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Phonetic radicals, not phonological coding systems, support orthographic learning via self-teaching in Chinese

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Abstract

According to the self-teaching hypothesis (Share, 1995), phonological decoding is fundamental to acquiring orthographic representations of novel written words. However, phonological decoding is not straightforward in non-alphabetic scripts such as Chinese, where words are presented as characters. Here, we present the first study investigating the role of phonological decoding in orthographic learning in Chinese. We examined two possible types of phonological decoding: the use of phonetic radicals, an internal phonological aid, and the use of Zhuyin, an external phonological coding system. Seventy-three Grade 2 children were taught the pronunciations and meanings of twelve novel compound characters over four days. They were then exposed to the written characters in short stories, and were assessed on their reading accuracy and on their subsequent orthographic learning via orthographic choice and spelling tasks. The novel characters were assigned three different types of pronunciation in relation to its phonetic radical – 1) a pronunciation that is identical to the phonetic radical in isolation; 2) a common alternative pronunciation associated with the phonetic radical when it appears in other characters; and 3) a pronunciation that is unrelated to the phonetic radical. The presence of Zhuyin was also manipulated. The children read the novel characters more accurately when phonological cues from the phonetic radicals were available and in the presence of Zhuyin. However, only the phonetic radicals facilitated orthographic learning. The findings provide the first empirical evidence of orthographic learning via self-teaching in Chinese, and reveal how phonological decoding functions to support learning in non-alphabetic writing systems.

Keywords: phonological decoding, orthographic learning, Chinese, phonetic radical, Zhuyin

1. Introduction

In order to read fluently, one needs to be able to recognise written words rapidly and automatically (Perfetti, 1992). The *self-teaching hypothesis* (Share, 1995) suggests that orthographic learning, the transition from laborious alphabetic decoding to fluent whole word recognition (Castles & Nation, 2006; Nation & Castles, 2017), depends on converting print to speech sounds, or phonological decoding. This hypothesis has been tested and supported in many alphabetic languages (e.g., English: Cunningham, 2006; Dutch: de Jong, Bitter, van Setten, & Marinus, 2009; Hebrew: Share, 2004). Given the growing interest in the universals of learning to read (Perfetti, Cao, & Booth, 2013; Share, 2015), an important question arises as to whether learning to read in non-alphabetic languages is dependent on a similar process. The present study tests the self-teaching hypothesis in a non-alphabetic language, Chinese. Specifically, for the first time, we investigate the role of phonological decoding in orthographic learning by self-teaching in Chinese. We examine both the use of the phonetic radical, the internal phonological aid, and Zhuyin, the external phonological coding system.

According to the self-teaching hypothesis (Share, 1995), phonological decoding draws the reader's attention to a novel word's orthographic details, and thus functions as a self-teaching mechanism children use to learn to read new words. This hypothesis makes two important claims about the acquisition of word-specific orthographic representations. First, orthographic knowledge of a word can be acquired without explicit teaching. Second, and more critically, orthographic learning is dependent on phonological decoding as a necessary condition. To test this hypothesis, Share (1999) asked second grade Hebrew-speaking children to read aloud pseudowords (e.g., *yait*) in the context of stories. Three days later, the children spelled the target pseudowords more accurately, named more them rapidly and correctly identified them more often than the alternative homophonic spellings (e.g., *yate*). These results suggested that word-specific orthographic learning had taken place. In a separate experiment, another group of children performed a lexical decision task with concurrent articulation (repeatedly saying "dubba" aloud), where phonological decoding was reduced. The results showed that orthographic learning was greater in the read aloud condition than in the concurrent articulation condition, suggesting that phonological decoding contributes directly to orthographic learning. De Jong and colleagues (2009) and Kyte and Johnson (2006) replicated these results in Dutch and English respectively. The importance of phonological decoding is also supported by studies showing a positive correlation between correct decoding and successful orthographic learning (Bowey & Miller, 2007; Cunningham, 2006; Cunningham et al., 2002; Kyte & Johnson, 2006).

The reliance on phonological decoding in orthographic learning can also be revealed by a word regularity effect. In alphabetic languages, regular words (e.g., *cheap*) are processed more accurately than irregular words (e.g., *breath*), as has been shown in children's word naming (e.g., Laxon, Masterson, & Coltheart, 1991) and lexical decision tasks (e.g., Schmalz, Marinus, & Castles, 2013). This effect has often been used to index the degree of reliance on phonological decoding. If phonological decoding is indeed the foundation of orthographic learning, the regularity effect should also be found in word learning. Wang, Nickels, & Castles (2012) tested this hypothesis using a modified version of the self-teaching paradigm. They trained Grade 3 children to read regular pseudowords (e.g., *ferb,* pronounced as "ferb") and irregular pseudowords (e.g., *cleap,* pronounced as "clape"). Ten days later, orthographic learning was assessed with a spelling and an orthographic decision task. It was indeed found that regular items gained stronger orthographic representations than irregular ones, suggesting that orthographic learning is less effective when only partial decoding is possible, as in the irregular words.

Yet the precise nature of phonological decoding remains unclear. Share (1995) adopted a very broad definition of phonological decoding to refer it to the process of deriving speech information from print "through whatever means" (p.152). In other words, phonological decoding is not restricted to grapheme-phoneme conversion but could, for instance, also involve the use of larger units like bodies and rimes, or even phonetic radicals and characters in Chinese. However, the latter possibilities have not been tested.

In Chinese, there are no grapheme-phoneme correspondences in the writing system. Instead, a character, the basic reading unit in Chinese (see discussion in Li & McBride, 2014), represents a morpheme and maps onto the sound of an entire syllable rather than smaller phonological units such as phonemes. Therefore, the print-to-sound conversion is entirely syllable based. Notably, only a subcomponent of a character contains phonological information. An estimated 80%-90% of modern Chinese (Kang, 1993) and 72% of elementary textbooks (Shu, Chen, Anderson, Wu, & Xuan, 2003) consist of compound characters (or "compounds") with a semantic and a phonetic radical. For example, 油 |you2| ("oil") is composed of a semantic radical 氵 meaning "liquid" on the left and a phonetic radical 由 |you2| on the right. Given that only the phonetic radical of a whole character provides phonological information, phonological decoding is always "partial" in Chinese. Previous studies in reading development of Chinese suggest that Chinese children are sensitive to the radicals as subcomponents of compounds. For example, they can copy pseudocharacters better when they are formed by discernible radicals than arbitrary strokes (Anderson et al., 2013), and when the radicals are in familiar positions than in illegal positions (Anderson et al., 2013; Tong & McBride, 2014). They are also aware of the phonetic radical's function and use it in naming compounds (Ho & Bryant, 1997; Shu, Anderson, & Wu, 2000) and in learning compounds' pronunciations (Anderson, Li, Ku, Shu, & Wu, 2003; Chen, Anderson, Li, & Shu, 2014; He, Wang, & Anderson, 2005; Yin & McBride, 2015). Yet, whether the phonetic radical is used as a way to "phonologically decode" an unfamiliar compound to achieve orthographic learning is not clear. Hence, the first aim of this study was to investigate whether the phonetic radical is utilised as a means of phonological decoding during orthographic learning in Chinese.

In addition, it has been found that children not only use the phonetic radicals directly, but also use analogy to read unfamiliar characters (Chen et al., 2014; He et al., 2005; C. S.-H. Ho, Wong, & Chan, 1999). That is, children can either infer the pronunciation of an unfamiliar compound by its phonetic radical, or, they can infer the pronunciation by making an analogy to another compound that contains the same phonetic radical but has a different pronunciation to the phonetic radical. Chen et al. (2014) investigated whether young children use known characters to read novel ones via direct mapping from phonetic radicals or via analogy. In their study, the children first learned to read a clue character (e.g., 胥|xu4|), and were then asked to name an unknown target compound character (e.g., 揟|xu4|) where the clue character functioned as the phonetic radical. The target therefore could be read via the clue character acting as its phonetic radical. In another condition, the clue and the target were both compounds sharing the same phonetic radical (e.g., 溍|jin4| and 縉|jin4|). Hence, the target could be read by making an analogy to the clue character. The children's naming accuracy of the target compounds did not differ significantly between the two conditions, indicating that they used both phonetic radicals and whole characters (analogy) to read unfamiliar compounds. It was also found that when both ways were available, younger children used more direct mapping while older children used more analogy to read unknown compounds. These two approaches to phonological decoding via the phonetic radical are called the “phonetic strategy” and the “analogy strategy” (Chen et al., 2014; He et al., 2005; Ho et al., 1999). Although these previous studies suggested that children do use information from phonetic radicals when reading unfamiliar compounds, whether this strategy facilitates orthographic learning remains untested.

The second proposed type of phonological decoding we aim to explore is the role of Zhuyin or Pinyin. Zhuyin and Pinyin are external phonological coding systems used in Taiwan and Mainland China respectively. These systems are taught at the beginning of elementary school, and are normally mastered by the children by the end of the first semester (Cheung & Ng, 2003). They are presented to children alongside characters in textbooks. Since these external aids are highly consistent in orthography-to-phonology conversions, children can use them to reliably sound out any unfamiliar character. It could be argued that reading with Zhuyin/Pinyin, compared to phonetic radicals, permits more successful and reliable decoding, which allows for better conditions to build up entries in the orthographic lexicon (Lin et al., 2010; Share, 1995).

Importantly, investigating whether Zhuyin facilitates orthographic learning provides a unique opportunity to better understand how phonological decoding contributes to orthographic learning. Although phonological decoding and orthographic learning have now been investigated for more than two decades, exactly how phonological decoding promotes successful orthographic learning is far from clear. Previous research has demonstrated that successful phonological decoding does not necessarily lead to orthographic learning at an item level (Nation, Angell, & Castles, 2007; Wang, Nickels, Nation, & Castles, 2013). A recent study has also found that using text-to-speech software, although providing the correct phonology by reading aloud each word, had no impact on orthographic learning (as revealed by spelling and word naming) or even a negative one (as revealed by orthographic choice) in poor readers of Dutch (Staels & Broeck, 2015). These findings seem to support Share's (2004; 2008) claim that while phonological decoding is necessary, correct phonological decoding does not guarantee successful orthographic learning. More importantly, the function of phonological decoding is not only to provide the phonological forms that can be mapped on to orthographic representations, but also to draw the reader's attention to the orthographic details (see also Ehri, 2014). However, this latter proposal has never been directly tested. If the benefit of phonological decoding is to activate the correct phonology, then Zhuyin should facilitate learning. On the other hand, decoding via Zhuyin potentially draws readers' attention away from the characters and could hence interfere with the establishment of specified orthographic representations. Thus, if the benefit of phonological decoding is more about attending to the orthographic details, then Zhuyin may hinder orthographic learning.

In sum, the present study investigated whether and how children use the internal phonological aid – the phonetic radical – and the external phonological coding system– Zhuyin, to decode and to acquire novel Chinese compounds. To do so, we used a version of self-teaching paradigm developed by Wang, Castles, Nickels, & Nation (2011), where the spoken vocabulary of the target words was acquired prior to orthographic exposure. This way, a novel written word could be presented as having an "irregular" spelling to the children. We measured orthographic learning twice – immediately after orthographic exposure and five days later. Previous investigations on the retention of orthographic learning in alphabetic languages have reported mixed results. Some found a decay after a 6-7-day delay compared with a 1-day delay (Bowey & Muller, 2005; Nation, Angell, & Castles, 2007) while others found almost full retention after a week or even 30 days (Ouellette, 2010; Share, 2004). Therefore, we did not have specific predictions about the retention of orthographic knowledge in the present study.

To investigate how children might use cues from the phonetic radicals, we capitalised on the word regularity effect observed in English orthographic learning (Wang et al., 2012). The regularity of a Chinese compound is defined based on whether or not it has an identical pronunciation as its phonetic radical (the pronunciation of the phonetic radical is determined as when it is a stand-alone character; Fang, Horng, & Tzeng, 1986; Hue, 1992; Lee, Tsai, Su, Tzeng, & Hung, 2005). For example, the character 由 (|you2|) can function as a phonetic radical, making the compound 油 (|you2|, "oil") regular, and 袖 (|xiu4|, "sleeve") irregular. Note that the definition of Chinese compound regularity here can only be compared to English words' regularity at a conceptual level. That is, they are both about whether a word's or compound's pronunciation follows a rule, but they differ in the particular rule across the two orthographies. In English, the rule is to follow the most common grapheme-phoneme correspondences. In Chinese, it is when the compound character maps on to the phonetic radical's phonology (Lee, 2008). If children use the phonetic radical as a way to phonologically decode compounds, children should learn regular compounds better than irregular ones. If children also use analogy in phonological decoding (Chen et al., 2014), then among the irregular compounds, those that can be decoded via the analogy strategy should be learned better than those that cannot. If children do not use the phonetic radical at all in learning new compound characters, we should expect no differences between learning regular, irregular and compounds that are pronounced completed unrelated to the phonetic radical.

2. Method

2.1. Participants

Seventy-nine Grade 2 children (47 boys) aged between 7.4 and 8.7 years (M = 8.1, SD = 0.35) participated in the study. Six children (1 boy) were not able to attend all sessions and were therefore excluded from the final analysis. Participants were recruited from three classes in an elementary school in Taipei, Taiwan. All participants had Mandarin Chinese as their first language. Children of this age were selected because they were likely to have developed awareness of the internal radical structure of Chinese characters (Anderson et al., 2013), and to be proficient in Zhuyin (Cheung & Ng, 2003).

All participants completed three classroom-based tests to assess their word reading ability, spoken vocabulary and non-verbal IQ. The children's reading ability was measured with the *Graded Chinese Word Recognition Test* (Huang, 2001). It consists of 200 characters arranged in increasing order of difficulty. The children were asked to write down the characters' Zhuyin in order of presentation. Scoring was discontinued when the child failed to write the correct Zhuyin for 20 characters consecutively. The internal consistency reliability for this test is high (Cronbach's $\alpha = .99$). The children in this study scored an average of 69 (SD = 23), which is higher than the mean score of 46.84 for second graders in Taiwan, $t(73) = 8.32$, $p < .001$. In addition, a shortened version (100 items) of the *Peabody Picture Vocabulary Test-Revised* in Chinese by Lu & Liu (1994) was administered to assess the participants' receptive vocabulary. The *Kaufman Brief Intelligence Test Matrices, 2nd edition*

(Kaufman & Kaufman, 2004) was used as an indicator of the children's non-verbal cognitive ability. The sample showed a normal distribution on all three measures.

2.2. Materials

Twelve compound characters were used for training (*M* strokes = 11; see Appendix A). Eleven of them were pseudocharacters and one was an extremely low-frequency character (鋰 "lithium"). We confirmed with the teachers that this character should be unfamiliar to children at this age. All target compounds were novel combinations of a familiar semantic radical on the left and a familiar phonetic radical on the right (e.g., 糸羊). This is the most common compound structure (90% have phonetic radicals on the right, Hsiao & Shillcock, 2006), and children are familiar with it (Lui, Leung, Law, & Fung, 2010; Shu et al., 2003). Therefore, all the targets were designed in this structure to maximise the likelihood of the children making use of the phonetic cues in them.

The selected phonetic radicals could all act as stand-alone characters, and were all high in frequency (more than 500 occurrences per million) based on the *Chinese Character Frequency - A trans-regional diachronic survey* (Ho, 1998). We selected phonetic radicals that do not always provide reliable compound phonology and therefore can be used to create both regular and irregular novel compounds.

The twelve novel target compounds were all assigned three different pronunciations: regular, irregular and unrelated. Take the target 糸羊 for example: the regular pronunciation was |yang2|, which was the same as its phonetic radical 羊|yang2| ("sheep"); the irregular pronunciation was |xiang2|, which was not the same as its phonetic radical, but based on an existing compound that contains this phonetic radical 祥|xiang2| ("luck"); the unrelated pronunciation |tao2| was not related to the initial and final phonemes of its phonetic radical or any existing compounds that contained this phonetic radical. The existing compounds whose pronunciations we used as the irregular pronunciations were all high-frequency characters based on (Ho, 1998). We also made sure the regular pronunciation had the same tone as the phonetic radical's, as Chinese children's tone awareness has been shown to correlate with vocabulary knowledge and character recognition (Tong, Tong, & McBride, 2014), which are both central to our aims in this study.

To increase the children's focus on the target words, we used semantic radicals that were highly familiar to Grade 2 children (see Appendix A). Although we chose semantic radicals that occurred in textbooks for Grade 2 children, it became apparent during the first learning session that many participants were not able to write these radicals. Therefore, in order to ensure that their focus stayed on the target compounds and that the task was not too difficult, in the subsequent session, we selected two semantic radicals (亻 and 釒) to form the rest of the items, with one item from each condition (regular, irregular, unrelated) sharing one semantic radical.

The twelve compounds were grouped into three sets, which were matched on phonetic radical frequency (p = .21) and visual complexity (number of strokes) (p = .92). All children learned the same twelve items. However, the pronunciation of each compound that they learned depended on the set they were allocated to. The three sets were counterbalanced in regular, irregular and unrelated conditions for the three groups of participants. This way, the three groups learned all items and all three conditions, controlling for potential confounds from visual-orthographic complexity of the items or the children's familiarity with any items over others (see Appendix A).

The target compounds were embedded in three-character word phrases as names of inventions for the children to learn. We did so because Chinese words are often word phrases composed of two to three characters. Half of the words are in the form of 電___機 |dian4__ji1| "electric __ machine" and the other half 超__機 |chao1____ji1| "super ___machine", with the target compound inserted in between the two characters (e.g., 超鋰機 and 電絆機). Many electric devices and machines' names in Chinese are created this way, such as 電視機 (television). Names like 電__機 or 超__機 are consistent with the inventions' semantic category, and learning such names is congruent with the children's real world experience.

Each invention was described in a story, where the word appeared four times. The texts ranged in length from 72 to 81 characters ($M = 77$), and the stories were child friendly, with no difficult phrases for second grade children (see Appendix B for an example). The texts had two versions – one with Zhuyin and the other without. Zhuyin for each character was retrieved from *The Revised Chinese Dictionary* (Ministry of Education, 2007). They were presented on the right side of the characters as in the textbook format.

2.3. Procedure

The procedure was similar to the paradigm developed by Wang et al. (2011). It consists of four phases, taking place over a period of fifteen days. In the *oral vocabulary learning phase*, the children learned the spoken form of the target items. In the *orthographic exposure phase*, the children were first tested on their vocabulary knowledge of the targets, and were then exposed to the targets' written form. After orthographic exposure, orthographic learning was measured in the *immediate testing phase*. In the 5-day *delayed testing phase*, the effect of orthographic learning was measured again. Familiarity with the oral form and meaning of the trained items was also tested.

Oral vocabulary learning phase (Sessions 1 – 4, over 7 days). Participants were taught vocabulary knowledge of the new words via pictures and oral explanations (see Appendix B for an example). Eight of these inventions were adapted from Wang et al. (2011, 2012), with another four from Mimeau, Ricketts, & Deacon (in prep.). The words were names of inventions as shown in the pictures by "超級博士 |chao1 ji2 bo2 shi4| (Super Professor)". Definitions of the inventions included their functions and key features presented in the pictures. Half of the items – two from each set, six in total – were trained in Session 1 (Day 1) and the other half in Session 2 (Day 2). In Session 3 (Day 4) and 4 (Day 7), all twelve items were trained together. The children received training for 20 minutes each day as a class in their classrooms. The training procedure was as follows:

1. The experimenter showed the children the picture and taught them the name of the invention in spoken form (e.g., This is a 電糹羊機 |dian4 yang2 ji1|). The children repeated the name.

2. The experimenter described the semantic features of the invention (e.g., 電糹羊機 |dian4 yang2 ji1| is used to take out the food you don't like from a meal. It has a tube and two open ends.) The children were asked to repeat the invention's name again.

3. The children repeated the invention's name and its definition.

4. Picture-naming task. The children were asked to recall the name of the invention when presented with a picture (in random order). Feedback was provided.

5. In Sessions 3 and 4, the children were also asked to complete twelve sentences like

"If I had a 電絲羊機 |dian4 yang2 ji1|, I would use it to …" or "If I want to take out the food I don't like from a meal, then I should use …"

Orthographic exposure phase (Sessions 5-6, over 3 days). Prior to exposure to the orthographic forms of the target words, each child was assessed with a picture-naming task to test their vocabulary knowledge of the trained words. Feedback was provided irrespective of whether the child named a picture correctly or incorrectly. Before they started reading, they were instructed to use what they had learned earlier about the invention names to help with the reading. The child was then asked to read aloud the stories with the target words in it. No feedback was provided. The children read aloud six stories (with each target item appearing four times in each story) in Session 5 and another six in Session 6. The children were randomly assigned to either stories with or without Zhuyin. Children were individually tested in a separate room.

Word reading accuracy was recorded during story reading. The correct pronunciation was the one that matched with the one the child had previously been exposed to in the *oral vocabulary learning phase*. After reading each story, the child completed two comprehension questions.

Immediate testing phase (Sessions 5-6, over 3 days). Immediately after the story-reading, orthographic learning was assessed with a spelling task and an orthographic choice task.

Spelling task. The target words were read aloud by the experimenter and the child was asked to try to write them down exactly as s/he had seen in the stories. One score was given to each correct spelling.

Orthographic choice task. The child was presented simultaneously with four choices and asked to circle the one they had seen in the stories. The four options were the target word, a phonological foil and two visual distractors (see Appendix C). The phonological foil and visual distractors were either novel combinations of high-frequency radicals or extremely low-frequency characters with high-frequency radicals. All phonetic radicals of the choices had over 200 occurrences per million either as isolated characters or in real compounds they form in Ho (1998). The children should be familiar with the radicals that form the choices. The visual distractors were created by replacing either the semantic or the phonetic radical with a visually similar one. The phonological foil had the same semantic radical as the target, but its phonetic radical was a homophone of the targets' phonetic radical. However, this homophone may differ in tone due to limited high frequency phonetic radicals to select from (see Appendix C). For example, the phonological foil of 絴 |yang2| in the regular condition was 紻, where the phonetic radical 央 |yang1| differed from the target's phonetic radical only in tone.

Delayed testing phase (Session 7, over 1 day). Five days later, the children completed another spelling and orthographic choice task to measure how well the learning had been retained. These two tasks were conducted at a group level. In addition, each child was individually assessed on picture naming task to measure how much vocabulary knowledge had been retained, and on target word reading as a measure of orthographic learning. These latter two tasks were tested individually as verbal responses were required.

3. Results

The present study aimed to answer two primary questions. First, do children use phonetic radicals to phonologically decode and to establish orthographic representations of novel Chinese compound characters; and if they do, do they use it to directly generate the pronunciation of the compounds (the "phonetic strategy") or infer from orthographic neighbours (the "analogy strategy")? Second, do children use Zhuyin to decode and to establish orthographic representations of novel Chinese compounds? In the following section, we first report results on oral vocabulary learning, followed by the effect of Zhuyin and compound type on reading accuracy. Next, the overall orthographic learning is evaluated. Finally, we report the effect of Zhuyin and compound type on orthographic learning.

3.1. Oral vocabulary learning

After four sessions of vocabulary training, the mean proportion of correct picture naming of the 12 target items was .70 (*SD* = .28) immediately prior to orthographic exposure, and maintained at .73 (*SD* = .25) on the delayed orthographic testing day (Session 7). This indicates that the children had acquired substantial vocabulary knowledge of the target words, and that this knowledge was retained throughout the experiment.

3.2. Effect of Zhuyin and compound type on reading accuracy

During the orthographic exposure phase, the target compounds were read in story contexts, either with or without Zhuyin. Reading accuracy was scored as a measure of phonological decoding. The mean proportion of target compounds that were decoded correctly was .93. Although this proportion was reasonably high, there was a moderate level of variation (*SD* = .14, range = .42 - 1.0). A repeated-measures analysis of variance (ANOVA) was conducted with compound type (regular, irregular, unrelated) as the within-subjects variable, and Zhuyin (with Zhuyin, without Zhuyin) as the between-subjects variable (see Table 1).

Table 1. *Mean proportions of reading accuracy by compound type and by with (+)/without (-) Zhuyin during orthographic exposure.*

	+Zhuyin	-Zhuyin	Average
Regular	.99 (.04)	.94 (.14)	.97 (.10)
Irregular	.97 (.08)	.93 (.19)	.95 (.15)
Unrelated	.96 (.12)	.78 (.27)	.87 (.27)
Average	.97 (.07)	.88 (.17)	.93 (.14)

Note: Standard deviations in parentheses.

There was a significant main effect of Zhuyin, $F(1, 71) = 9.05$, $p = .004$, $\eta_p^2 =. 11$, and a significant main effect of compound type, $F(2, 142) = 16.31$, $p < .001$, $\eta_p^2 = .19$. These effects were qualified by an interaction between Zhuyin and compound type, $F(2, 142) = 6.65$, $p = .002$, $\eta_p^2 = .09$. Because reading accuracy for regular and irregular items were at ceiling both with and without Zhuyin (see Table 1), we only carried out simple main effect analysis for the effect of Zhuyin on reading the unrelated items, which was significant, $F(1, 72) = 11.70$, $p = .001$, $\eta^2 = .14$. Follow-up analyses reflected that without Zhuyin, reading accuracy was lower in the unrelated than in the regular condition, $t(35) = 4.12$, $p < .001$, $d = .69$, and was also lower in the unrelated than in the irregular condition, $t(35) = 4.30$, $p < .001$, $d = .72$.

3.3. Orthographic learning

Before running further analyses that would determine whether phonetic radicals and Zhuyin contributed to orthographic learning via the mechanism of phonological decoding, we first analysed whether orthographic learning had occurred at all.

Table 2 shows the results of the three orthographic learning measures – spelling, orthographic choice and word reading. Spelling and orthographic choice tasks were conducted immediately after the target words were presented in the stories, and again after a 5-day delay. The word reading task was carried out only at the delayed test after spelling and orthographic choice task to avoid an extra exposure of the target words at the end of the initial orthographic learning assessment.

Table 2. *Mean proportions of accuracy of orthographic learning measured immediately after learning and in the delayed test.*

		Spelling	Orthographic choice	Delayed word reading
Session	Immediate	.22 (.15)	.74 (.19)	n/a
	Delayed	.12 (.11)	.58 (.19)	.59 (.16)

Note: Standard deviation in parentheses.

Spelling accuracy in both the immediate and the delayed testing sessions was not high. However, given that spelling is quite a challenging task for Grade 2 children, and that the children would not have been able to spell Chinese words by chance, being able to spell some items correctly indicates that they had acquired some specified orthographic knowledge of the trained items.

The occurrence of orthographic learning was also substantiated by the orthographic choice results, where the proportion of targets correctly identified in the immediate and the delayed tests were both well above chance level (.25), suggesting that the children acquired considerable orthographic knowledge of the target compounds. Among the error responses, .16 (*SD* = .14) and .21 (*SD* = .13) of the choices were made on the phonological foils in the immediate and delayed tasks respectively, while choices made on the visual distractors represented a slightly smaller proportion of .11 (*SD* = .10) and .19 (*SD* = .12) in the two sessions.

Orthographic learning was also measured by reading accuracy in the delayed test. Given that the target words were presented as a word list without context or Zhuyin support, the reading performance (*M* accuracy = .59, *SD* = .16) suggested that the compounds' orthographic representations had been established and held over time.

The results from these three orthographic learning measures provided evidence that within four written exposures, orthographic learning in Chinese had taken place via self-teaching.

3.4. Effect of Zhuyin and compound type on orthographic learning

Two repeated measures ANOVAs were conducted separately for the spelling and orthographic choice tasks. Zhuyin (with Zhuyin, without Zhuyin) was the between-subjects variable. Compound type (regular, irregular, unrelated) and testing session (immediate, delayed) were the within-subjects variables. Another repeated measures ANOVA was conducted with word reading accuracy in the delayed session, with Zhuyin as the between-subjects factor and compound type as the within-subjects factor. The results of all main effects and interactions are reported in Table 3. We first present results on the effect of Zhuyin, and then the effect of compound type on orthographic learning.

Table 3. *ANOVA summary for orthographic learning by Zhuyin, compound type and testing session.*

	Spelling				Orthographic choice				Reading accuracy			
Source	*df*	*F*	*p*	η_p^2	*df*	*F*	*p*	η_p^2	*df*	*F*	*p*	η_p^2
Zhuyin	1	0.21	.649	.001	1	2.16	.146	.029	1	0.01	.908	.000
Compound type	1.63	42.23***	.000	.373	2	72.61***	.000	.506	2	236.76***	.000	.769
Session	1	25.27***	.000	.262	1	71.73***	.000	.503		n/a		
Zhuyin × Compound type	1.63	0.80	.430	.011	2	0.21	.810	.003	2	0.13	.881	.002
Zhuyin × Session	1	1.20	.277	.017	1	0.35	.557	.005		n/a		
Compound type × Session	1.97	0.57	.556	.008	2	2.87	.060	.039		n/a		
Zhuyin × Compound type × Session	1.97	4.32*	.017	.057	2	0.45	.641	.006		n/a		

Note. *$p < .05$. **$p < .01$. ***$p < .001$. Mauchly's test indicated that the assumption of sphericity was violated for compound type in the spelling test; therefore, the degrees of freedom were corrected using the Greenhouse-Geisser correction.

3.4.1. *Effect of Zhuyin on orthographic learning*

Spelling. There was a significant three-way interaction between Zhuyin, compound type and testing session (see Table 3). Pairwise comparisons were carried out for all two-way interactions. The only significant interaction was found for compound type and session in the without Zhuyin condition, $F(1.86, 65.23) = 3.54$, $p = .038$, $\eta_p^2 = .092$. Further analyses showed that the interaction came from the difference between regular and irregular compounds being only significant in the delayed session $t(35) = 4.40$, $p < .001$, $d = .98$, but not in the immediate session, $t(35) = 1.36$, $p = .18$, $d = .33$. There was also no significant main effect of Zhuyin or two-way interactions involving Zhuyin.

Orthographic choice. There were no significant three-way or two-way interactions with Zhuyin involved. There was also no main effect of Zhuyin.

Delayed word reading. The interaction between Zhuyin and compound type was not significant. There was also no significant difference in delayed word reading accuracy between the with and the without Zhuyin conditions.

These results indicated that Zhuyin had no impact on orthographic learning. The exception was that only when Zhuyin was not presented was the interaction between compound type and testing session significant. However, as we did not make predictions about this effect, we are cautious in providing an interpretation about this result before it is replicated in future work. Also, this effect was not present in the other two measures of orthographic learning – orthographic choice and delayed word reading.

3.4.2. *Effect of compound type on orthographic learning*

Figure 1 shows the mean proportions of accuracy for spelling and orthographic choice by compound type over the immediate and delayed testing sessions.

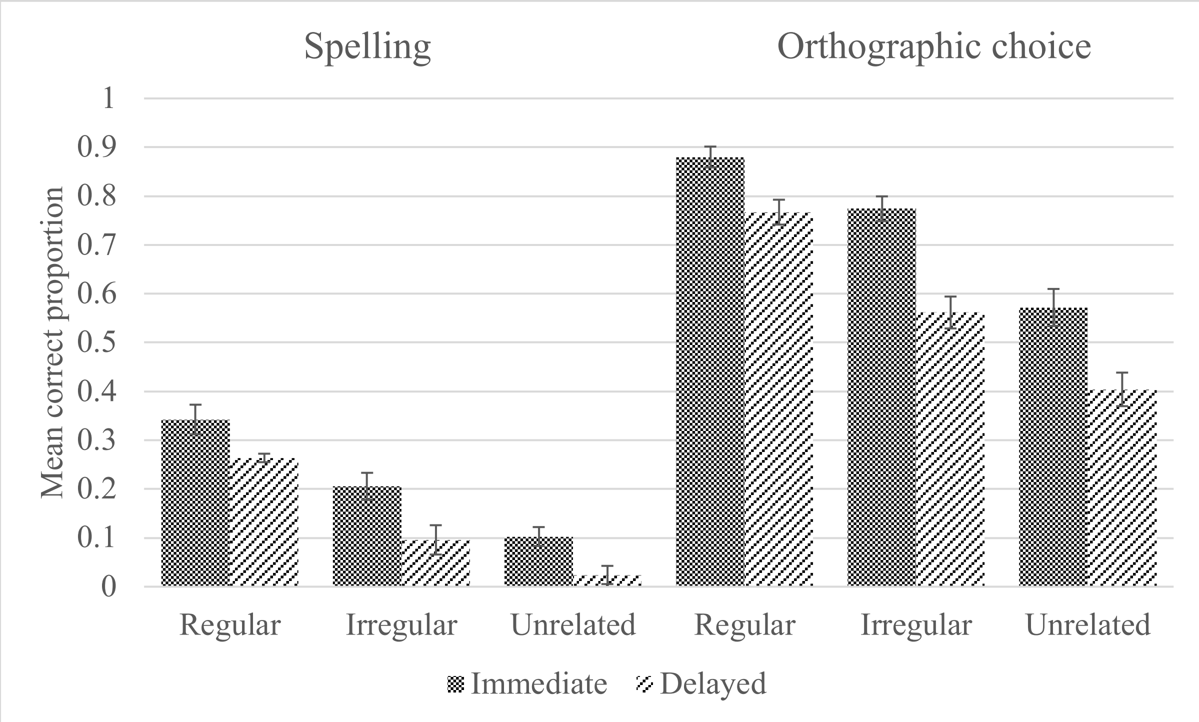

Figure 1. *Mean proportions of correct spelling and orthographic choice by compound type in the immediate and delayed sessions (with the error bars indicating standard errors)*.

Spelling. There were no significant two-way interactions (*p*s > .05). The main effect of compound type was significant, $F(1.63, 134.61) = 42.23$, $p < .001$, $\eta_p^2 = .37$. For both testing sessions, regular compounds were significantly more correctly spelled than unrelated compounds (immediate: $t(72) = 7.73$, $p < .001$, $d = 1.10$; delayed: $t(72) = 7.64$, $p < .001$, $d = 1.12$); irregular items also had higher spelling accuracy than unrelated ones (immediate: $t(72) = 3.34$, $p = .001$, $d = .50$; delayed: $t(72) = 3.53$, $p = .001$, $d = .45$). The difference between correct spelling of regular and irregular compounds was also significant (immediate: $t(72) = 3.33$, $p = .001$, $d = .55$; delayed: $t(72) = 5.18$, $p < .001$, $d = .79$. There was also a significant main effect of session, $F(1, 134.61) = 25.27$, $p < .001$, $\eta_p^2 = .26$, reflecting an overall decline in spelling accuracy (see Figure 1).

Orthographic choice. Similar to the results from the spelling measure, the two-way interactions were not significant. The main effect of compound type was significant, $F(2,142) = 72.61$, $p < .001$, $\eta_p^2 = .51$. Post hoc paired *t*-tests results were in line with the spelling outcomes. The proportion of correct choices was significantly higher for regular than for unrelated compounds (immediate: $t(72) = 9.37$, $p < .001$, $d = .12$; delayed: $t(72) = 10.97$, $p < .001$, $d = 1.40$); and for irregular than for unrelated compounds (immediate: $t(72) = 5.77$, $p < .001$, $d = .73$; delayed: $t(72) = 3.88$, $p < .001$, $d = .55$). The difference between correct choices made for regular and for irregular compounds was also significant (immediate: $t(72) = 3.74$, $p < .001$, $d = .57$; delayed: $t(72) = 5.61$, $p < .001$, $d = .82$). The main effect of session was also significant, $F(1, 142) = 71.73$, $p < .001$, $\eta_p^2 = .50$, showing that the children were less accurate at picking the correct choices in the delayed testing session (see Figure 1).

Delayed word reading. The main effect of compound type was significant. Word reading accuracy was significantly higher for regular ($M = .89$, $SD = .19$) than unrelated items ($M = .21$, $SD = .21$), $t(72) = 23.36$, $p < .001$, $d = 2.73$, and for irregular ($M = .65$, $SD = .29$) than unrelated items, $t(72) = 13.88$, $p < .001$, $d = 1.62$, as was shown by the post hoc comparisons. Regular compounds also elicited more correct reading than irregular compounds, $t(72) = 7.25$, $p < .001$, $d = .85$.

Results from all three measures of orthographic learning showed a consistent pattern, indicating that compound type had an effect on orthographic learning. Regular and irregular compounds were learned better than unrelated compounds. Regular items also gained stronger orthographic representations than irregular ones. The children’s orthographic knowledge of the trained items decayed over time across all compound types.

4. Discussion

According to the self-teaching hypothesis, phonological decoding is pivotal to acquiring orthographic knowledge of novel words. This study was the first to investigate the role of phonological decoding in orthographic learning by self-teaching in a non-alphabetic orthography – Chinese. Specifically, we examined whether and how Chinese children use the phonetic radical, the internal phonological aid, and Zhuyin, the external phonological coding system, to decode and acquire orthographic knowledge of novel compound characters.

The findings of this study provided strong evidence that orthographic learning in Chinese took place via self-teaching. The results of spelling, orthographic choice and word reading consistently showed that the children developed knowledge of the compound characters' orthography as a whole (i.e., the specific combination of the semantic and phonetic radical). Specifically, we found that the children spelled the target compound characters correctly, chose the targets over phonological foils and visual distractors, and read the targets by mapping onto the spoken form based on the oral vocabulary training rather than onto the phonetic radical. Importantly, when asked to read the irregular and unrelated items, they rarely responded with the pronunciations of the phonetic radicals (only 6 out of 356 errors). Their performance in these tasks stands in stark contrast to what young children would do when asked to name an unknown compound character (Ho & Bryant, 1997; Shu et al., 2000). These studies found that young children would typically decompose the character into radicals and use the phonetic radical's pronunciation to name it. Yet this approach cannot account for the results we found in this study. Taken together, the current study provided unequivocal evidence of orthographic learning in Chinese in a self-teaching environment.

The effect of compound type, as an indicator of utilising the phonetic radical, was significant in both phonological decoding and orthographic learning. Reading accuracy during orthographic exposure and subsequent orthographic learning measures both showed advantages for regular and irregular compounds over unrelated compounds. Although regular items were not decoded more successfully than irregular items, they were learned better. There was also a general decline in orthographic memory of the items five days after initial exposure.

4.1. The role of phonetic radicals

Our findings are consistent with previous work showing that young children use the phonetic radical to read Chinese compounds and learn their pronunciations (e.g., Shu et al., 2000; Anderson et al., 2003). The regularity effect was observed in orthographic learning in Chinese, which is consistent with what has been found in English (Wang et al., 2012). This finding could also be considered in line with a recent cross-linguistic study suggesting that orthographic learning was more efficient in shallow (i.e., regular) than in deep (i.e., irregular) orthographies (van Daal & Wass, 2017).

The experimental design also allowed us to look at the nature of phonological decoding in Chinese. The results support the idea that the phonetic radical can be utilised to phonologically decode a new compound via the phonetic and via the analogy strategies (Chen et al., 2014; He et al., 2005; Ho et al., 1999).

However, we did not find evidence suggesting that when both direct mapping and analogy are available, young children tend to favour the former (Chen et al., 2014). Instead, we found that the regular and irregular compounds, although demanding the use of different decoding strategies, were decoded equally well, indicating that Grade 2 children do not have preference for direct mapping over analogy. However, it is important to note that unlike Chen et al. (2014), the current study adopted a more ecologically valid learning environment, where vocabulary knowledge was provided prior to written word exposure. It is possible that when children can utilise their vocabulary knowledge when learning new written words, the difference between using the two decoding strategies diminishes. In addition, because we ensured that the irregular items were based on high frequency neighbours that children are familiar with, the children did have the orthographic knowledge to use the analogy strategy (cf. Chen et al., 2014).

The finding that orthographic learning was less strong in the delayed than in the immediate test is consistent with previous studies that reported a general decay of orthographic knowledge of newly learned words over time (Bowey & Muller, 2005; Nation et al., 2007). Nevertheless, the orthographic choice and word reading outcomes demonstrate robust orthographic learning even 5 days after initial print exposure. An interesting future direction would be to compare the retention rate for different types of words (e.g., regular vs. irregular).

The findings suggest that children do use phonetic radicals to assist them when learning to read novel words in Chinese. An interesting question is then how children learn novel compounds with unrelated phonetic radicals? The results clearly showed that the children still managed to acquire some orthographic knowledge of these items. One possibility is that the children had acquired the vocabulary knowledge so well that they were using it to learn the compounds' written forms, with support from the story context. According to the *lexical quality hypothesis* (Perfetti & Hart, 2002), word-specific representations are formed with the joint work of orthography, phonology and semantics. For the unrelated compounds, the orthography-phonology connection is fully compromised; therefore, there is likely an increase on the reliance of semantic information. This idea is consistent with previous findings in English that vocabulary knowledge is associated with learning irregular words only (Ouellette, 2006; Ricketts, Nation, & Bishop, 2007; Wang et al., 2013), where phonological decoding is partial. Future studies are required to examine whether a similar interaction among vocabulary knowledge, semantic information provided from the compound component (that is, the semantic radical) and compound regularity can be found in orthographic learning in Chinese.

4.2. The role of Zhuyin

We found that Zhuyin facilitated character reading during orthographic exposure. As we had expected, reading accuracy was almost at ceiling when Zhuyin was presented (on average 97.30% correct), which was significantly higher than the without Zhuyin condition (on average 88.19% correct). This indicates that Zhuyin helps to generate the correct phonology of the novel compounds. However, the facilitation in reading did not translate into better orthographic learning. Although we found that Zhuyin mediated the interaction between compound type and testing session in spelling accuracy, the other measures consistently suggested that Zhuyin did not influence orthographic learning results.

Another aim of examining Zhuyin in this study was to explore if phonological decoding contributes to learning via providing the correct phonology or via enhancing readers' attention to the orthographic details. Share (2004) suggested that decoding accuracy alone is not sufficient to ensure successful orthographic learning; phonological decoding only provides opportunities for building up novel words' orthographic representations via drawing the learner's attention to the words' orthographic details. Accordingly, Zhuyin may hinder orthographic learning, because as an external phonological aid, it distracts the children's attention from the orthography, despite providing the correct pronunciation for the character. The results did not support this prediction. We did not find that the children relied on the transparent Zhuyin system so much that their orthographic learning was less effective when Zhuyin was available. Instead, the results suggested that the children learned novel compound characters equally well with or without Zhuyin. One possible explanation for the null effect is that the distraction cancelled out the facilitation from correct phonology. That is, Zhuyin contributed to getting the correct phonology but also drew readers' attention away from the orthographic details. This seems to suggest that getting the correct phonological form is not sufficient for orthographic representations to form. The finding is also consistent with previous work showing that contextual information, which may also reduce the readers' attention on the word's orthographic features, only facilitated decoding but had no effect on orthographic learning (Cunningham, 2006; Ehri & Roberts, 1979; Landi, Perfetti, Bolger, & Dunlap, 2006; Nation et al., 2007). In a similar vein, it has been suggested that spelling is a more effective practice than reading for orthographic learning (Ouellette, 2010; Shahar-Yames & Share, 2008), as it requires even closer attention to the identity and order of letters than reading. Future research tracking eye-movements could directly measure the children's visual attention during character reading with Zhuyin to further test whether Zhuyin distracts the reader's attention during orthographic learning.

Although we did not find Zhuyin to facilitate orthographic learning, it would be too strong to conclude that Zhuyin, as well as other phonological coding systems like Pinyin, are not helpful tools in learning to read. They can be beneficial in many ways. For example, they help children to reliably sound out characters without available phonological cues, either from existing vocabulary knowledge or phonetic radicals. This is especially helpful for beginning readers who have limited radical or character knowledge. Pinyin has also been found to effectively promote character learning for twelve-year-old non-native speakers (Chung, 2002). In addition, Zhuyin or Pinyin enhances children's sensitivity to phonological units, including syllables, phonemes, rimes and tones (Chung, 2002; H. S. Huang & Hanley, 1997; Lin et al., 2010), which is known to be an important predictor of children's character recognition (Li et al., 2012; Shu et al. 2008).

4.3. Implications and future directions

Although longitudinal and cross-sectional studies have acknowledged the importance of phonological skills in learning to read Chinese (Ho & Bryant, 1997; Hu, 2012; Hu & Catts, 1998; Huang & Hanley, 1997; Li et al., 2012; Shu et al., 2008), very few attempts have been made to explicitly manipulate phonological processing in Chinese and to examine how it contributes to orthographic learning. We found empirical evidence that phonological decoding facilitates orthographic learning in Chinese. This finding adds to the current orthographic learning literature that has mainly focused on alphabetic writing systems. The findings support the idea that the self-teaching hypothesis is an orthography-general theory and shows that in non-alphabetic languages, orthographic learning can also take place via phonological decoding.

Our findings also have pedagogical implications. First, explicit instruction on using the phonetic radical for phonological decoding may improve Chinese character acquisition. Yin and McBride (2015) demonstrated that even kindergarteners' sensitivity to phonetic regularity and positional patterns was related to word reading a year later. Currently in schools, children are only taught to decompose compounds into subcomponents and to observe that regular compounds and their phonetic radicals shared the same pronunciations (Wu, Li, & Anderson, 1999). Teaching them to explicitly use the two decoding strategies via the phonetic radical, especially analogy, might help them to improve their learning irregular compounds. Second, although phonological coding systems such as Zhuyin are useful in generating novel characters' pronunciations, this study has shown that it does not promote orthographic learning. In fact, we observed that some children relied heavily on Zhuyin in the spelling task. Instead of writing down the target items, some children tried to produce the Zhuyin symbols. It might be that using this aid delays children's transition to character reading and hinders their written vocabulary growth.

An important limitation of the current study is that the phonetic radicals of the compounds were not fully matched on consistency. Previous studies have shown that consistency – the degree to which characters with the same phonetic radical are pronounced the same (Xing, Shu, & Li, 2004) – may affect phonological decoding. When regularity is controlled, consistent characters have been found to be named faster than inconsistent ones for both adults (Hue, 1992; Lee et al., 2005) and children (Tzeng, Lin, Hung, & Lee, 1995). Chen et al. (2014) also demonstrated that consistency information affects children's choice of decoding strategy. Importantly, its impact was more pronounced in sixth graders than in fourth graders, suggesting an increasingly implicit use of consistency as children's print experience grows. In this study, the compounds' regular pronunciations were also more consistent than the irregular pronunciations. Therefore, we could not tease apart the effects of regularity and consistency. The influence of consistency, as well as its interaction with regularity, on phonological decoding and orthographic learning needs to be addressed in future research.

4.4. Conclusion

This study was the first to investigate the role of phonological decoding in orthographic learning in Chinese. It was demonstrated that orthographic learning in Chinese, just like in alphabetic languages, can take place within four exposures in a self-teaching paradigm. We found that children used information from phonetic radicals, which supports the universality of the role of phonological decoding in orthographic learning. Moreover, our findings showed that Chinese children used both direct mapping from phonetic radicals and analogy during phonological decoding and orthographic learning. Direct mapping was found to be more effective than analogy to help build up orthographic representations. Finally, it was found that Zhuyin, the external phonological coding system, helped children to correctly sound out unfamiliar characters. However, it does not contribute to better orthographic learning, which seems to indicate that the function of phonological decoding is not just to provide the correct phonology, but also to draw readers' attention to the novel words to be learned.

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Appendix A. Target compound characters and pronunciations (with Pinyin transcriptions)

	Target	Regular pronunciation		Irregular pronunciation		Unrelated pronunciation	
		Zhuyin	(Pinyin)	Zhuyin	(Pinyin)	Zhuyin	(Pinyin)
Set A	秼	ㄓㄨˇ	(zhu3)	ㄨㄤˇ	(wang3)	ㄎㄢ	(kan1)
	汲	ㄐㄧˊ	(ji2)	ㄒㄧ	(xi1)	ㄊㄠˊ	(tao2)
	僜	ㄉㄥ	(deng1)	ㄔㄥˊ	(cheng2)	ㄆㄧㄢˋ	(pian4)
	鉼	ㄆㄧㄥˊ	(ping2)	ㄔㄥˋ	(cheng4)	ㄉㄜˊ	(de2)
Set B	䘨	ㄐㄧㄠ	(jiao1)	ㄧㄠˇ	(yao3)	ㄎㄢ	(kan1)
	絴	ㄧㄤˊ	(yang2)	ㄒㄧㄤˊ	(xiang2)	ㄊㄠˊ	(tao2)
	鋰	ㄌㄧˇ	(li3)	ㄇㄞˊ	(mai2)	ㄆㄧㄢˋ	(pian4)
	仩	ㄓˇ	(zhi3)	ㄔㄜˇ	(che3)	ㄉㄜˊ	(de2)
Set C	埥	ㄑㄧㄥ	(qing1)	ㄘㄞ	(cai1)	ㄎㄢ	(kan1)
	槁	ㄍㄠ	(gao1)	ㄎㄠˋ	(kao4)	ㄊㄠˊ	(tao2)
	伷	ㄧㄡˊ	(you2)	ㄒㄧㄡˋ	(xiu4)	ㄆㄧㄢˋ	(pian4)
	鉡	ㄅㄢˋ	(ban4)	ㄆㄤˋ	(pang4)	ㄉㄜˊ	(de2)

Appendix B. An example of a picture and its description used in the *oral vocabulary learning phase*, and a story used in the *orthographic exposure phase*

Description: 電絴機 ("dian4 yang2 ji1")可以用來把你不喜歡的食物從菜裡挑出來。它有一根管道，兩個開口。(English translation: 電絴機 is used to take out the food you don't like from a meal. It has a tube and two open ends.)

Stories:

with Zhuyin	小明的午餐裏有豌豆，可是他不喜歡豌豆。於是，小明把菜倒進了電絴機，按了一下電絴機上的按鈕。經過電絴機的處理，菜再出來的時候就沒有豌豆了。之後小明把電絴機洗乾淨，收起來。
without Zhuyin	小 明 的 午 餐 裏 有 豌 豆， 可 是 他 不 喜 歡 豌 豆。於 是， 小 明 把 菜 倒 進 了 電 絴 機 ， 按 了 一 下 電 絴 機 上 的 按 鈕 。 經 過 電 絴 機 的 處 理 ，菜 再 出 來 的 時 候 就 沒 有 豌 豆 了。之 後 小 明 把 電 絴 機 洗 乾 淨 ，收 起 來 。
(English translation)	Xiao Ming was eating his lunch. He saw peas in his bowl and he does not like them. He poured his meal into the 電絴機 ("dian4 yang2 ji1"). Then he pressed the buttons on the 電絴機. The food went into the tube of the 電絴機, and came out from the other end with no peas in it. Xiao Ming then washed the 電絴機 and put it away.

Appendix C. Items in the orthographic choice task

	Target	Visual Distractor 1	Visual Distractor 2	Phonological Foil		
				Regular	Irregular	Unrelated
Set A	⿰禾主	⿰牛主	⿰禾王	秼	⿰禾亡	⿰禾有
	⿺辶及	⿰王及	⿺辶久	⿺辶己	迺	⿺辶匋
	僜	⿰牛登	⿰亻⿱癶見	⿰亻等	⿰亻成	⿰亻片
	⿰金平	⿰彳平	銤	⿰金屏	鋥	鍀
Set B	⿰衤交	校	⿰衤义	⿰衤甬	⿰衤要	⿰衤交
	⿰糸羊	⿰金羊	⿰糸羔	紻	⿰糸羊	綯
	鋰	⿰扌里	錁	⿰金⿷匚里	⿰金買	⿰金片
	⿰亻止	⿰木止	⿰亻企	侄	俥	⿰亻㝵
Set C	埥	⿰王青	⿰土背	⿰土頁	埰	⿰土看
	⿰亻高	槁	偳	俈	⿰亻考	⿰亻匋
	伷	⿰王由	⿰亻甲	佑	⿰亻秀	⿰亻片
	鉡	⿰阝半	⿰金未	⿰金般	鎊	鍀

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