Research report

Effect of radical-position regularity for Chinese orthographic skills of Chinese-as-a-second-language learners

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ABSTRACT

The present study investigated the influence of radical position regularity in Chinese character orthographic tasks among Chinese-as-a-second-language (CSL) learners. The role that radical position regularity plays in the learning of Chinese characters was also verified by showing the aforementioned regularity. To address this issue, two experiments were conducted using the Chinese Radical Assembly Game (CRAG). The first experiment involved 88 CSL. The participants were grouped into high and low grades according to the results of a character recognition assessment. The participants were then randomly assigned to an REG group (radical regular arrangement matrix) and an RAN group (radical random arrangement matrix). The results showed there was no difference in the orthography performance between the REG and RAN groups. However, the orthography performances of the high-grade individuals were better than those of the low-grade individuals in the REG group. The second experiment involved another 84 CSL learners. The results showed that the orthography performances of the low-grade individuals were not different than those of the high-grade individuals after giving radical position regularity to the REG. It supports the effect of radical position regularity and suggests that the aforementioned regularity was helpful to CSL learners in the process of learning Chinese characters.

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1. Introduction

The five core reading abilities of the grapheme-phoneme correspondence system in English are phonemic awareness, phonics, vocabulary, fluency, and reading comprehension (National Reading Panel, 2000). However, Chinese is not a language that is characterized by a grapheme-phoneme correspondence system. These five core reading abilities are not completely applicable to the Chinese language. Six cognitive abilities have been proposed as the core reading abilities required for Chinese reading: oral language skills, morphological awareness, orthographic skills, syntactic skills, text comprehension, and fluency (Ho, 2010). Similar to spelling skills in Western languages, radical orthographic skills are an exclusive feature of Chinese learning.

Previous studies have suggested that orthographic skills are usually acquired during a late phase of literacy development (Cheng & Chen, 1991; Ho, Yau, & Au, 2003; McBride-Chang, 2004). Chinese lexical knowledge includes three concepts: orthographic knowledge, semantic knowledge of radicals, and phonetic knowledge of radicals (Cheng, 1992). The development of knowledge of the Chinese language expands only when the Chinese vocabulary of the speaker is large (e.g., 1000 characters), and this is particularly true for the development of orthographic knowledge. Radical position regularity is a type of orthographic knowledge that encompasses the rules of the specific positions of radicals in Chinese characters. The orthographizing task performances of Chinese-as-a-second-language (CSL) beginning learners would thus benefit from a method of instructing radical position regularity. Consequently, radical position regularity is essential to Chinese orthographic knowledge among CSL learners. Instructing regularity to improve Chinese character orthographization is applicable in the pedagogical field.
2. Literature review

2.1. Radical representation and radical position regularity

Radical representation is the primary process that occurs before individuals begin to learn Chinese characters (Perfetti, Liu, & Tan, 2005; Taft, Zhu, & Ding, 2000; Wu et al., 2013). Taft et al. believed that individuals are required to go through three stages before achieving Chinese character recognition proficiency; these stages involve the recognition of features, radicals, and characters. Character representation cannot be developed without the radical recognition stage. A previous study investigated the role of radicals by modeling the learning process and found that individuals can acquire the form structure, phonetic and semantic features of a Chinese character by merely inputting the radical and its corresponding position in the character. This study supports the claim that radical representation is a prerequisite process for the recognition of Chinese characters. An fMRI study of the brain mechanisms involved in Chinese semantics found that the medial frontal gyrus (MFG, BA10) is activated when reading characters with hand-radicals (Wu et al., 2013). This result suggests that the processing of characters with hand-radicals invokes the link between the semantic functions of Chinese characters and this sensory-motor region of the human brain. Radical representation plays a critical role in triggering the semantic processing of whole Chinese characters.

Whereas phonetic features are critical to word recognition within the word spelling regularity of grapheme-phoneme correspondence systems (Ferrand & Grainger, 1994; Perfetti & Bell, 1991), radical positions play an important role in Chinese character recognition in the Chinese language system (Taft & Zhu, 1997; Taft, Zhu, & Peng, 1999). The critical reason for the essential role of radical positions in the Chinese language system is the diversity of radical positions; this diversity allows two Chinese characters that share the same radicals to have completely different meanings, such as “杏” (xing, means apricot) and “呆” (dai, means foolish). A corresponding result from previous research showed that students recognize Chinese words according to the positions of the radicals in the character and are not confused by situations in which the same radicals are in different positions. Studies employing the primed naming task and lexical constituency model have shown the importance of the radical position in the process of Chinese character recognition (Perfetti & Tan, 1998; Perfetti et al., 2005).

The positions of radicals are critical for the transformation of radical representations into characters. According to the model proposed by Taft et al. (2000), individuals first observe the radicals, e.g. “女” (nü, means girl) and “木” (mu, means son), and then judge their corresponding positions (e.g., vertical separation) and thus create character representations, e.g., Chinese character “杏” (hao, means good). In contrast to the linear structure of English words, the structures of Chinese characters vary widely. Yeh, Li, and Chen (1999) established a system by categorizing Chinese characters into 12 types of forms. These form types included, for example, left and right, up and down, L-shaped, box-shaped etc.

When a radical appears in a specific fixed position, that position—radical combination is referred to as a radical position regularity. For example, the radical “木” (mu, means leaver) usually appears on the left side of left and right structures. Of the Chinese characters that contain the radical “木” (mu), 91% are consistent with this pattern. Additionally, individuals categorize Chinese characters based on the following two dimensions: 1) horizontal separation (left and right positions) and vertical separation (upper and lower positions) and 2) closed or open positions (Yeh & Li, 2002). The present study further investigated the influence of radical position regularities on orthographizing tasks. Does performance in orthographizing tasks benefit from knowledge of radical position regularities?

2.2. How do individuals acquire radical position regularity?

One possible solution to this question is that statistical learning processes are used to understand the relationships between language materials based on experiences of language learning (Aslin, Safran, & Newport, 1998; Safran, Aslin, & Newport, 1996). In other words, individuals acquire language rules by regularization (Reali & Griffiths, 2009; Wonnacott & Newport, 2005). An individual’s awareness of character components (e.g., radicals) and their corresponding phonographic features increase with experience with the forms of Chinese characters (Ziegler & Saffran, 2007). Therefore, knowledge of language rules develops gradually with the growth of the vocabulary; this is the so-called general lexical knowledge, which includes orthographic knowledge.

An individual’s first language acquisition and their acquisition of a second language are different (Norris & Ortega, 2000). For example, the results from previous research have generally shown that first-language learning is an implicit process because individuals acquire the rules of phonics, semantics and grammar through observation, imitation and daily interaction with others in the native language environment. However, learning a second language is an explicit process because individuals actively and intentionally learn the regularities of a second language (Cook, 2010; Schmidt, 1990). Chen et al. (2013) implemented a radical plan of teaching Chinese characters on an E-learning platform. After three weeks, the scores on Chinese orthographizing tasks were higher among the experiment group than among the Control group, who received courses employing traditional methods. This result demonstrates that orthographic knowledge can be improved by explicit learning processes and education on the concept of radicals. Therefore, it is worthwhile to discuss the effect of the knowledge of radical position regularity on performance in Chinese orthographizing tasks.

2.3. Measurement of orthographic knowledge

Thus far, the majority of studies of orthographic knowledge have employed the lexical decision task (Hong, 1997; Ho, Chan, Tsang, & Lee, 2002). The task involves the presentation of a stimulus and requires the participants to judge the rationality of the stimulus according to Chinese orthography. The design of this task is simple and is able to control the presentation of stimuli according to research purposes. However, this task asked individuals to only respond to the adequacy of Chinese characters. This task did not provide an understanding of the extent to which the individuals had acquired radical regularity from their process of using radicals. The Chinese radical assembly game (CRAG) provides an e-learning platform for users to compose radical components into a Chinese character on a square matrix according to Chinese character orthography (Hwang, Hong, Cheng, Peng, & Wu, 2013). Fig. 2 provides an example. Users first choose the radicals and place them in the matrix for the Chinese character orthographizing tasks. Participants are required to compose the radicals into true Chinese characters within a time limit (e.g., 3 min). During the CRAG, an individual’s responses and accuracy rate are collected to verify the individual’s understanding of Chinese character orthography. Situations involving radical use and regularity acquisition are collected in the CRAG, which is indeed innovative compared with the traditional approach. Radical position arrangements are based on the positions of radicals, which are based on radical position regularity in the CRAG matrix. Chen, Chang, Chiu, Sung, and Chang (2011) established the Chinese orthographic database. In the
present study, we selected radicals from this dataset that fulfill the left-and-right structure and appear in this structure with frequencies greater than 50%, which is referred to as the radical regular arrangement matrix (REG). For example, the frequency with which the radical “石” (shí, means stone) lies on the left side of the left-and-right structure is 83%, so this radical was placed on the left side of the radical matrix (Fig. 2). On the other hand, the matrix that the radical arranges randomly is called the radical random arrangement (RAN).

2.4. Present study

Based on language statistical learning theory and individual language acquisition processes (Aslin et al., 1998; Cheng, 1992; Norris & Ortega, 2000), the present study hypothesized that individuals with low-grade character recognition abilities have not acquired orthographic knowledge due to the insufficiency of their Chinese vocabularies. These individuals are unable to increase their accuracy rates even in the “radical regular arrangement (REG)” matrix task. In contrast, individuals with high-grade character recognition abilities have already developed Chinese orthography due to sufficient Chinese vocabulary. Therefore, the rate of correctly orthographizing Chinese characters should be increased through the use of the REG matrix. Additionally, the present study made this language rule an explicit learning process by actively providing radical position regularity in the matrix. We hypothesized that these participants would perform better, especially participants who had not yet developed orthographic knowledge and thus low-grade character recognition ability.

In summary, the present research intended to investigate the following questions:

1) In the CRAG, will the REG matrix increase the rate at which participants correctly assemble Chinese characters regardless of their grade of character recognition ability?

2) Will the performance of CSL learners with different grades of character recognition ability be improved by providing radical position regularity in the radical matrix?

3. Experiment 1: the effect of the “radical regular arrangement (REG)” matrix on the orthographic performances of CSL learners with different grades of character recognition ability

The purpose of experiment 1 was to demonstrate the effect of the REG matrix on CSL learners with different grades of character recognition ability. Will the orthographic task performances of CSL learners be improved by the REG matrix in the CRAG? Statistical learning theory has claimed that participants with high grades of character recognition ability should benefit from the “radical regular arrangement” design and should perform better in the orthographic task.

3.1. Experimental design

Experiment 1 entailed a 2 × 2 complete block design. The independent variables were the types of radical arrangement in the matrix and the grades of character recognition ability. Radical
arrangement indicates the way in which the radicals were arranged in a radial matrix. There were two types of radical matrices: a radical regular arrangement (REG) and a radical random arrangement (RAN). In a matrix, if the radical was positioned according to the frequency with which that radical appeared in the left-and-right structure of the Chinese characters, that radical was considered to be in the regular arrangement; if the radical was placed randomly in the radical matrix, it was considered as being in a radical random arrangement. The character recognition abilities of the CSL learners were assessed by a character recognition assessment (CRA) test. Based on the results of the CRA tests, the participants were grouped as follows: participants who correctly identified more than 50% of the items were placed in the high-grade character recognition ability group, and participants were assigned to the low-grade character recognition ability group if they correctly identified less than 50% of the items. The dependent variable was the ratio of correctly identified Chinese characters in the orthographizing CRAG task, and the formula used was based on the number of correctly orthographized characters divided by the total number of trials. The number of total trials was determined by the number of Chinese characters that the participants assembled and submitted to the system. The number of correctly orthographized characters was the number of rational characters identified by the system.

3.2. Participants

Experiment 1 included 88 Chinese-heritage language students from Singapore, Europe and the Americas who participated in the CRA and CRAG. These participants considered Chinese to be their second language, and they were learning Chinese for the first time in Taiwan. The ages of the participants ranged from 15 to 30 years old: 49 participants were male, and 39 were female. The participants were first assigned to high- or low-grade character recognition ability groups based on the results of the CRA test. Within each group, the participants were randomly assigned to receive the REG matrix or the RAN matrix in the CRAG.

3.3. Materials

The materials for experiment 1 were developed based on the Chinese orthographic database (COD) that was established by Chen et al. (2011). This database disassembled 6097 common Chinese characters, established 439 basic radicals, and summarized 11 types of spatial-structure relationships. Each radical was examined, and the following characteristics were summarized: the number of Chinese characters derived from the radical, the frequency with which the radical appeared at each position in a structure, the percentage with which the radical conformed to the radical position regularity, the number of derived characters that fulfilled the radical position regularity, and the number of derived characters that defined radical position regularity. For example, 22 Chinese characters can be derived from "舟" (zou, means boat), such as "船" (chuān, means ship) and "艘" (bān, means boat), and this radical appears on the left side of all derived characters. Hence, the percentage with which "舟" (zou) conforms to the radical position regularity (i.e., the left) is 100%.

Thirty-six radicals were chosen from the database according to the following criteria: the number of derived characters exceeds 6, the percentage with which the radical conformed to the radical position regularity exceeds 50% (Table 1), and each pair of radicals can be assembled into 18 Chinese characters, e.g., "金银" (yín, means silver), "金银" (bān, means silver), "银子" (xiān, means fresh), "金银" (kǎn, means hack), and "妃" (fei, means princess). Screening with these criteria, two radical matrices were designed. One of radical matrices was a REG matrix (left, Fig. 1); the radicals in this matrix were arranged based on the frequencies of the position in which they appeared in the left-and-right structure. For example, the radical “金” (jin, means gold) is usually placed on the left side in the left-and-right structure; 95% of Chinese characters with this structure conformed to regularity, including “金” (jin) itself. Thus, the radical “金” (jin) was placed on the left side of the REG radical matrix. As another example, the radical “欠” (qiàn, means owe) appears on the right side in the left-and-right structure in 98% of the characters. The other radical matrix was an RAN matrix (right, Fig. 1). In this matrix, the radicals were randomly arranged, whereas the REG matrix was designed according to the radical position regularity. The radicals that frequently appear on the left sides of the structures were placed on the left side of the REG matrix, whereas the radicals that frequently appear on the right sides of the structures were placed on the right side of the matrix. The radicals used in two matrices were identical; however, in the RAN matrix, the arrangement of the radicals was random and did not conform to radical position regularity.

3.4. Experimental tools

1. Character Radical Assembly Game (CRAG)

The CRAG is a computer game that was developed by Hwang et al. (2013). The user selects radicals to orthographize rational Chinese characters (Fig. 2). The interface is a plate of radicals, and the user designs a matrix by deciding on the number of radicals and selecting the components of the radicals. The user submits his/her answers within a time limit by choosing and assembling the radicals with a computer mouse. If the answers provided are rational Chinese characters, they are posted on the right side of the 3 × 3 grid. Once a radical is used, the user cannot select that radical to assemble the next character. For example, if “女” (nǚ) and “子” (zǐ) are assembled into the character “奌” (hǎo), then “女” (nǚ) and “子” (zǐ) cannot be chosen in the next trial. The information bar at the bottom of the page in the CRAG presents the user’s score, the number of failed trials, and the radicals that have been used. The score is calculated by doubling the number of accurate assemblies and subtracting the number of failed trials. Failure is defined by the number of failed trials. Radicals used is defined as the number of radicals used to assemble rational characters. When the CRAG ends, the system summarizes the performance of the user in terms of the name of the player, the total number of trials, the score, the number of failures, and the duration of the task (Fig. 3). In addition to the statistics mentioned above, the system also records which radicals were selected and assembled by the user to compute the correct rate, and the correct rate indicates the user’s Chinese orthographic ability.

The administrator’s management interface is shown in Fig. 4. This interface is composed of the following five sections: an items list, a member list, a game administration page, a radical page, and data output. The items list allows the administrator to set the radical regularity, the number of radical matrices that meet the radical position regularity, and the number of derived characters that defined radical position regularity. For example, 22 Chinese characters can be derived from “舟” (zou, means boat), such as “船” (chuān, means ship) and “艘” (bān, means boat), and this radical appears on the left side of all derived characters. Hence, the percentage with which “舟” (zou) conforms to the radical position regularity (i.e., the left) is 100%.

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2. Character Recognition Assessment

The character recognition assessment (CRA) is an e-assessment that was designed for CSL learners (Chen & Chang, 2011). The CRA helps teachers evaluate the Chinese character recognition abilities
of CSL learners. This assessment contains 280 Chinese characters. The Chinese characters are presented on the screen one at a time. At the start of the assessment, the system provides the option of using “pinyin” or “phonetic symbols” that indicate the pronunciation of the characters (Fig. 5). For example, if the “phonetic symbols” option is chosen and the character “工” (gong, means labor) is presented, then the user is required to select ㄍ, ㄨ, and ㄥ in that order. If the “pinyin” option is selected, then the user is required to input “gong1” and click “submit” to advance to the next character. Correct answers are awarded one point, and incorrect answers result in no points. An index of character recognition ability is calculated as the ratio of accurate to inaccurate responses. For example, if a participant provides 210 correct responses for 280 items, his/her character recognition ability would be 210/280 = 0.75.

Regarding the reliability and validity of the test, the coefficient of internal consistency is 0.975, and the coefficient of split-half reliability is 0.98. Using the results of the listening, speaking, reading and writing tests as criteria for validity, the correlations are between 0.39 and 0.75. Additionally, the correlation between the CRA and the Chinese Character Recognition Test is high ($r = 0.83 - 0.91, p < 0.001$). In summary, the CRA has acceptable reliability and validity.

### Table 1
Summary of the radicals used in experiment 1.

<table>
<thead>
<tr>
<th>Position</th>
<th>Radical</th>
<th>Number of derived characters</th>
<th>Percentage conforming</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td>女</td>
<td>193</td>
<td>59</td>
</tr>
<tr>
<td>Left</td>
<td>弓</td>
<td>40</td>
<td>63</td>
</tr>
<tr>
<td>Left</td>
<td>木</td>
<td>388</td>
<td>67</td>
</tr>
<tr>
<td>Left</td>
<td>火</td>
<td>128</td>
<td>69</td>
</tr>
<tr>
<td>Left</td>
<td>石</td>
<td>77</td>
<td>83</td>
</tr>
<tr>
<td>Left</td>
<td>舟</td>
<td>22</td>
<td>100</td>
</tr>
<tr>
<td>Left</td>
<td>言</td>
<td>194</td>
<td>79</td>
</tr>
<tr>
<td>Left</td>
<td>聿</td>
<td>79</td>
<td>61</td>
</tr>
<tr>
<td>Left</td>
<td>金</td>
<td>182</td>
<td>95</td>
</tr>
<tr>
<td>Left</td>
<td>桿</td>
<td>91</td>
<td>82</td>
</tr>
<tr>
<td>Left</td>
<td>魚</td>
<td>49</td>
<td>82</td>
</tr>
<tr>
<td>Left</td>
<td>黑</td>
<td>19</td>
<td>53</td>
</tr>
<tr>
<td>Right</td>
<td>羊</td>
<td>26</td>
<td>50</td>
</tr>
<tr>
<td>Right</td>
<td>亜</td>
<td>24</td>
<td>53</td>
</tr>
<tr>
<td>Right</td>
<td>且</td>
<td>25</td>
<td>54</td>
</tr>
<tr>
<td>Right</td>
<td>眾</td>
<td>49</td>
<td>52</td>
</tr>
<tr>
<td>Right</td>
<td>犬</td>
<td>25</td>
<td>59</td>
</tr>
<tr>
<td>Right</td>
<td>朵</td>
<td>22</td>
<td>13</td>
</tr>
<tr>
<td>Right</td>
<td>鬼</td>
<td>79</td>
<td>7</td>
</tr>
<tr>
<td>Right</td>
<td>鬝</td>
<td>61</td>
<td>41</td>
</tr>
<tr>
<td>Right</td>
<td>犬</td>
<td>54</td>
<td>58</td>
</tr>
<tr>
<td>Right</td>
<td>且</td>
<td>82</td>
<td>8</td>
</tr>
<tr>
<td>Right</td>
<td>亜</td>
<td>79</td>
<td>86</td>
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<tr>
<td>Right</td>
<td>且</td>
<td>61</td>
<td>51</td>
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<td>Right</td>
<td>且</td>
<td>54</td>
<td>98</td>
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<tr>
<td>Right</td>
<td>且</td>
<td>59</td>
<td>97</td>
</tr>
<tr>
<td>Right</td>
<td>且</td>
<td>82</td>
<td>88</td>
</tr>
</tbody>
</table>
3.5. Experimental procedure

All participants performed the CRA for 30 min. Based on the results of the CRA, the participants were placed in groups of high and low grades of character recognition ability. Within each group, the participants were randomly assigned to work with an REG or an RAN matrix in the CRAG. The experimenter provided the participants instructions for playing the game. The time of each game was 3 min.

3.6. Data analysis

Two-way ANOVA was conducted to investigate the interaction between the type of radical matrix and the grade of character recognition ability. When this interaction was significant, analyses of the simple main effects of each independent variable were conducted.

3.7. Results and discussion

Table 2 shows the means and standard deviations (SDs) of the accuracies of the participants who used each of the two matrices in the CRAG. The interaction between the type of radical matrix and the grade of character recognition ability was significant (F(1,84) = 9.05, p < 0.01, \( \eta^2 = 0.10 \)). The main effect of the grade of character recognition ability was significant (F(1,84) = 25.74, p < 0.01, \( \eta^2 = 0.23 \)), and the main effect of the radical matrix type was not significant (F(1,84) = 2.01, p = 0.16, \( \eta^2 = 0.02 \)) (see Table 3).

An analysis of the simple main effects revealed that, among the participants who used the REG matrix, the CRAG scores of the high-grade character recognition ability group were higher than those of the low-grade group (F(1,86) = 32.61, p < 0.01, \( \eta^2 = 0.28 \)). This finding supports the supposition that individuals with high-grade character recognition abilities achieved higher scores in the orthographizing task because of the radical position regularity within the REG matrix and that the participants with low-grade character recognition abilities did not benefit from the REG matrix. Among the participants who used the RAN matrix, the scores were not significantly different between those with low- and high-grade character recognition abilities (F(1,86) = 2.12, p = 0.15, \( \eta^2 = 0.02 \)). In summary, the performances of the participants with high- and low-grade character recognition abilities were not different when radical position regularity cues were absent; however, the high- and low-grade groups scored differently when radical position regularity cues were provided. The scores of the participants with high-grade character recognition abilities were better because these participants developed an understanding of radical position regularity, which distinguished these participants from those with low-grade character recognition abilities (Figs. 6 and 7).

4. Experiment 2: the effect of radical position regularity cues on orthographic performance among CSL learners with different character recognition abilities

Experiment 2 aimed to examine the effect of radical position regularity on the performances of CSL learners in an orthographizing task. Are character recognition abilities improved by radical position regularity cues? According to a second-language acquisition theory (Cook, 2010; Schmidt, 1990), the performances of the participants in the orthographizing task should be improved by the presence of radical position regularity cues, especially among individuals who have not developed orthographic knowledge and thus have low-grade character recognition abilities.

![Fig. 5. The answer page of the CRA (left: pinyin; right: phonetic symbols).](image-url)
Taiwan for the invited to participate in this experiment. The students were visiting 4.2. Participants recognition ability groups based on their CRA scores. The depen-
dependents were grouped into high and low grades of character 4.3. Experimental materials and tools participants were grouped into high- and low-grade character recognition ability groups based on their CRA scores. The partic-
participants were from Singapore, Europe, and America, and their ages ranged from 15 to 30 years old; 38 were male, and 46 were female. The participants were grouped into high- and low-grade character recognition ability groups based on their CRA scores. The de-
dependent variable was the accuracy rate in the CRAG orthographic task.

4.1. Experimental design

Experiment 2 was a 2 × 2 complete block design. The inde-
dependent variables were radical position regularity cues (with/ without) and grade of character recognition ability (high/low). The cue group was informed that the radicals in the matrix were ar-
ranged according to the frequency of the positions that the radicals occupy in Chinese characters, whereas the without-cue group was not informed of this arrangement and received instructions regarding only how to play the game. As in the first experiment, the participants were grouped into high and low grades of character recognition ability groups based on their CRA scores. The de-
dependent variable was the accuracy rate in the CRAG orthographic task.

4.2. Participants

Eighty-four Chinese language students of Chinese heritage were invited to participate in this experiment. The students were visiting Taiwan for the first time to learn Chinese as a second language. The participants were from Singapore, Europe, and America, and their ages ranged from 15 to 30 years old; 38 were male, and 46 were female. The participants were grouped into high- and low-grade character recognition ability groups based on their CRA scores. Within each of these groups, the participants were randomly assigned to the with-cue or without-cue group.

4.3. Experimental materials and tools

As in experiment 1, the REG matrix was used. An REG matrix is shown on the left in Fig. 1. The CRAG and CRA were also used in experiment 2.

4.4. Experimental procedure

All participants performed the CRA for 30 min. The participants were then assigned to the high- or low-grade character recognition ability group according to their performance in this assessment. Within each group, the participants were randomly assigned to the with-cue or without-cue group. All participants used the REG matrix in the CRAG, but only the with-cue group was informed of the regularity of the radical positions. The participants were free to choose one radical from each side of the radical matrix to assemble a legitimate Chinese character. The participants in the without-cue group were instructed only in the rules of the game.

4.5. Data analysis

Two-way ANOVA was conducted to investigate the interaction between the presence of the radical position regularity cue and the grade of character recognition ability in the CRAG with an REG matrix. Subsequent analyses of the simple main effects of each independent variable were performed if the interaction was significant.

4.6. Results and discussion

The analyses revealed that the interaction between the presence of the radical position regularity cue and the grade of character recognition ability was significant (F(1,80) = 6.04, p = 0.02, η² = 0.07). The main effect of the grade of character recognition ability was significant (F(1,80) = 31.95, p < 0.01, η² = 0.28); however, the main effect of the presence of the radical position regularity cue was not significant (F(1,80) = 0.07, p = 0.79, η² = 0.00).

Analyses of the simple main effects revealed that the performances of the participants in the high-grade character recognition ability group were significantly improved by the absence of the radical position regularity cue (F(1,82) = 32.90, p < 0.01, η² = 0.28). However, there was no significant difference between the performances of the CSL learners with low and high grades of character recognition ability based on the presence or absence of the radical position regularity cue (F(1,82) = 5.10, p = 0.03, η² = 0.06). The difference between the participants with high- and low-grade character recognition abilities was eliminated by the presence of the radical position regularity cue. The CSL learners with more experience with the language material may have developed orthographic knowledge through internal statistical learning pro-
processes. The REG matrix helped to improve performance in this orthographizing task. However, the presence of the radical position regularity cue in the CRAG with an REG matrix allowed even CSL learners with low-grade character recognition abilities to improve their performances in this orthographizing task.

5. General discussion

Radical recognition plays an important role in the acquisition of semantics as individuals learn Chinese (Perfetti et al., 2005; Taft et al., 2000; Wu et al., 2013). The learning of radicals is associated with the phonetics, semantics and orthographies of Chinese char-
acters. Specifically, orthographic knowledge is the most difficult and time-consuming to obtain. From the perspective of language learning and development, statistical learning theory claims that individuals can learn the relationships between different language elements from their learning experiences (Aslin et al., 1998; Saffran et al., 1996). For example, when learning Chinese, individuals can construct orthographic knowledge of Chinese vocabulary, radical-
derived regularities in pronunciation, and radical semantics from their experiences of language learning; i.e., with language learning experience, character recognition ability grows, orthographic
knowledge develops, and, thus, the Chinese character vocabulary of the learner grows. Moreover, from the perspective of second-language learning, individuals actively access the language and learn the language with a purpose, which is the definition of an explicit process (Cook, 2010). The results of a previous pedagogical experiment showed that character recognition ability can be improved by radical knowledge (Chen et al., 2013). The present study used the CRAG to investigate the influences of radical arrangements and radical position regularity cues on CSL learners with high and low grades of character recognition ability. The performances on this orthographizing task were analyzed in terms of the arrangements of the radicals in the matrices (i.e., the REG and RAN matrices) and the experimental treatment (i.e., with or without the radical position regularity cue).

Our results suggest that the performances of CSL learners with high-grade character recognition abilities in this orthographizing task were better when the task used an REG matrix than when it used an RAN matrix. Performance on this orthographizing task with an REG matrix was significantly different between CSL learners with high and low grades of character recognition ability. However, the performances of the participants with high and low grades of character recognition ability were not different when the orthographizing task involved the RAN matrix. These results are consistent with statistical learning theory (Saffran et al., 1996). Individuals build orthographic knowledge gradually as their character recognition abilities grow. These results also support the claim that orthographic knowledge is acquired in the later period of Chinese learning (Cheng & Chen, 1991; Ho et al., 2003; McBride-Chang, 2004). Additionally, CSL learners with high-grade character recognition abilities not only understood radical position regularity but were also able to use the arrangement of the radical matrix to perform better in the task when the REG matrix was used. In other words, the implicit learning of radical position regularity likely benefits the performances of CSL learners with higher levels of Chinese character knowledge in orthographizing tasks.

In contrast, the performances of CSL learners with low-grade character recognition abilities in orthographizing tasks could be improved by explicit learning of radical position regularity in the condition in which the radical position regularity cue was provided before the test, the performances of the CSL learners with low and high grade Chinese character knowledge in the orthographizing task were equal. This finding is consistent with the results of experiment 1 that demonstrated that radical position regularity was helpful in this Chinese orthographizing task and that radical position regularity could be explicitly communicated to learners. Statistical learning was not the only manner in which the individuals acquired the rules of the Chinese language; rather, explicit instruction was also helpful for expanding the individuals’ Chinese vocabularies. This result supports the claim that the process of learning a second language is explicit (Cook, 2010). Individuals who are learning a second language acquire regularity through the process of explicit learning. In summary, character position regularity was empirically demonstrated to be helpful to CSL learners when performing an orthographizing task. Thus, character position regularity is necessary for learning the Chinese language.

One deficiency of the present research is that we were unable to control for the previous Chinese language experience of the participants from different countries. For example, the CSL learners from Japan and Korea likely had more experience with Chinese languages, such as Kanji, that have adopted logographic Chinese characters in Japanese. Hence, these participants may be better equipped to learn Chinese than those from other countries. In further research regarding the learning of Chinese, it might be worthwhile to discuss the effects of the learners’ native languages.

Chinese lexical knowledge includes orthographic knowledge, semantic knowledge of radicals, and phonetic knowledge of radicals (Cheng, 1992). In the present study, we examined the influence of orthographic knowledge on individuals’ orthographic abilities. The results of this study suggest that the CRAG should be applied in future research to examine the roles of radical semantic knowledge, radical phonetic knowledge, and the character recognition abilities of CSL learners in orthographizing tasks. Moreover, it would also be worthwhile to verify the applicability of the CRAG with other orthographic structures (Yeh et al., 1999).

One particular innovation of this study is the use of the CRAG to examine the development of character recognition ability among CSL learners. Statistical learning theory and second language acquisition theory are supported by the results of the present study. The CRAG is pedagogically applicable and recommended for Chinese language learning. Finally, the results of this research also provide advice about learning Chinese character orthography; instruction regarding radical orthographic knowledge should help CSL beginners to enrich their knowledge of Chinese characters.

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