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Research paper

Radical repetition effects in beginning learners of Chinese as a foreign language reading

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A R T I C L E I N F O

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A B S T R A C T

The aim of the present study was to examine whether repetition of radicals during training of Chinese characters leads to better word acquisition performance in beginning learners of Chinese as a foreign language. Thirty Dutch university students were trained on 36 Chinese one-character words for their pronunciations and meanings. They were also exposed to the specifics of the radicals, that is, for phonetic radicals, the associated pronunciation was explained, and for semantic radicals the associated categorical meanings were explained. Results showed that repeated exposure to phonetic and semantic radicals through character pronunciation and meaning trainings indeed induced better understanding of those radicals that were shared among different characters. Furthermore, characters in the training set that shared phonetic radicals were pronounced better than those that did not. Repetition of semantic radicals across different characters, however, hindered the learning of exact meanings. Students generally confused the meanings of other characters that shared the semantic radical. The study shows that in the initial stage of learning, overlapping information of the shared radicals are effectively learned. Acquisition of the specifics of individual characters, however, requires more training.

1. Introduction

Reading requires knowledge of the writing system. A beginning reader must discover that written words are composed of graphic forms, or graphemes, which can be translated into sound and meaning. For instance, in learning to read alphabetic words, children acquire letter-phoneme associations that enable them to phonologically recode and pronounce the word, which in turn leads to the identification of the corresponding words (Ehri, 2005). Perfetti and colleagues have proposed "universal phonological principle" in which they state that both English and Chinese rely on phonological process during the comprehension of written text (Perfetti, Zhang, & Berent, 1992). The interactive-activation and competition frame work proposed by McClelland and Rumelhart (1981) poses that we recognize prints through activation of visual features which interactively propagate their connections to related letters and word that contain those letters in specific locations of the words. In a similar vein, Chinese characters can be thought of as decoding the strokes (= features of line orientations of an alphabet) that leads to decoding of radicals (= letters), which comprises characters (=syllables/words) (Taft & Zhu, 1997). Nevertheless, reading Chinese differs greatly from reading alphabetic orthographies because the mapping of orthographic units to sounds occurs not on the phoneme level but on the syllable or word/character level (Leong, 1997; Yang, McCandliss, Shu, & Zevin, 2009). Moreover, the graphic features of Chinese characters, so-called radicals, often relate

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not only to phonetic but also to semantic information. This makes the recognition of Chinese characters a complex process in which graphic, phonological and semantic information interacts. Perfetti, Liu, and Tan (2005) evidenced a distinctive time course for the activation of graphic, phonological and semantic constituents during the reading of Chinese words in a group of native adult Chinese participants. Unlike English, where phonology on the word level can be activated before the full orthographical specification is done, in Chinese characters, the character-level phonology can only be activated after the presented orthography has been recognized as a character. Nonetheless, phonetic and semantic radicals provide cues that facilitate word recognition (Yang, Zevin, Shu, McCandliss, & Li, 2006). For skilled readers of Chinese, the radical has been shown to be an important processing unit in reading (e.g., Feldman & Siok, 1999; Taft & Zhu, 1997). Priming studies, for instance, have reported that shared radicals between prime and target can facilitate or interfere with the processing of target characters (Ding, Peng, & Taft, 2004; Ding, Taft, & Zhu, 2000; Taft & Zhu, 1997; Taft, Zhu, & Peng, 1999). More specifically, Ding, Peng and Taft showed in a series of experiments in skilled adult Chinese readers that lexical decision is facilitated if the target character is preceded by a radical that comprises the target character. This was not the case if the visually similar but different radical was presented as a prime (Ding et al., 2004). Another study, on the other hand, showed an inhibitory effect when the semantic radical was the same between the prime and target, but the characters themselves were semantically unrelated (Feldman & Siok, 1999). These studies show that skilled readers have acquired a link between characters, radicals, and meanings that facilitates the choice of response when the prime pre-activates the candidate option, and inhibits when the prime activates competing options.

About 80–90% of Chinese characters are so called *ideophonetic* compound characters consisting of two or more components (radicals), with usually a semantic radical and a phonetic radical (Ho, Ng, & Ng, 2003). For example, the character 涌 means “gush” and is pronounced as /yong/. The left component 氵 is a semantic radical which indicates “water”, and the right component 甬 is a phonetic radical which has the same pronunciation with 涌 /yong/. Thus the two radicals that comprise the character 涌 provide information about the global meaning of the character and how it is pronounced. In this example, the semantic radical suggests that the word is water-related, and the phonetic radical suggests that the word is pronounced as /yong/. Not all Chinese characters follow this rule that the phonetic and semantic radicals give hints about the character's pronunciation and meaning, respectively. For instance, the semantic radical 氵 may be used in a character that is not “water-related” (e.g. 法 meaning law). The phonological radical is also an indication, as it does not tell which tone the phoneme is, and can be pronounced slightly different, (e.g. 蛹 /yong3/, 通 /tong1/, 痛 /tong4/), or completely different (e.g., 挟 /jia2/, 陕 /shan3/). Nonetheless, many characters follow this rule, and as such, knowledge of phonetic and semantic radicals will aid in reading regular characters. Benefits of reading regular characters probably arise from the activation of the phonetic values of phonetic radicals, and this knowledge can be applied in reading not-yet-learned characters that use the same phonetic radical (Anderson, Li, Ku, Shu, & Wu, 2003). The radicals influence lexical access, and may be a basic unit of Chinese orthographic representations (Ding et al., 2004). However, the influence of accessing phonological and semantic counterparts seem to act differently in Chinese from English. Unlike English, Chinese scripts allow dissociation between phonologically similar but visually different characters. For instance, a study showed that semantic judgement is interfered more when targets are primed by the semantically related radicals than by phonetically related radicals (Leck, Weekes, & Chen, 1995).

Given that the radicals have an important role in reading Chinese, one question that arises is whether the knowledge of radicals aid learning to read Chinese characters or not. In children, Carlisle (1955) defined morphological awareness as “children's conscious awareness of the morphemic structure of words and their ability to reflect on and manipulate that structure” (p. 194). Morphological awareness has been seen as an important predictor of success in learning to read and write Chinese (Liu, Li, & Wong, 2017; McBride-Chang, Shu, Zhou, Wat, & Wagner, 2003; Packard et al., 2006), just like phonological awareness has been shown to be important for learning to read in alphabetic systems (e.g., Mann, 1993). This is because in Chinese, characters map directly onto morphemes, in the similar way letters usually map onto phonemes in alphabetical scripts (Li, Anderson, Nagy, & Zhang, 2002). In Chinese primary schools, traditionally, children learn to read characters by rote memorization of characters as a paired-associate learning task (that is, how each character is read and what it means) rather than by being explicitly taught that there are underlying orthographic structures in characters (Wu, Li, & Anderson, 1999). Most of the characters are compound characters that consist of combinations of radicals, with usually a phonetic and a semantic radical. Since skilled readers have been shown to benefit from radical knowledge, it is not surprising that children can also benefit from knowledge of radicals in learning to read. They indeed show reading performance advantages for regular characters where both semantic and phonetic radicals can act as cues for the meaning and the pronunciation, respectively (Shu, Anderson, & Wu, 2000). One study demonstrated that Chinese children can use their knowledge of radicals when reading unknown Chinese characters (Ho et al., 2003). In a series of tasks, the authors tested the children's ability to make use of the phonetic and semantic radical knowledge in children. In both phonetic and semantic tasks, the children who showed high performance on guessing the appropriate phonetic/semantic of a pseudoword had a high level of word reading in general. Another study, using a path analysis, showed that knowledge of semantic radicals affected the ability to read characters (Liu et al., 2017). Children who were able to use their semantic radical knowledge to guess the semantic category of a pseudoword (matching the picture that was in the same semantic category as that of the semantic radical) were the ones who showed good word reading and sentence comprehension (Ho et al., 2003). Given Chinese children do make use of radical knowledge in learning to read, a method called “concentrated character learning method” was introduced in China in the 80s in which Chinese characters with the same semantic and phonetic radicals are taught together (Tian, 1987).

It seems quite evident that radical knowledge helps Chinese children learning to read for the first time. What about adult learners of Chinese whose native language is based on an alphabetic system? Reading requires learning the interrelation of orthography, phonology and semantics (e.g., Perfetti et al., 2005; Plaut, McClelland, Seidenberg, & Patterson, 1996). Reading processes are shared among different languages in the sense that writing systems encode spoken language, but some aspects are more language specific (Perfetti & Dunlap, 2008; Perfetti et al., 2005). For instance, the level of print-to-sound mapping may occur on different levels (letters/graphemes-phonemes to morphemes-phonemes) for different writing systems. Depending on their native language, people may use different strategies in acquiring a second language (L2). According to McGinnis (1999), rote learning was a common self-reported strategy by English-speaking first-year college learners of Chinese as L2. However, the use of knowledge of radicals has been found to be beneficial as well (Ke, 2003). If multiple characters with common radicals share the same feature such as pronunciation or categorical meaning, exposure to these sets of characters can aid in extracting the association between the specific radical and the character's pronunciation/meaning. A recent study showed indeed that training on knowledge of radicals to English learners of Chinese not only enhanced their performance on a phonetic and semantic radical awareness test but also on an orthographic knowledge test three weeks later (Chen et al., 2013). In their study, two groups of students learning Chinese were compared. One group followed a traditional class focusing on word-based instructional approach, whereas the other group followed a special training program focusing on the radicals, starting with the radical orthographic knowledge, and clustering the characters that share a specific radical separately for semantic and phonetic radicals. After three weeks of training, the radical training group performed better on radical recognition, semantic radical awareness, and phonetic radical awareness tests. But because this study was a between-group comparison, it was not clear to what extent training phonetic and semantic radicals led to differential learning outcomes within the same individual. Furthermore, they had already acquired some knowledge of Chinese at the time of the study and their training scheme consisted of a longer period of time with learning 7 to 8 new characters each day. Thus the initial effect of repetition has not become clear with their study.

In this study, we investigated in a short period of time, whether exposure to a set of characters with shared radicals would lead to better learning of novel Chinese characters than exposure to a set of characters whose composing radicals are not shared with other characters. We trained a group of Dutch university students who had no knowledge of Chinese language. The students were trained on a set of Chinese characters. Some characters shared the same set of phonetic and/or semantic radicals. We predicted that exposure to the characters that overlapped in phonetic and/or semantic radicals would benefit learning, with phonetic overlap aiding pronunciation and semantic overlap aiding meaning association. We assumed that learning the phonetics and semantics of the trained radicals would further assist in reading novel characters consisting partially of phonetic and semantic radicals from the trained set.

2. Methods

2.1. Participants

A total of 30 university students were recruited from a Dutch university's experiment participation portal (11 males, 19 females, mean age 23.6, range 18–28). Informed consent was obtained from each participant. They were compensated for their participation. None of the participants reported dyslexia, any hearing or speaking problems, and they all had normal or corrected-to-normal vision and hearing. Inclusion criteria also required that participants should not have any knowledge of Chinese characters or other Asian languages. Due to technical problems, the data of one participant (female) was not recorded properly, and thus the analyses are based on 29 participants.

2.2. Stimulus materials

Thirty-six Chinese compound characters comprising two radicals each, one semantic and one phonetic, from a pool of 21 phonetic and 21 semantic radicals, were used for training and test (see Appendix I for the whole list). In order to investigate the effect of repeated exposure to the same radical across different characters, some radicals appeared in multiple characters whereas other radicals appeared in only one character. The characters can be divided into one of the following conditions based on the combination of radicals used: 1) Repeated phonetic and repeated semantic radicals (P+S+); 2) Repeated phonetic radicals and unique semantic radicals (P+S-); 3) Repeated semantic radicals and unique phonetic radicals (P-S+); 4) Unique phonetic and semantic radicals (P-S-). Nine characters fell into each condition. In the repeat conditions, the same radical appeared in three different characters within a condition.

In the P+S+ condition, all possible combinations of the three phonetic radicals (甬 /-ong/, 半 /-an/, 夹 /-ia/) and the three semantic radicals (氵WATER, 扌HAND, and 亻HUMAN) were used. This resulted in nine compound characters. The same three phonetic radicals were combined each with three unique semantic radicals in the P+S- condition, and the three semantic radicals used in P+S+ condition were each combined with three unique phonetic radicals in the P-S+ condition. None of the semantic or the phonetic radicals overlapped with other characters in the stimulus set for the last P-S- condition. Overall, the result of this manipulation resulted in a set of compound characters that contained 3 phonetic radicals each occurring in 6 different characters (甬 /-ong/, 半 /-an/, 夹 /-ia/), with all the characters that shared the same radical having the same rime, and 3 semantic radicals (氵WATER, 扌HAND, 亻HUMAN) each occurring in 6 different characters. There were 18 unique semantic and 18 unique phonetic radicals that occurred in only one character. In sum, the participants were trained on 36 characters consisting of phonetic and semantic combination from 21 phonetic and 21 semantic radicals. Due to the restriction in combining radicals to create a set of characters that met our conditional constraint, the selection of radicals chosen was limited.

For each Chinese character, a one-word translation of the character in English was assigned. The frequency of the translated English word was on average 42.8 per million and range 0–191 per million according to CELEX (http://celex.mpi.nl/). The mean frequency did not significantly differ between conditions ($F = 0.316$, $p = .814$). For every character, a sound file of the pronunciation produced by a young female native Chinese was created.

Two lists of new characters were created for the phonetic radical knowledge test using all 21 trained phonetic radicals (Appendix I

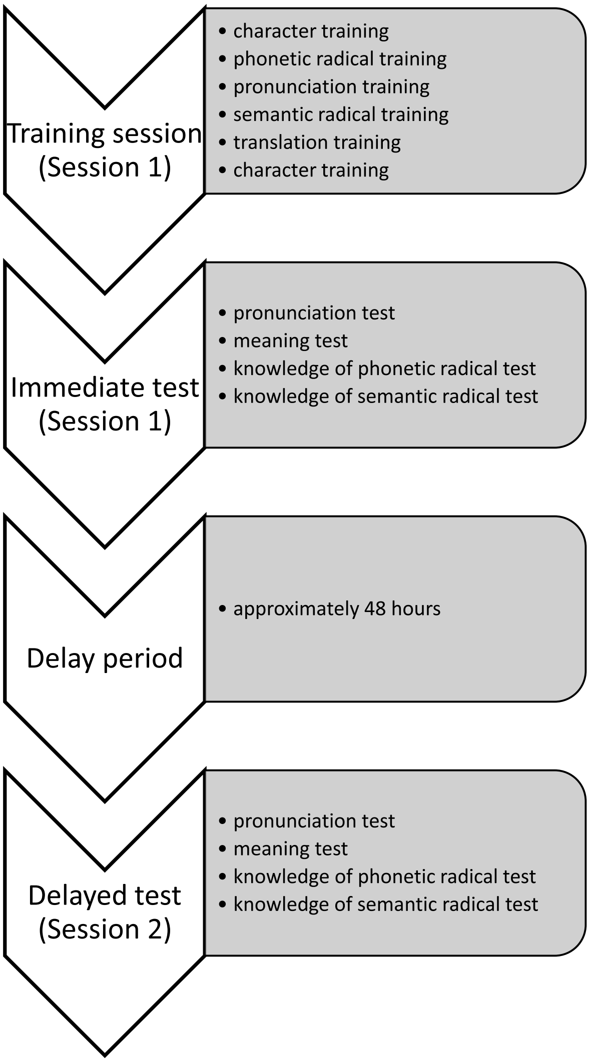

Fig. 1. Experimental procedure.

lists 1 and 2) combined with another semantic radical. In a similar manner, two lists of new characters were created using all 21 trained semantic radicals (Appendix II lists 3 and 4). No radicals repeated within a list. One of the two lists were used for the immediate test, and the other for the delayed test, with the use of two lists counterbalanced across participants.

2.3. Procedure

The experiment consisted of two sessions with two days in between (Fig. 1). In the first session, participants were trained and tested on a set of Chinese characters in a sound-attenuated booth. They sat in front of a computer screen at a comfortable distance and wore a headphone. Two days later, the participants returned to the laboratory and took part in the tests.

2.4. Training

Training consisted of six training phases: character training, phonetic radical training, pronunciation training, semantic radical training, translation training, and another round of character training. On average, it took 50 min to do all the training tasks (range 25–92 min).

2.4.1. Character training

In the first character training phase, participants were exposed to each of the 36 characters together with its pronunciation and the corresponding English translation. Each presentation began with a fixation cross for 1000 ms, followed by the display of the semantic radical for 1000 ms. The semantic radical disappeared and the phonetic radical appeared for 1000 ms. Then the whole character was shown with the English translation underneath for 2000 ms, before the pronunciation of the character was played through the headphone, followed by a prompt to press the spacebar to hear the pronunciation again. After hearing the second pronunciation example, the participants were prompted to press the space bar for the next character (self-paced procedure). During the pronunciation period, the character and its English translation stayed on the screen.

2.4.2. Phonetic radical training

Participants were informed that in this phase, they would learn the sound of a part of the characters, the so-called 'radical'. All 21 phonetic radicals used in the trained set were presented one at a time and the pronunciation was played two times each.

2.4.3. Pronunciation training

In this phase, all trained characters were presented once, one at a time together with the meaning in English and the pronunciation. Participants' task was to repeat the pronunciation of the Chinese characters within 2 s.

2.4.4. Semantic radical training

In this phase, participants were first informed that they would learn about the radicals related to the meaning of the characters. All 21 semantic radicals used in the trained set were presented once each with their semantic category presented on top of the radical in English upper case. After 1000 ms, participants were prompted to press the spacebar to go to the next trial.

2.4.5. Translation training

In this phase, participants were prompted to type in the meaning of the trained character one by one. When one character appeared on the screen, participants typed in the English translation of that character which appeared in black font below the character. When the "enter" key was pressed, the participants received feedback in the form of the correct translation shown in green font and they heard the character's pronunciation through the headphone.

2.4.6. Character training

The training ended with another character training phase. This phase was the same as the character training at the beginning of training, but the presentation of the composing radicals was shortened to 500 ms each, and the pronunciation of the character was delivered 1000 ms after the character appeared on the screen. Hearing the pronunciation for the second time and proceeding to the next trial was self-paced, just like the first character training.

2.5. Immediate test

Directly after the training, four tests were administered in the following order: Pronunciation test, meaning test, phonetic radical test, semantic radical test. No feedback was given during the tests.

2.5.1. Pronunciation test

In this test, participants were asked to pronounce all the trained characters one by one. Participants were instructed to pronounce within 3 s when the character appeared on the centre of the screen, although recordings continued until 5 s after the character appearance on the screen to ensure that the complete response was recorded. Participants were prompted to press the spacebar to continue to the next trial after pronouncing a character. The vocal response was recorded for further offline analyses.

The voice recordings were scored offline by two independent native Chinese raters who were blind to the experimental manipulation, and the mean score between the two scorers was taken as the score for each character per session. The raters scored how well participants pronounced the characters according to the following instructions: 2 points if the character is pronounced correctly (ignore any tone mistakes), 1 point if the character is nearly correctly pronounced (i.e. if there is substitution/omission/commission of 1–2 phonemes), 0 points if no response was made, or the mistake was more than two phonemes.

2.5.2. Meaning test

In this test, the trained characters were presented one at a time. Participants' task was to type in the meaning, similar to what they did during the translation training.

2.5.3. Knowledge of phonetic radical test

To test if participants acquired knowledge of the phonetic radicals, we asked the participants to guess the pronunciation of 21 unknown characters consisting of trained phonetic radicals combined with new semantic radicals (Appendix II List 1 and 2). Each novel character was presented on the centre of the screen with four response options labelled "sound 1" to "sound 4" below the character. Each label corresponded to one of the four response keys (number keys 1 to 4). Whenever the participant pressed one of the number keys, they heard a sound file of one of the phonetic radical sounds exposed during the phonetic radical training. One sound option corresponded to the character on the screen. Participants' task was to choose which of the four options was most likely to be the pronunciation of the new character. Participants were instructed to press the "enter" key after hearing the chosen pronunciation option. Reaction time was measured as the time difference between the onset of the character presentation and the "enter" key press.

2.5.4. Knowledge of semantic radical test

To test the participants' knowledge of the semantic radicals, we used a different set of 21 characters consisting of trained semantic radicals combined with new phonetic radicals (see also Appendix II List 3 and 4). The novel characters were presented on the centre of the screen with four different category names in upper case English below the character, each corresponding to number keys 1 to 4, from left to right respectively. All of the category names had appeared during the semantic radical training session. Participants' task was to choose which of the four category options was most likely to fit the new character by pressing one of the four number keys. Reaction Time was measured as the time difference between the onset of the character and the pressing of the response option button.

2.6. Delayed test

Participants came back to the lab two days after the initial session (approximately 48 h). They performed the same four tests as during the immediate test session. For the pronunciation and meaning tests, the trial orders were different from the immediate tests. The remaining two lists of recombined characters which were not used during the immediate test, were used for the knowledge of phonetic radical test and for the knowledge of semantic radical test.

3. Results

3.1. Pronunciation test

The inter-rater agreement was 80.5%. 14.7% of the trials had 1-point difference, and 4.7% of the trials were rated with 2-point difference. Wherever there was a discrepancy between ratings, an average of the two score was taken. Overall, the production of characters was very difficult, and some participants were not able to produce any correct or near correct pronunciations, reflected in the low performance scores (score range 0–16, max possible score = 18, see Fig. 2A and Table 1).

A repeated measures ANOVA of pronunciation performance with within subject factors Session (1/2) × Phonetic radical repeats (+/-) × Semantic radical repeats (+/-) was performed. This revealed a main effect of Phonetic repeats ($F(1,28) = 7.365$, $p = .011$, $\eta_p^2 = 0.208$, mean ± S.E.: phonetic repeats (P+) 3.2 ± 0.7, phonetic no-repeats (P-) 1.9 ± 0.3). Participants were better at pronouncing the characters that comprised phonetic radicals that repeated across six different characters, than at pronouncing characters with unique phonetic radicals. No other main effects or interaction effects were observed (all $p > .223$). The results suggest that repeating phonetic radicals across different characters helped participants to learn to pronounce the characters.

3.2. Meaning test

For every trial, the translation of the character that students typed in was categorized as either 1) correct, 2) category correct (i.e., either the response was the category that the semantic radical represented or the translated word was in the same semantic category), 3) similar (words that share some aspects of the target meaning), 4) incorrect, or 5) no response. The results are displayed in Fig. 2B.

First we analyzed the number of correct translations provided for characters in a repeated measures ANOVA (Factors: Session (1/2), Phonetic radical repeat (+/-), Semantic radical repeat (+/-)). We found a main effect of Session (1 > 2; $F(1,28) = 18.211$, $p < .001$, $\eta_p^2 = 0.399$), Radical repeat (phonetic repeat < no-repeat; $F(1,28) = 48.615$, $p < .001$, $\eta^2 = 0.635$; semantic repeat < no repeat; $F(1,28) = 24.976$, $p < .001$, $\eta_p^2 = 0.471$), and an interaction effect of phonetic by semantic repeat ($F(1,28) = 98.280$, $p < .001$, $\eta_p^2 = 0.642$). Participants performed worse if the radical repeated across different characters, but this was more so if the semantic radicals were shared with multiple characters than when phonetic radicals were shared across multiple characters.

A closer inspection of the incorrect responses revealed that the responses were sometimes similar to the target translation or the translation pertained to either the categorical meaning of the semantic phoneme or it was a translation of a character of the same

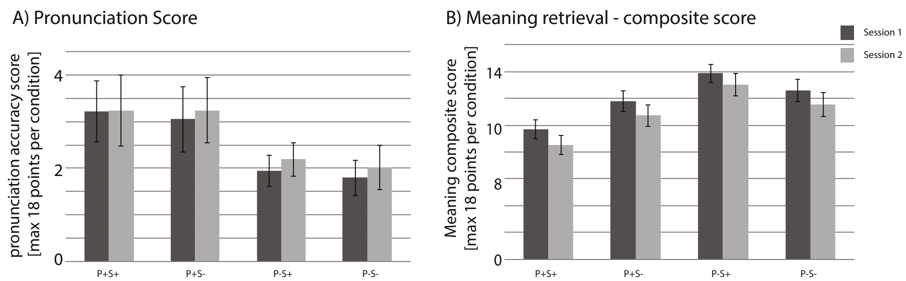

Fig. 2. Trained characters - accuracy score.

A) Pronunciation: For every correct response 2 points were given, and for 1–2 phoneme difference 1 point was given leading to maximum of 18 points per condition. B) Meaning: For every correct response 2 points were given. If participants responded with either the category of the radical, or the meaning of another character that shared the same semantic radical, 1 point was given. If similar word response was made, the trial also received 1 point. This led the composite score to a maximum of 18 points per condition. P+: phonemic radical repeats, P-: phonemic radical no-repeats, S+: semantic radical repeats, S-: semantic radical no-repeats. Error bars denote S.E.M. Session 1: immediate test, Session 2: delayed test.

Table 1
Behavioural performance on the trained Chinese characters. Mean ± S.E.M.

		Pronunciation Test	Meaning Test				
			Number of responses (max 9)				composite
condition	Day	Score (max 18 pts)	correct	category correct	similar	incorrect	Score (max 18)
P + S+	Session 1	3.2 ± 0.7	3.4 ± 0.4	2.9 ± 0.3	0.0 ± 0.0	2.2 ± 0.4	9.7 ± 0.7
	Session 2	3.1 ± 0.7	2.7 ± 0.4	2.9 ± 0.3	0.1 ± 0.1	2.7 ± 0.4	8.5 ± 0.7
P + S-	Session 1	3.0 ± 0.7	5.9 ± 0.4	0.1 ± 0.0	0.1 ± 0.0	2.6 ± 0.3	11.8 ± 0.8
	Session 2	3.3 ± 0.7	5.1 ± 0.4	0.4 ± 0.1	0.1 ± 0.0	3.0 ± 0.4	10.7 ± 0.8
P-S+	Session 1	1.8 ± 0.4	6.2 ± 0.4	1.5 ± 0.2	0.0 ± 0.0	1.0 ± 0.2	13.9 ± 0.7
	Session 2	2.3 ± 0.3	5.9 ± 0.5	1.1 ± 0.2	0.1 ± 0.0	1.5 ± 0.3	13.0 ± 0.8
P-S-	Session 1	1.8 ± 0.4	6.2 ± 0.4	0.1 ± 0.0	0.1 ± 0.1	2.2 ± 0.4	12.6 ± 0.8
	Session 2	1.9 ± 0.4	5.6 ± 0.5	0.2 ± 0.1	0.1 ± 0.1	2.6 ± 0.4	11.6 ± 0.9

P+: phonetic radical repeats, P-: phonetic radical no-repeats, S+: semantic radical repeats, S-: semantic radical no-repeats. Session 1: immediate test, Session 2: delayed test. For both pronunciation and meaning tests, no-response trials are not included. For the meaning test, the composite score was calculated as (number of correct trials x 2) + (number of correct category trials) + (number of similar response trials) per participant.

semantic category. To see if adding trials whose translation was close to that of the correct response (in the same vein as near correct pronunciation), we also computed a composite score for each condition: (number of correct trials x 2) + (number of trials with the word category correct) + (number of trials whose word meanings were similar to that of the correct one). We ran a repeated measures ANOVA with the same factors Session (1/2) × Phonetic radical repeats (+/-) × Semantic radical repeats (+/-) on this composite score as the dependent variable. We observed a main effect of Session (1 > 2; $F(1,28) = 23.453$, $p < .001$, $\eta_p^2 = 0.456$), Phonetic radical repeats (repeat < no-repeat; $F = 36.969$, $p < .001$, $\eta_p^2 = 0.569$), but no main effect of semantic radical repeats. Interaction of Phonetic × Semantic radical repeats was also observed ($F(1,28) = 51.592$, $p < .001$, $\eta_p^2 = 0.648$). We observed a similar pattern as when only correct responses were taken into account: There was forgetting over time, phonetic repeats across different characters hindered the meaning retrieval, and meaning retrieval was best when the semantic radical but not the phonetic radical repeated. When both radicals were repeated, performance on the meaning test was the worst.

3.3. Knowledge of phonetic radical test

During the phonetic radical knowledge test, participants had to use their knowledge of the trained phonetic radicals to guess the pronunciation the novel characters from four possible options. We compared both the accuracy score and the reaction time (RT). The data are presented in Fig. 3A and B. Since some participants had no correct responses for one of the conditions in one or both sessions, only the data of 19 participants who had values in all conditions for both sessions were tested with repeated measures ANOVA for the RTs with factors Session (1/2), Phonetic radical repeats (+/-). For the accuracy score, we did not find any main or interaction effects (Session $p = .204$, Phonetic radical repeats $p = .108$, interaction $p = .899$). RT, on the other hand, showed a trend towards the main effect of Session (1 slower than 2; $F(1,18) = 3.164$, $p = .092$, $\eta_p^2 = 0.149$), and Phonetic radical repeats (repeats faster than no repeats; $F(1,18) = 3.418$, $p = .081$, $\eta_p^2 = 0.160$).

3.4. Knowledge of semantic radical test

We also tested accuracy and RTs for the semantic radical knowledge test (see Fig. 3C and D) with two repeated measures ANOVA (accuracy and RT) using all participant data (n = 29). The analysis of accuracy showed a main effect of Radical repeats (repeats > no-repeats $F(1,28) = 9.375$, $p = .005$, $\eta_p^2 = 0.251$) but no main effect of Session or interaction. RT comparisons showed a main effect of Session (1 slower than 2; $F(1,28) = 8.238$, $p = .008$, $\eta_p^2 = 0.227$), Radical repeats (repeats faster than no repeats; $F(1,28) = 14.010$, $p = .001$, $\eta_p^2 = 0.333$), and a trend towards interaction Session × Radical repeats ($F(1,28) = 3.927$, $p = .057$, $\eta_p^2 = 0.123$). Interaction effect was driven by the fact that radical repeats did not speed up across days ($p = .216$), whereas the no-repeats speeded up from Session 1 to Session 2 ($p = .004$, Bonferroni corrected).

Both semantic and phonetic radical knowledge tests showed that repeated radicals were responded faster, and for the semantic radicals, with higher accuracy. For phonetic radical knowledge, there was nodifference between the two testing moments and for the semantic radical knowledge, there was an improvement from Session 1 to Session 2 suggesting no forgetting over the delay. Repetitions of the same radicals across different characters increased the knowledge of those radicals.

4. Discussion

Our study revealed that repetition across different characters helped learners to gain knowledge of both semantic and phonetic radicals to a certain extent. Repetition of phonetic radicals across different characters was beneficial for pronunciation of the trained characters. Semantic radical shared across multiple characters, on the other hand, was only effective on the categorical level. On the

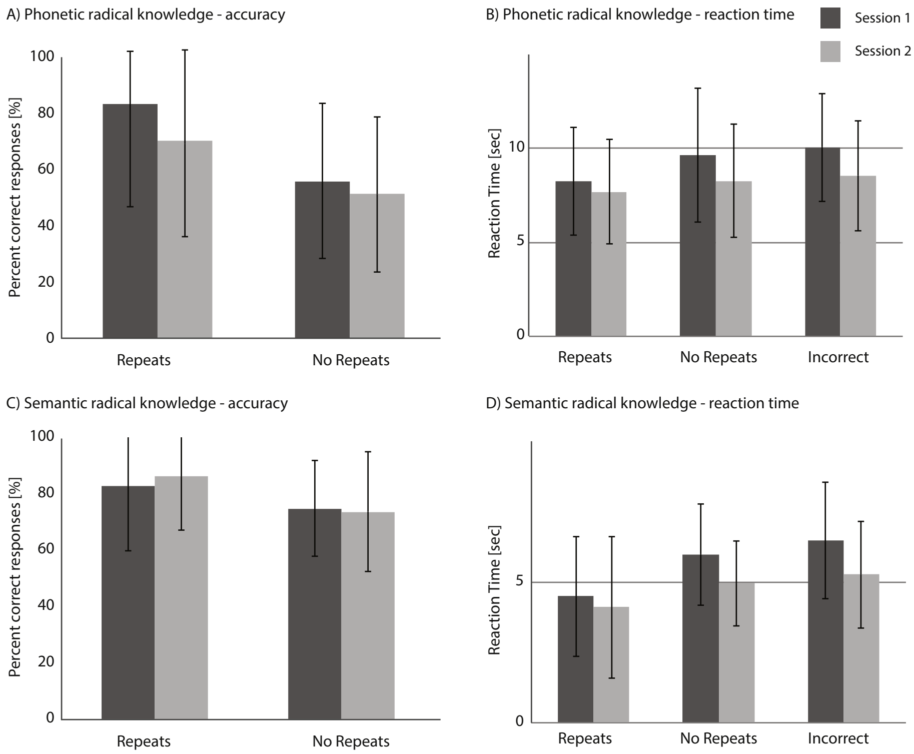

Fig. 3. Radical knowledge test.
A) Phonetic radical knowledge test accuracy. B) Phonetic radical knowledge test reaction time. C) Semantic radical knowledge test accuracy. D) Semantic radical knowledge test reaction time. Error bars denote S.E.M. Session 1: immediate test, session 2: delayed test.

individual character level, semantic radical repeats hindered the retrieval of exact meaning of the character due to a mix up with meanings of other characters that shared the semantic radical. Radical repetition across different characters was effective for learning radical values. Participants could use the knowledge of radicals for pronouncing and deriving categorical meaning for untrained characters, more so for the radicals that repeatedly appeared across different characters in the training set.

Adapted from the interactive-activation and competition frame work (e.g., McClelland & Rumelhart, 1981), Taft and Zhu (1997) proposed that Chinese characters are composed of hierarchically ordered components, with the strokes being the lowest unit of the Chinese writing system, followed by the sub-lexical units (radicals), and then lexical units (characters and words) and that the process of reading follows this hierarchy. It can thus be supposed that, when reading Chinese characters, the stroke combination activates the representations of radicals and subsequently the representation of characters and words. Even in learners of Chinese as a foreign language (L2), this seems to be the case, as recent studies have found that learners of Chinese as L2 with good radical knowledge have higher proficiency than learners with weaker radical knowledge (Su & Kim, 2014; Tong & Yip, 2015). However, this may only be true for students who are at a more advanced stage of learning. According to Elio and Anderson (1984), in order to extract schema in category learning, it seems better to start with only few variations, and increase the number of items only when students are able to handle the variations. In our study, more repetition may have been required for the students to truly benefit from the knowledge of radicals in Chinese character reading. At least for the radicals that overlapped across different characters, the number of repetitions was high enough to acquire the associated value in both pronunciation and category meaning. But for those characters whose radicals were unique to one specific character in the training set, the number of repetitions was apparently not enough.

When memory representations of each individual character are not strong enough, partial cueing to retrieve the associated meaning can be confusing. It has already been shown in the memory literature that shared cueing hinders memory retrieval compared to unique cues (Moscovitch & Craik, 1976). If we assume that the radicals serve as retrieving cues, this was the case in our study for meaning retrieval of the trained characters. When the semantic radical was shared among the trained characters, the students often confused the meaning of the tested character with another one that shared the semantic radical, or they were only able to relate the categorical meaning to the tested character. This finding suggests that radical repetition at an early stage of learning can be misleading and students may remember wrong translation if the memory representation of the character is not yet strong enough.

Characters that shared a phonetic radical with other characters had worse performance in meaning retrieval than characters that shared the semantic radical. This pattern is an interesting observation. Unlike alphabetic languages where reading involves letter-phoneme mappings, Chinese characters can map directly from graphic form to meaning. Nonetheless, when decoding Chinese characters, it has been shown that spoken syllable is also activated (Perfetti, 1995). This observation is in accordance with the Universal Phonological Principle which states that reading a word activates phonology at the lowest level that the specific writing system allows (Perfetti & Dunlap, 2008; Perfetti et al., 1992, 2005). If this is the case, activation of phonology of the trained character may also have activated the meaning of the other trained characters sharing the phonology, raising competition between these characters for the correct meaning association. However, it should be noted that in our study the confusion with other characters tended to be within the same category of the shared semantic radicals and not in the shared phonetic radicals. One speculation is that the radical-to-phonology mapping was less varied than radical-to-meaning mapping and thus this led to stronger phonology-radical associations than semantic-radical associations when the training was still at an early stage (Taylor, Davis, & Rastle, 2017).

Repetition effects on knowledge abstraction of both phonetic and semantic radicals were evidenced given faster reaction times for characters that shared phonetic and semantic radicals with other characters. These effects were more prominent for the semantic radicals where we observed a main effect of semantic radical repeats versus no-repeats in categorical association of novel characters. However, the duration of the training on a set of 36 characters was apparently too demanding to truly benefit the repetition of shared radicals to apply the extracted knowledge of radicals to novel character reading. It is also important to note that character knowledge was only tested with a delay of two days, with only one-time training. Further research in testing the effect over multiple training scheme and a longer delay will give indications to what types of repetitions are beneficial for learning to read a novel script, especially when it is referring to the transition from a phoneme-based to a morpheme-based orthography.

To conclude, we showed that repetition of radicals across multiple characters in learning to read Chinese as a foreign language is partially effective in pronouncing characters and associating their meanings. However, to reach a better performance level, more repetition within the trained set can be considered necessary to attain stabilized memory representations of the studied characters.

Conflicts of interest

The authors have declared that no competing interests exist.

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Appendix C. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jneuroling.2018.03.001.

Appendix I

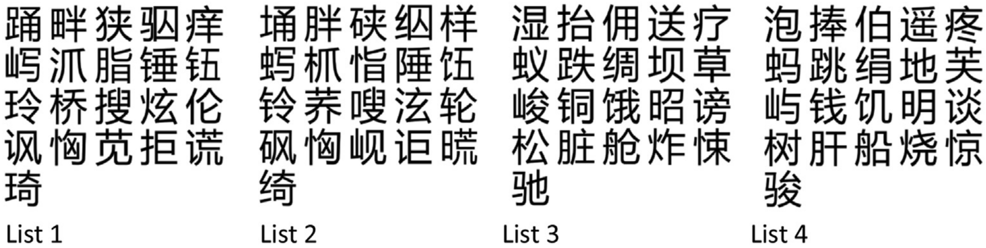
		S+			S-		
		WATER	HAND	HUMAN			
P+	-ONG	涌 gush \yong\ WATER	捅 stab \tong\ HAND	俑 figurine \yong\ HUMAN	通 path \tong\ PASSAGE	痛 ache \tong\ ILLNESS	蛹 cocoon \yong\ INSECT
	-AN	泮 shore \pan\ WATER	拌 whisk \ban\ HAND	伴 partner \ban\ HUMAN	跘 stumble \ban\ FOOT	绊 bind \ban\ STRING	坢 field \pan\ GROUND
	-IA	浃 wet \jia\ WATER	挟 pick \jia\ HAND	侠 knight \xia\ HUMAN	荚 pod \jia\ PLANT	峡 canyon \xia\ MOUNTAIN	铗 sword \jia\ METAL
P-		泅 swim \qiu\ WATER	抓 grasp \zhua\ HAND	伍 army \wu\ HUMAN	馊 rancid \sou\ FOOD	枫 maple \feng\ TREE	炬 torch \ jǜ\ FIRE
		洋 ocean \yang\ WATER	指 finger \zhi HAND	伶 actor \ling\ HUMAN	昡 bright \xuan\ SUN	胸 chest \xiong\ BODY	慌 nervous \huang\ MOOD

泻	捶	侨	论	舰	骑
pour	punch	emigrant	discuss	fleet	ride
\xie\	\chui\	\qiao\	\lun\	\jian\	\qi\
WATER	HAND	HUMAN	SPEECH	SHIP	HORSE

P+ phonetic radical repeat, P- phonetic radical no-repeat, S+ semantic radical repeat, S- semantic radical no-repeat. The third line corresponds to the pronunciation and the fourth line to the semantic category that the characters were associated with.

Appendix II

Lists used for phonetic radical knowledge test (List 1 and 2, immediate and delayed, counter-balanced across participants), and for semantic radical knowledge test (List 3 and 4, immediate and delayed, counter-balanced across participants).



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