Sphericity) before conducting a repeated-measures MANOVA analysis. Table 1a and 1b show that Epsilon is 1.000 (greater than 0.75) and thus indicates perfect Sphericity. The sphericity assumption is met.

Table 1a. *Mauchly's Test of Sphericity*

Within Subjects Effect	Measure	Mauchly's W	Approx. Chi-Square	df	Sig.
Condition	Recognition	1.000	.000	0	.000
	Approximate production	1.000	.000	0	.000
	Precise production	1.000	.000	0	.000
	Awareness	1.000	.000	0	.000

Table 1b. *Mauchly's Test of Sphericity*

		EPSILON		
Within Subjects Effect	Measure	Greenhouse-geisser	Huynh-feldt	Lower-bound
Condition	Recognition	1.000	1.000	1.000
	Approximate production	1.000	1.000	1.000
	Precise production	1.000	1.000	1.000
	Awareness	1.000	1.000	1.000

The 2 × 2 × 4 (level × condition × performance) repeated-measures MANOVA analysis, see Table 2, indicated a significant effect of condition ($p < .001$), and a significant interaction effect between condition and level ($p = .043$).

Table 2. *Repeated-Measures MANOVA Analysis for Character Learning*

Effect	Wilks' Lambda	SS	df	MS	Error df	F	p
Between subjects							
Intercept	.064	1849.432	4	462.358	29	105.668	.000
Level	.378	178.749	4	4.687	29	11.945	.000**
Within subjects							
Condition	.250	59.583	4	14.896	29	21.712	.000**
Condition*Level	.720	9.005	4	2.251	29	2.823	.043*

Note. ** $p < .05$, ** $p < .01$.*

Since the two groups of learners have different proficiency in Chinese character writing, we do expect to see a main effect of level. Because the interaction effect was significant, the interpretation focuses on the interaction effect rather than on the main effect of condition (i.e., the learning methods). The Scheffé test was chosen to perform Post hoc tests because the two groups are different in size. Additionally, the test is more conservative and will reduce the risk of a Type I error. Post hoc tests with the Scheffé test, see Table 3, showed pairwise comparisons of the two levels and conditions broken down by the four measures in character writing: recognition, approximate production, precise production and awareness of conventional character formation. The results suggest that novice participants performed significantly better with the aid of the multimedia program in all measures evaluated in the study, while first-year participants did better on two measures, the tests of precise production and awareness.

Of the four Multivariate test results given, Wilks' Lambda (Wilks'Λ) is commonly used. For between subjects, Wilks' Lambda is .378. Thus, the proportion of the variance in the outcomes that is not explained by an effect is .378. For within subjects, Wilks' Lambda is .250. Thus, the proportion of the variance in the outcomes that is not explained by an effect is .250.

Table 3. *Pairwise Comparisons of the Level and Condition by the Four Measures (Performance)*

Measure	Level	MD (Multimedia-Prevailing)	SD	p
Recognition	Novice	1.333	.454	.005**
	First-year	.938	.482	.059
Approximate production	Novice	1.778	.473	.001**
	First-year	.125	.502	.795
Precise production	Novice	2.000	.505	.001**
	First-year	1.750	.536	.002**
Awareness	Novice	3.833	.540	.001**
	First-year	2.375	.573	.001**

Note. *The test is based on estimated marginal means, ** $p < .01$.*

Performance in Variations of Character Formation

A homogeneity test is reported (see Table 4) before we move onto a paired t-test. The significance is .211

which is greater than .05. We can assume that the variances are approximately equal. We have met our assumption. A paired t-test was used to compare the mean number of variants for the targeted characters produced by the learners using the two learning methods. The results, see Table 5, indicated that participants produced more formation variants in the prevailing task (*M* = 6.35, *SD* = 3.45) than in the multimedia task (*M* = 2.80, *SD* = 1.81). In other words, the multimedia method helped the learners significantly reduce the variations of character formation (t[17] = 5.089, *p* = .000, two-tailed) during the learning process in the study.

Table 4. *Test of Homogeneity of Variances*

Levene Statistic	df1	df2	sig.
2.252	3	35	.211

Table 5. *Paired-Samples t-Test of Character Writing Variants for the Twenty Target Characters between the Two Learning Conditions*

Pair	Paired Differences			t	p
	M	SD	SE		
Prevailing-Multimedia	3.55	3.12	.698	5.089	.000**

*Note. ** p < .01.*

Learners' Perceptions

Learners' Perceptions of Stroke Demonstration Formats in the Two Learning Methods (Number-Marking Worksheet and the Multimedia Method)

The participants' ratings on the survey items 1 and 2 were analyzed with a repeated measures MANOVA to test whether the learners' perceived one stroke demonstration format to be more useful than the other, and whether this depended on the level of prior learning experience. Table 6 shows that the main effect of the stroke demonstration types was significant (*p* = .001); however, the main effect of learning experience was not significant (*F* = .44, *p* = .512) and the interaction between demonstration types and levels was not significant (*F* = .194, *p* = .663). The effect of stroke demonstration types was clear: The participants in this study perceived that using multimedia animation (*M* = 6.15) was slightly better than using prevailing numbering to demonstrate the stroke sequence (*M* = 4.65).

Table 6. *Tests of Within-Subjects Contrasts for Learners' Perceptions of Demonstration Formats*

Source	SS	df	MS	F	p
Demonstration type	37.590	1	37.590	13.713	.001**
Demonstration * Level	.531	1	.531	.194	.663

*Note. **p < .01.*

Learners' Perceptions of their Confidence in Character Reproduction

Items 3 and 4 on the survey explore the participants' degree of confidence in learning character writing with the aid of the two learning tools. Table 7 indicated that the main effects of condition (learning methods), as well as the interaction effects between condition and level, were observed in the repeated MANOVA test for the two statements. However, the main effect of level of experience was not significant (F = .009, p = .927). To take a closer look at the interaction effects, post hoc tests with the Scheffé test were conducted to reveal that the novice learners have more confidence in character reproduction after taking the multimedia task (F = 15.935, p = .001), while, for the first-year learners, there was no difference based on task type (F = .398, p = .503).

Table 7. *Tests of Within-Subjects Contrasts for Learners' Perceptions of Confidence in Character Reproduction*

Source	SS	df	MS	F	p
Condition	23.890	1	23.890	9.817	.004**
Condition * Level	11.184	1	11.184	4.596	.040*
Error (condition)	77.875	32	2.434		

*Note. *p < .05, ** p < .01.*

Learners' Preference for Either of the Learning Methods

Statements 5 and 6 of the survey inquire about the participants' preference for the learning tools. A repeated MANOVA test was carried out to see whether the learners liked one learning method more than the other and whether this depended on the level of prior learning experience. The result, see Table 8, tells us that there was a main effect of condition, the learning methods, (Wilk's Lambda = 0.848, F = 5.735; p = .023), but not for level of prior experience (F = 0.554, p = .462). The interaction effect between task type and level (Wilk's Lambda = 0.775, F = 9.278; p = .005) was also significant, suggesting that the interaction may explain the variability among the means of the participants' responses. Since the interaction was significant, the interpretation focuses on this rather than on the main effect of condition.

Table 8. *Result of a Repeated MANOVA Test for Learners' Preference to the Learning Methods*

Effect	SS	df	MS	F	p
Between subjects					
Intercept	1759.441	1	1759.441	947.194	.000
Level	1.030	1	1.030	.554	.462
Error	59.441	32	1.858		
Within subjects					
Condition	22.378	1	22.378	5.735	.023*
Condition * Level	36.201	1	36.201	9.278	.005**
Error	124.858	32	3.902		

Note. ** p < .05, ** p < .01.*

Post hoc tests with the Scheffé test demonstrated that the first-year participants liked the prevailing (M = 5.38) and multimedia tasks (M = 5.06) to about the same degree (F = 14.97, p = .598) while the novice participants liked the multimedia task (M =6.28) more than they liked the prevailing task (M =3.67, p = .000). That is, the first-year participants did not have a significant preference on either of the tools, whereas the novice participants preferred the multimedia program as a means of self-learning. Post hoc tests with the Scheffé test showed additional pairwise comparisons of the two levels of experience broken down by task type that suggest the following: the first-year participants liked the prevailing task more than the novices did (p = .015), but liked the multimedia task less than the novices did (p = .013).

INTERPRETATION AND DISCUSSION

Multimedia Effects on Learning Character Handwriting

The multimedia effects on the precise production and awareness of conventional formation were significant among the participants in this study. This begs the question: Why and how did the multimedia method affect the improvement of the invisible progress in the course of learning? In answering the question, we look to the differences in the “input enhancement” (Smith, 1993) of the two learning conditions.

When an instructor assigns character homework, the exercise is usually devised to show the movement (visual exercises), and to direct learners to feel the movement (kinesthetic exercises). We will focus on the visual exercises for a moment. On a worksheet used in the prevailing method, a target character is presented with numbers referring to the sequence of the strokes and with a still diagram showing stroke position. The learners need to fulfill the writing trial with the final printed product in sight without a precise movement indicating the exact writing procedure.

The other condition, the multimedia method, might provide more comprehensive input for the participants. From a cognitive point of view, learning a language involves working memory. Baddeley (2003) provides a review of working memory and language learning. He proposed that working memory could be divided into three subsystems: the central executive, the visuospatial sketchpad, and the phonological loop. The one that is concerned with visual information is the visuo-spatial sketchpad, which “serves the function of integrating spatial, visual, and possibly kinesthetic information into a unified representation which may be temporarily stored and manipulated” (p. 200). The multimedia-learning program provides stroke animation that shows the movement required for each stroke of a character. This animated visual demonstration might help enable learners to incorporate information about a stroke’s directionality and component formation in a vividly successive manner. This could offer continuous and detailed input for the visuo-spatial sketchpad to better prepare learners for kinesthetic exercises, which immediately followed.

With regard to the kinesthetic exercises, in the prevailing task, the participants did not have immediate feedback on their writing. They completed the writing task and moved on. In a regular class setting at college, character homework is graded and returned a few days later. When they receive the delayed feedback on their writing, the whole learning process has been done, and due to the pacing of college assignments, it is rare that students would review and fix the problems, as they have already moved to the next lesson.

In the multimedia task, however, when the participants committed any writing errors, immediate feedback was prompted after submission to specify any problems. They watched the stroke animation again to review what the accurate form should be and, by the system’s workflow, were forced back to correct themselves. It seems that during this cognitive activity of handwriting, learners’ attention was directed to the visual details that distinguish the differences between what they thought it was and what it truly is. The process cycled until the character was completed in an authentic manner. Therefore, even though there might be factors unique to each participant that influence the likelihood of apprehension in conventional formation, the input enhancement combined with customized, error-specific feedback, helped the participants facilitate input assimilation, integrate new forms, modify their output, and improve the quality of handwriting. This in turn accentuated the learning of conventional character formation in the study.

Multimedia Effects on Variations of Character Formation

The effects of the processes illustrated above are further evidenced by the variations of character formation produced by the participants in this study. In the multimedia task, these variations were significantly less than in the prevailing task. Take one of the targeted characters, 囚 (meaning, *prisoner*), as an example to depict modifications produced during the learning process; the outer surrounding box is authentically formed in a fixed manner, which consists of three strokes (see Figure 2 for an illustration of the standard formation). The authentic way to write this character is to construct the 冂 part first, then insert a two-stroke character for person 人 inside the cell, and finally close the bottom of the character with a finishing horizontal line. There were six types of variations of this character found in the prevailing task (#1 and #6 represent the same error type), while none was observed in the multimedia task, neither among novice nor among the first-year learners, for this example. Figure 2 shows all of the variations that emerged from the data in the prevailing task for this character. In order to highlight the deviant formation, only the parts that were incorrectly written were shown, and arrows were used to indicate directions or movements of strokes.

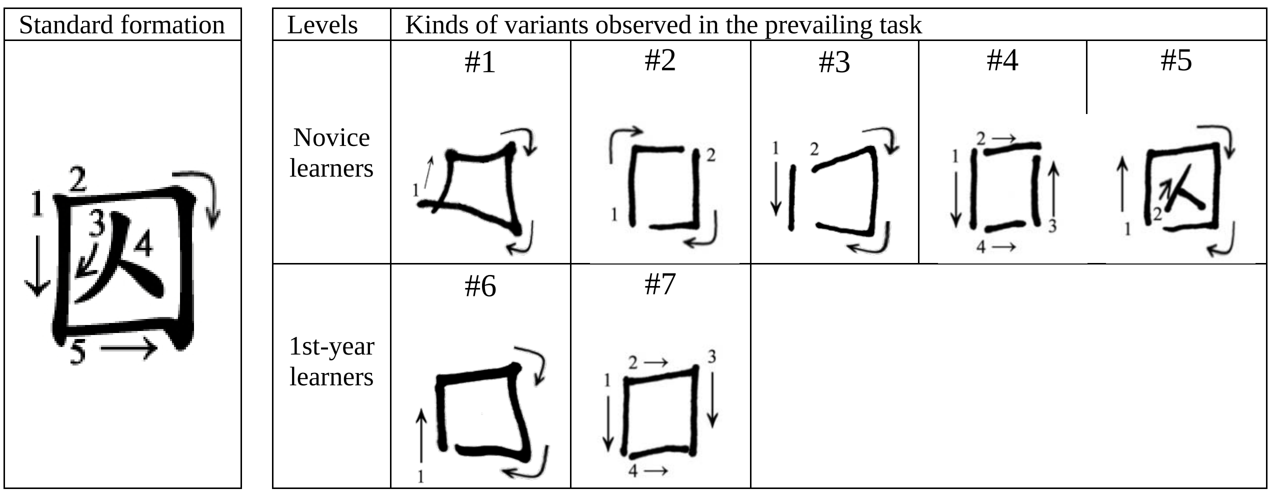


Figure 2. An example of variance in the prevailing worksheet task.

Some participants compressed the three-stroke box into one (#1, #5, and #6) or two strokes (#2 and #3), and while others extended it into four strokes in the prevailing task (#4 and #7). Some of them changed the stroke number and/or sequence while others made the shape of a character improperly proportioned (#1, #3, and #6) or created inappropriate gaps of joints (#2, #3, #4, and #7). As described previously in this discussion, things could easily go wrong during the prevailing learning process since there is no visual demonstration with feedback. For the novice participants, the components and the character are brand new stimuli; therefore, they have not yet developed a precise perception of how the components are formed. Thus, they sequentially engendered more variations. Nevertheless, for the first-year participants, they have learned three characters with the same box component (i.e., 图, 国, and 回; meaning, *map*, *country*, and *to return*, respectively) in their prior experience of character learning; we did not expect to see variations in first-year participants' characters productions.

In order to further examine if these kinds of errors were inadvertent, we scrutinized those corresponding characters produced by the participants who made these modifications in their character production tests and in the writing exercises as well. We found that those variations were not random productions. Two patterns were observed: one is that the first-year participants wrote the character in the wrong way throughout the study; the other is that they changed the way they wrote the character every time they produced it. That is, the variations were unpredictable for the character. In the former pattern, the wrong formation was reinforced in the writing exercise while the latter showed the fluctuations during the learning process. This phenomenon illustrates how different learning methods might have an impact on the dimension of interlanguage variation in character handwriting. More examples of the participants' handwriting in the awareness tests can be seen at the following links:

The target character: 官 (Meaning, *officer*)

- Prevailing task: one of the 7 types of formation errors among novice participants (Link 1)
- Prevailing task: one of the 4 types of formation errors among first-year participants (Link 2)
- Multimedia task: one of the 2 types of formation errors among novice participants (Link 3)
- Multimedia task: No error was made for this character among the first-year participants

The problem of formation variation indeed exists but is usually neglected in handwriting instruction especially when students are expected to fulfill the motor-skill training through self-learning. As mentioned before, it is difficult for teachers to correct students' errors in detail. They are usually tempted to allow students to reproduce a visual approximation of a character rather than to follow the authentic character formation paradigm. Sassoon (1995), in her research on handwriting acquisition, pointed out that this method of teaching a writing system, i.e., allowing students to reproduce a visual approximation of a character, may allow students "to express themselves more quickly in writing, but may also have a disastrous effect later on. As [hand]writing is a physical act, any aspect of it quickly becomes automated, and when practiced, becomes increasingly difficult to alter" (p.21). This is particularly true in learning logographic characters. In the following sections, we will turn to the second phase of the study and focus on the participants' points of view.

Learners' Perception of the Two Learning Methods

Degree of Confidence in Character Reproduction

The novice participants had more confidence in character reproduction when they learned with the aid of the multimedia tool and that was echoed in their performances in all the measures in the current study. In their corresponding open-ended responses, 15 UOIs were obtained. The primary reason for their perceived confidence was that the multimedia method reinforced the correct character formation (67%) in learning process by giving immediate feedback that challenged their misconceptions. The following are a few comments given by the learners in this category: "It showed what I was doing wrong when I felt it right," and, "I feel more immersed in the character … feedback on my characters helps correct errors early before they become a habit."

Another category explaining the degree of confidence was that the multimedia method enhanced their memorization (27%). Some of the learners noted that "… even if I wasn't able to remember the character right away I could remember how to copy them correctly and I could recall more of them than I could with the paper task," and another participant noted "Watching the animation and copying the movements greatly improved my memory."

For the first-year participants, the use of the learning methods did not bring a statistically significant difference in the degree of confidence in character reproduction. We looked at their responses that commented on their rating on survey item 3, which inquired about their degree of confidence in character reproduction in the prevailing task. Thirteen UOIs were obtained with 9 in the main category (regular practice). That is, among the first-year participants, 69% of the qualitative data indicated that their confidence resulted from the regularity of the practice form in the prevailing method. One example from these responses is "I already felt confident doing this due to Chinese class. " However, along with these kinds of responses, a concern with the uncertainty of authentic formation also emerged. This problem is stated by a first-year learner as “you can whip through without really absorbing what you are writing.”

Although the first-year participants did significantly better in the precise production and awareness tests, their ratings did not reflect this result. It is very likely that their confidence in character reproduction results from whether they could recognize a character and whether they could produce the approximate shapes of characters, but not the precise production or better awareness of internal structures. That is, their confidence might come from the quantities, instead of the quality of their productions.

Preference between the Two Methods

The novice participants’ ratings and responses were clear: they liked the multimedia aid as a means of self-learning. Three advantages, among 24 UOIs, were specifically identified from the participants’ qualitative responses to survey item 6, (a) provide maximum correctness (54%), (b) provide animation (25%), and (c) provide motivation (21%). The first two were addressed previously, so we will elaborate more on the third. Some novice participants considered it more motivating to fulfill the multimedia task because the system would not let go until they completed a correct entry. Some of the comments were, “It was more fun and motivated me to try harder,” and “It felt like a game so I wanted to be perfect.”

We also looked at their verbal responses to the prevailing method, survey item 5, in order to see why there was a significant difference in their preference. Among 16 UOIs, the first category that emerged to the top was the sense of uncertainty in accuracy regarding the paper worksheet (44%); the second category was expediency. Some of them noticed the possibility that one could go through the paper exercise in a quick manner (25%). The first-year participants, interestingly enough, perceived this disadvantage noted by the novice participants, as an advantage.

The survey result revealed that the first-year participants liked the prevailing method more than the novices did. The first emerging reason, among 17 UOIs, was that they could complete writing exercises with the prevailing method in a faster and more flexible manner (41%), which seemed to be a major concern to them. Some participants wrote, “I have more control over ways of writing a character.” “Sometimes a different way (to write a character) feels more natural and I want to deviate.”

Our quantitative analysis also depicted that the first-year learners liked the multimedia task less than the novices did. This is also reflected in their comments toward the multimedia method: “Completing the task on the computer forced me to slow down when practicing because the program was checking my accuracy. I couldn’t rush through it.” One participant who habitually began a stroke from bottom to top commented that he was irritated at having to change his stroke: “…many ways (of writing a character) are easier for my memory.”

The first-year learners’ perception was, in all probability, influenced by their prior experience of learning characters in the contemporary conditions of character learning. With many new words in every lesson, they have a legitimate need to value their exercise time. It is also reasonable that they would prefer a more flexible way to achieve a high score on a vocabulary quiz. Since only the skills of recognition and approximate production are praised in tests, the accuracy and conventional formation of characters are consequently ignored during the learning process. Once a handwriting habit is established, learners find it awkward to change it.

From this, we can also see how goal orientation of a learning task might color learners’ learning attitudes and affect learning processes. The prevailing task allows information to travel only one-way—the goal of the task becomes “completion” to the learners while the process becomes secondary. The multimedia program, however, requires a two-way information exchange between the learning tool and the learners. This puts an impetus on the learner to interact: they expected their output to be comprehended or acknowledged by the learning tool to see if their output was appropriately formed. This expectation pushed them to actively attempt to learn the character formation. The primary goal of the task was shifted to the learning of the target knowledge needed to complete the task. This goal orientation of the learning tasks leads our attention to the likely problems and educational implications in character handwriting instruction.

Educational Implications

Do teachers want to emphasize the quantity or the quality of characters in teaching or learning handwriting? In addition to the participants' perceptions, the phenomenon that our participants produced much more variations and less precise production with the prevailing method informs practitioners of a need to be more realistic in their curriculum objectives in character learning. We share a similar view with Ke (1998), who accurately pointed out that "although curriculum philosophies vary from program to program, it appears that at the initial stages of Chinese language learning, we need to control the amount of characters for our students to produce" (p. 98). If we overemphasize the quantity of characters, for instance, requesting beginners to write all the characters in the vocabulary list of a lesson by memory, quality and authenticity of character handwriting are most typically sacrificed. By controlling the amount, students could focus on character formation and the establishment of character writing skill. Because learners must find a way to be productive anyway, with limited time and cognitive constraints, the chance is greater that they would deviate to "draw" characters freestyle to compose approximate shapes instead of writing characters in a conventional and authentic manner.

Instructors might underestimate the difficulties that confront adult learners. Our observation in the learners' character variations indirectly showed that the participants' errors were not random, and could be classified into several types. It is beyond the scope of this article to analyze the stroke error types of learners' production that might result from their established cognitions, such as their L1 writing system. The fact that the multimedia effects improved the participants' performance in conventional character formation and reduced their variations in the study presented the great possibility that this developing technology (i.e., multimedia with immediate error-specific feedback) appears to have positive effects on novice learners' short-term achievements and benefit the motor aspect of the character learning. That, in turn, could lay a more thorough groundwork for teaching handwriting, especially at the initial learning stage. It may be worth mentioning that although the Chinese characters and CFL learners were chosen to serve the purpose of the study, the proposed technology could also accommodate different kinds of writing systems including minute differences among Chinese societies as well as Japanese and Korean characters, which are written differently (e.g., with different stroke orders), or characters created by the Japanese and Korean.

Finally, while the conventional character formation has been the focus in this study, we are not arguing for the implementation of a rigorous stroke sequence per se. Rather, we would like to emphasize the feasibility and the desirability of developing culture-oriented automaticity in the beginning learners' production of common strokes and subcharacter components, with an emphasis on quality rather than quantity of characters in learning logographic handwriting.

LIMITATIONS AND FURTHER RESEARCH

First of all, we remain aware that the small number of participants and stimuli sheds doubt on the validity of the observed significances found in the data analyses. Thus, the results cannot be generalized. However, the findings of this study could offer insights into the possible effects and perceptions that the learning methods might bring to the two sublevel beginning learners (novice beginners and first-year learners who had some prior experience in developing their handwriting skills). Second, only short-term effects on writing performances were studied. Future research should be undertaken to determine if the multimedia effects are retained for a longer period of time at the initial stage of learning logographic character handwriting. Third, as mentioned earlier, a discussion of the writing error types is beyond the scope of this paper. It might be of interest for future studies to explore if the learning methods affect learners' error types in learning conventional character formation. Fourth, since we are interested in the multimedia effect on learning character handwriting, the criteria of character selection primarily focused on writing complexity and visual structure categories. Additionally, because the current study involved novice learners, we did not include high-density characters in the stimuli. Perhaps future research could cover more complex character or control other possible factors, for example, degree of stroke repetition, the parallel of internal structure, character frequency, etc. It is our hope to highlight the need for more research to investigate the effects of learning methods in logographic handwriting instruction. Studies of this kind could provide information for practitioners and L2 beginners to better overcome difficulties in learning logographic character handwriting, to exploit viability of the new technology in this process, and thus to offer dynamic options to enhance instruction.

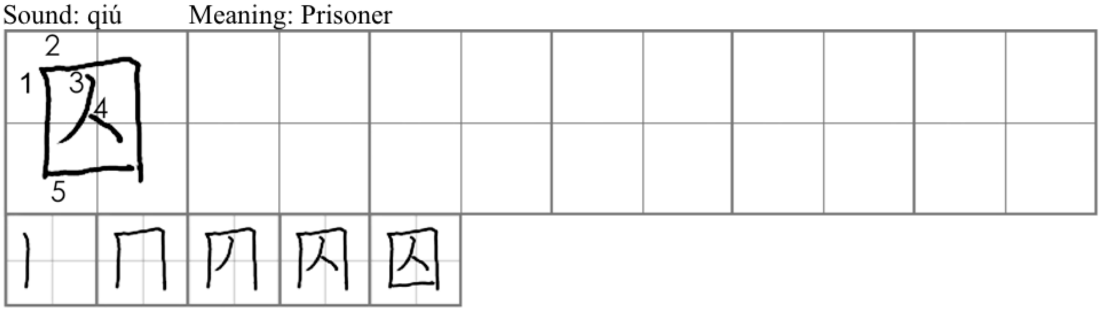
APPENDIX A.

Group	Top-bottom structure	Left-right structure	Enclosure structure	Integral structure	Average of stroke numbers in the group	Average of turning points in the group
1	尖 帛 官 (7.3)	狂 冶 (7)	囚 述 (6.5)	广 弗 勺 (3.6)	6	1.5
2	并 胃 毒 (8)	町 低 (7)	武 世 (6.5)	叉 刃 丹 (3.3)	6.1	1.4

Note. The enclosure structure includes visually partial enclosure and/or full enclosure. The numbers in the parentheses denote the average number of strokes among the characters in the structure categories.

APPENDIX B.

Sound: qiú Meaning: Prisoner



APPENDIX C.

Survey for Learning Methods in Chinese Character Writing

Participant #:

Instructions: Please rate the follow items from the 7-point scale where 1 indicates **strongly disagree** and 7 **strongly agree**. After you have rated one item, please also answer the corresponding "open-ended" question in the "comments" column based on your rating for the item. Your answers are confidential. Your opinions and feedback are valuable to the study. Thank you very much for your time and participation.

	Strongly Disagree			M			Strongly Agree	Comments: Please be specific. You can use the reverse side for more space.
Section I: Questions about the stroke demonstration								
1. I think that using numbers to mark the order of strokes would better teach me to write a character by myself.	1	2	3	4	5	6	7	In what way?
2. I think that using animation to show the order of strokes would better teach me to write a character by myself.	1	2	3	4	5	6	7	In what way?
Section II: Questions about character writing.								
3. I feel more confident that I have completely learned how to write a character after I have done the corresponding character exercise for the target character.	1	2	3	4	5	6	7	How or why?
4. I feel more confident that I have completely learned how to write a character after I have finished the corresponding digital exercise for the target character.	1	2	3	4	5	6	7	How or why?
5. I like to do the character exercise on a piece of paper for the prevailing task as a means of self-learning.	1	2	3	4	5	6	7	Primary reason?
6. I like to do the character exercise on a computer for the multimedia task as a means of self-learning.	1	2	3	4	5	6	7	Primary reason?

NOTES

1. Among the 3,500 Chinese characters for common use, the simplest characters have 1 stroke each, and the most complex character has 24 strokes. The majority of the characters have between 6 and 13 strokes (Taylor & Taylor, 1995). The average number of strokes for each group of characters in the current study is approximately 6 as our targeted participants are novice and beginning learners.

ACKNOWLEDGEMENTS

"Xue-wen Easy Go!" program was adapted and modified to serve the present study. The computer-assisted character-learning program was developed by the Center of Digital Language Research (CDLR) at Tamkang University in Taiwan. The experimental apparatus in the present study was supported in part by CDLR's grant from National Science Council (NSC 100-2631-S-032-001) in Taiwan. The authors of the article are grateful to the anonymous reviewers for their inspiring comments and suggestions.

ABOUT THE AUTHORS

Chen-Hui Tsai is currently a lecturer at the Department of East Asian Languages & Cultures at the

University of California, Berkeley. Her research interests are logographic character acquisition, as well as educational technology and SLA.

E-mail: chtsai@berkeley.edu

Chin-Hwa Kuo is a professor and chairman at the Department of Computer Science and Information Science and the director of Digital Language Research Center, Tamkang University, Taiwan. His research interests include computer assisted language learning and multimedia processing.

E-mail: chkuo@mail.tku.edu.tw

Wen-Bing Horng is a professor in the Department of Computer Science and Information Engineering, Tamkang University, Taiwan. His research interests include image processing, artificial intelligence, and information security.

E-mail: horng@mail.tku.edu.tw

Chun-Wen Chen received his Ph.D. in Computer Science and Information Engineering, Tamkang University, Taiwan in 2009. He is currently an assistant researcher in Center for Teaching and Learning, Taipei National University of the Arts, Taiwan. His research interests include image processing and artificial intelligence.

E-mail: mavins.chen@gmail.com

REFERENCES

Allen, J. (2008). Why learning to write Chinese is a waste of time: A modest proposal. *Foreign Language Annals, 41*(2), 237–251.

Baddeley, A. (2003). Working memory and language: An overview. *Journal of Communication disorders, 36*(3), 189–208.

Chapelle, C. (1998). Multimedia CALL: Lessons to be learned from research on instructed SLA. *Language Learning & Technology, 2*(1), 22–36. Retrieved from http://llt.msu.edu/vol2num1/pdf/article1.pdf

Chen, P. (1999). *Modern Chinese: history and sociolinguistics*. Cambridge: Cambridge University Press.

Creswell, J. (2003). *Research design: Qualitative, quantitative, and mixed methods approaches* (2nd Ed.). Thousand Oaks, CA: Sage Publications, Inc.

Everson, M. (1998). Word recognition among learners of Chinese as a foreign language: Investigating the relationship between naming and knowing. *Modern Language Journal, 82*(2), 194–204.

Fan, L., Tong, L., & Song, J. (1987). The characteristics of Chinese language and children's learning to read and write. *The Future of Literacy in a Changing World*, 87–94.

Fang, D. (2000). *Web-based Chinese characters CAI system for primary school learners.* Unpublished master's thesis, Department of Information and Computer Education, College of Science, National University of Tainan, Taiwan.

Gass, S. M. (1997). *Input, interaction, and the second language learner*. Mahwah, NJ: Lawrence Erlbaum Associates.

Hu, Z., Leung, H., & Xu, Y. (2008). Automated Chinese Handwriting Error Detection Using Attributed Relational Graph Matching, *Lecture Notes in Computer Science, 5145*, 344–355.

Hu, Z., Xu, Y., Huang, L., & Leung, H. (2009). A Chinese Handwriting Education System with

Automatic Error Detection, *Journal of Software, 4*(2), 101–107.

Ke, C. (1998). Effects of language background on the learning of Chinese characters among foreign language students. *Foreign Language Annals, 31*(1), 91–102.

Ke, C., Wen, X., & Kotenbeutel, C. (2001). Report on the 2000 CLTA articulation project. *Journal of the Chinese Language Teacher's Association, 36*(3), 25–60.

Keppel, G., & Wickens, T. (1991). *Design and analysis: A researcher's handbook.* Englewood Cliffs, NJ: Prentice-Hall.

Kim, D., Kim, E., & Bang, S. (1997). A variation measure for handwritten character image data using entropy difference. *Pattern Recognition, 30*(1), 19–29.

Kuo, C., Huang, Y., Horng, W., Chen, C., Chen, C., & Wang, Y. (2009). *Design of a Chinese Character Learning System Based on Orthographic Decomposition Strategy*. Paper presented at the International Workshop on Research and Practice of Advanced Learning (RePALT), Tokyo, Japan.

Leung, H. & Komura, T. (2006). Web-Based Handwriting Education with Animated Virtual Teacher [Special issue]. *International Journal of Distance Education Technologies, 4*(1) 71–80.

Li, K., Leung, H., Lam, S., & Tsang, C. (2007). An Assessment Tool for Judging the Overall Appearance of Chinese Handwriting based on Opinions from Occupational Therapists, *Lecture Notes in Computer Science, 4823*, 288–299.

Lin, C. (2003). *Effects of using language- Media teaching on learning Chinese character strokes and stoke orders- Exemplified with grade 2 primary school students in Hualien County*. Unpublished master's thesis, Department of Language and Literacy Education, College of Humanities, National Taichung University of Education, Taiwan.

Lin, L. (2004). *The Chinese characters assessment system for second grade elementary learners.* Unpublished master's thesis, Department of Educational Measurement and Statistics, College of Education, National Taichung University of Education, Taiwan.

Matsuo, K., Kato, C., Okada, T., Moriya, T., Glover, G., & Nakai, T. (2003). Finger movements lighten neural loads in the recognition of ideographic characters. *Cognitive Brain Research,17*, 263–272.

Ozaki, M., Adachi, Y., Ishii, N., & Koyazu, T. (1995). *CAI System to Improve Hand Writing Skills by means of Fuzzy Theory.* Paper presented at the Proceedings IEEE International Conference on Fuzzy Systems and the 2nd Internatoinal Fuzzy Engineering Symposium,Yokohama, Japan.

Pica, T. (1997). Second language teaching and research relationships: A North American view. *Language Teaching Research, 1*(1), 48–72.

Sassoon, R. (1995). *The acquisition of a second writing system*: Intellect Books.

Shen, H. (2004). Level of cognitive processing: Effects on character learning among non-native learners of Chinese as a foreign language. *Language and Education, 18*(2), 167–182.

Shimomura, T. (1980). *Informatics: input and output: Science of the stroke sequence of Kanji.* Paper presented at the Proceedings of the 8th International Conference on Computational Linguistics, Stroudsburg, PA, USA.

Smith, M. S. (1993). Input enhancement in instructed SLA. *Studies in Second Language Acquisition, 15*(2), 165–179.

Tan, L., Spinks, J., Eden, G., Perfetti, C., & Siok, W. (2005). Reading depends on writing, in Chinese. *Proceedings of the National Academy of Sciences of the United States of America, 102*(24), 8781–8785.

Tang, K., Li, K., & Leung, H. (2006). A web-based Chinese handwriting education system with automatic feedback and analysis. *Advances in Web Based Learning–ICWL 2006*, 176–188.

Tang, K., & Leung, H. (2006a). Reconstructing the Correct Writing Sequence from a Set of Chinese Character Strokes, *Lecture Notes in Computer Science, 4285*, 333–344.

Tang, K., & Leung, H., (2006b). Teaching Chinese handwriting by automatic feedback and analysis for incorrect stroke sequence and stroke production errors. *Proceeding of the 2006 conference on Learning by Effective Utilization of Technologies: Facilitating Intercultural Understanding, 151*, 107–114, Amsterdam, The Netherlands.

Taylor, I., & Taylor, M. (1995). *Writing and literacy in Chinese, Korean and Japanese* (Vol. 3). Philadelphia, USA: John Benjamins Publishing Company.

Teddlie, C., & Tashakkori, A. (2009). Foundations of mixed methods research. Thousand Oaks, CA: Sage.

Tonouchi, Y., & Kawamura, A. (1997). *An on-line Japanese character recognition method using length-based stroke correspondence algorithm.* Paper presented at the Proceedings of the Fourth International Conference on Analysis and Recognition, Washington, DC, USA.

Tsay, Y., & Tsai, W. (1993). Attributed string matching by split-and-merge for on-line Chinese character recognition. *IEEE Transactions on Pattern Analysis and Machine Intelligence, 15*(2), 180–185.

Wu, L. (2002). *Construction and effectiveness of online Chinese language learning systems.* (Unpublished master's thesis), Department of Information and Computer Education, College of Science, National University of Tainan, Taiwan.