Phonological Decoding in Orthographic Learning: Evidence from Chinese

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Thesis summary

An important part of children's reading development is the transition from laboriously sounding out a word to automatic word recognition, which is referred to as orthographic learning. In this thesis, I examine the role of phonological decoding in the process of *orthographic learning*. I also apply theories and findings generated in alphabetic languages to a non-alphabetic language, Chinese. This thesis is presented in three parts.

Firstly, a broad literature review on the role of phonological decoding in reading development is presented. In particular, the *phase theory* and the *self-teaching hypothesis* are discussed, with empirical evidence in several languages examined. The review also identifies a lack of empirical studies of non-alphabetic languages, and proposes how phonological decoding can be investigated in orthographic learning in Chinese.

Next, drawing on the literature review, an empirical study is presented to examine the mechanisms of phonological decoding in Chinese, and to address whether they make a direct contribution to orthographic learning. Two research questions are tested: 1) Whether and how Chinese children use phonetic radicals, the "internal approach" and, 2) Zhuyin, the "external approach" for phonological decoding and orthographic learning. The findings support that both approaches are adopted for phonological decoding in Chinese. However, only the internal approach directly contributes to orthographic learning.

Finally, theoretical implications of the findings are discussed. Directions for future research are also outlined.

Statements

I certify that the work in this thesis entitled "Phonological decoding in orthographic learning: evidence from Chinese" has not previously been submitted for a degree, nor has it been submitted as part of requirements for a degree to any other university or institution other than Macquarie University.

I also certify that this thesis is an original piece of research and it has been written by me. Any help and assistance that I have received in my research word and the preparation of the thesis itself has been appropriately acknowledged.

In addition, I certify that all information sources and literature used are indicated in the thesis. The research presented in this thesis was approved by the Macquarie University Ethics Review Committee, reference number: 5201500098 on 15th April 2016.

Signed:

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Chapter 1

General Introduction

Learning to read new words is an important part of literacy development. Moving from the slow and effortful sequential decoding to rapidly and automatically recognising words in print has been referred to as orthographic learning (Anne Castles & Nation, 2006). How this transition takes place has inspired considerable research interest in recent years. One of the important components in this process, phonological decoding, that is, deriving speech information from print, has been considered a key contributor to orthographic learning. The general aim of this thesis was to clarify the nature of phonological decoding, and to outline how it contributes to orthographic learning in different languages. This thesis also presents the first study to examine the mechanisms of phonological decoding and its contribution to orthographic learning in Chinese.

This thesis has three parts. The first section reviews how phonological decoding has been studied, and identifies a number of outstanding questions. The second section is an empirical study that addresses two of the questions that are identified in the review. Finally, findings of the empirical study are discussed in the context of what the current literature has established, and how some of the remaining questions can be addressed in future research. The three sections will be described in more detail below.

Section 1: Phonological decoding: definition, contribution and generalisability to a non-alphabetic language

This part is a broad literature review on phonological decoding and orthographic learning, with the last few sections devoted to research in learning to read in a non-alphabetic language, Chinese. This review is conducted with three main aims. The first is to outline how phonological decoding is conceptualised in two influential theories about learning to read new words – the *phase theory* (Ehri, 1998, 2002) and the *self-teaching hypothesis* (Share, 1999). Empirical evidence from studies conducted in several alphabetic languages is presented. The second aim is to identify outstanding questions regarding the mechanisms of phonological decoding and its function in orthographic learning, as well as to identify the lack of empirical research on phonological decoding and orthographic learning in non-alphabetic languages such as Chinese. Finally, this review proposes how phonological decoding could be examined in learning to read Chinese, and discusses how such research can inform theories about phonological decoding and orthographic learning in general.

Section 2: Examining the role of phonological decoding in orthographic learning in Chinese

Following on the literature review in Section 1, this empirical study aimed to determine the mechanisms of phonological decoding in Chinese, and whether they contribute to orthographic learning. There are two specific research questions: 1) whether and how Chinese children use the phonetic radicals, the “internal phonological aid”, and, 2) whether Chinese children use Zhuyin, the “external phonological aid”, for phonological decoding and orthographic learning. In order to investigate these questions, Taiwanese children in Grade 2 were taught the meaning and sound of twelve pseudo-characters, and were then exposed to their written forms in short stories. The characters were assigned three types of different pronunciations -- one identical to its phonetic radical (regular), one identical to a neighbour with the same phonetic radical (irregular), and one unrelated to the phonetic radical (unrelated). The provision of Zhuyin (with, without) was also manipulated. Immediately after learning and again 5 days later, spelling and orthographic choice tasks were administered. Word reading accuracy was also measured in the 5-day delayed testing session. These three tests were measures of orthographic learning. Our hypotheses were that 1) compared to unrelated characters, phonological decoding would be more successful and orthographic learning would be more effective for regular and irregular characters; 2) compared with the learning without Zhuyin condition, phonological decoding would be more successful and orthographic learning would be more effective in the with Zhuyin condition. The findings were interpreted in the context of the self-teaching hypothesis (Share, 1995), in which orthographic learning is assumed to take place as a result of successful phonological decoding.

Section 3: General discussion: Theoretical implications and future directions

Drawing on findings from the empirical study, this section discusses implications for a universal account of orthographic learning, and outlines directions for future research. By comparing what was found about orthographic learning in Chinese from the empirical study with existing literature in alphabetic languages, this section summarises the commonalities in orthographic learning across orthographies. Finally, a number of outstanding issues are outlined with proposals on how they could be addressed in the future.

Chapter 2

Phonological Decoding: Definition, Contribution and Generalisability to a Non-alphabetic Language

Abstract

Orthographic learning refers to the process of moving from effortful sequential decoding to automatic whole word recognition. Phonological decoding, deriving speech information from print, has been proposed to play a fundamental role in this process. However, the mechanism of its function is not well understood. In addition, its mechanism and contribution to orthographic learning have not been examined in non-alphabetic languages. The aim of this review was: 1) to provide a broad review of how phonological decoding and its function have been conceptualised in reading development theories, and of empirical evidence supporting its pivotal role in orthographic learning in several languages, and 2) to propose the possible mechanisms of phonological decoding in Chinese, and how they might contribute to orthographic learning. Approaches to testing these proposals are suggested.

Introduction

It has been widely acknowledged that phonological decoding – broadly defined as deriving speech information from print – plays a central role in the early literacy development. Beginning readers need to learn and establish a system of mappings between the graphemes of written words and phonemes of spoken words (Ehri, 1992). This knowledge enables them to move on to acquire a word recognition system that is rapid and automatic, a transition referred to as “orthographic learning” (Castles & Nation, 2006). This review will focus on phonological decoding and its role in orthographic learning. Also, a gap will be identified in current orthographic learning research. That is, no study has examined it in non-alphabetic languages. Finally, I will propose how the mechanisms of phonological decoding and its contribution to orthographic learning could be investigated in a non-alphabetic language, Chinese.

Over the last few decades, reading research has exhibited an “alphabetism” inclination (Share, 2015), ignoring the fact it might be impossible to use concepts and theories in the “alphabetic” reading science to describe reading and its development in non-alphabetic orthographies. An example is that the alphabetic reading units “letter” and “grapheme” do not have equivalent counterparts in non-alphabetic orthographies like Chinese. Hence, the units of phonological analysis and the process of phonological decoding cannot be the same in Chinese as in the alphabetic languages. The potential contribution of phonological decoding to orthographic learning is also likely to be different. It is important to recognise these differences so that they can be taken into account in reading development research. Therefore, the aim of this review is to evaluate the aspects of phonological decoding that have been studied and to examine whether the concepts and theories can be generalised to Chinese.

To this end, this review will start from a discussion on current influential theories in reading development. The focus will be on how these theories conceptualise phonological decoding. Next, cross-linguistic studies investigating the self-teaching hypothesis (Share, 1995) and orthographic learning in general will be reviewed. Particular attention will be drawn to the findings that are hypothesized to be a consequence of differences in *orthographic depth*. Based on these findings, whether the effect of orthographic learning in non-alphabetic languages like Chinese would be predicted to be strong within the self-teaching experimental paradigm will be discussed. A brief introduction of the Chinese writing system will then be provided, which will lead to the fundamental question – what could be the mechanisms of phonological decoding in Chinese? Before discussing plausible answers to this question, evidence to support the importance of phonological skills in learning to read in Chinese will be evaluated. This review will conclude with a discussion about how the mechanism of phonological decoding and its role in orthographic learning could be tested in Chinese.

Reading development: the phase theory

The phase theory (Ehri, 1998, 2002) posits that children go through four phases to learn the full orthography of words–the *logographic phase*, the *partial alphabetic phase*, the *full alphabetic phase* and the *consolidated alphabetic phase*. Accordingly, beginning readers start from recognising words purely as symbols. In other words, they rely on visual features to read words. For example, they may remember the meaning of the word *look* only because of the “two eyes” in the middle (Gough, Juel, & Griffith, 1992), without awareness of it being a word. Since pre-alphabetic readers read words merely as symbols, they would not notice the difference between *look* and *took*, but instead would see them as identical signs for the same concept, as they both have “two eyes” (Masonheimer, Drum, & Ehri, 1984). In this phase, no letter-sound knowledge or phonological decoding is used.

In the second, partial alphabetic, phase, children gradually establish grapheme-phoneme correspondences (GPCs) and start to map letter and letter clusters onto sounds. Because they have not yet acquired full knowledge of the alphabetic system, they can decode only part of the written words. Several studies have compared the partial alphabetic readers and the logographic readers on learning two types of spellings (De Abreu & Cardoso-Martins, 1998; Ehri & Wilce, 1985; Roberts, 2003). Phonetic spellings have letters representing some sounds in the words. For example, the word *mask* might be spelled as MSK. Visual spellings have letters without connections to the sounds. For example, the word *mask* might be spelled as uHo. It has been found that pre-alphabetic readers typically learn visual spellings better and the partial alphabetic readers learned the phonetic spellings better (Ehri & Wilce, 1985). This effect indicates that translating letters to sounds starts to be involved in reading in the partial alphabetic, compared with the logographic phase.

As the learners’ alphabetic knowledge increases, they can learn words via forming complete connections between print and sound. This is the full alphabetic phase. Now, the readers are able to decode unfamiliar words and retain correct spellings of words in memory much better than in the previous phase, as their phonological decoding skills enable them to distinguish similarly spelled words more easily. Ehri and Wilce (1987) trained kindergarteners in the partial alphabetic phase to practice reading similarly spelled words. Another control group practiced isolated grapheme-phoneme connections. Then they were given 15 words with similar spellings to learn to read (e.g., *stab, stamp, stand*). The experimental group, which was assumed to have reached the full alphabetic phase, learned to read most of the target words in three trials whereas, the control group, who remained partial alphabetic readers, never reached this level of learning.

The consolidated alphabetic phase emerges when the readers' written word vocabulary grows to a point that they become familiar with some recurring letter patterns. Hence, they can analyse larger units such as morphemes, rimes and syllables. Chunks like -*tion* and -*ight* are recognised as units rather than unassociated letter strings. Compared with letter-by-letter decoding, analysing chunks makes reading and remembering words, especially multisyllabic words, more efficient (Ehri, 2005).

Beyond the developmental phases, Ehri (1992, 1999, 2005) proposed that words that have been seen before are read by memory or by sight. Learning to read sight words is a process of building up connections between visual and phonological forms, which "glue" words' spellings to their pronunciations in memory. During the developmental phases, the connections between spellings of words and their pronunciations gradually improve in quality, until accurate and automatic sight word reading is achieved. This, in fact, is orthographic learning. Sight word reading is dependent on readers' knowledge of the alphabetic system. That is, before a word becomes familiar, it will still need to be read by using some strategies such as phonological decoding and analogy (Ehri, 2005).

The phase theory presents a developmental account of written word acquisition, with the prominent strategy children use in each phase underlined. Importantly, it identifies children's reliance on phonological decoding as the primary strategy in the alphabetic phases and as the premise for sight word reading. Ehri (2005) also suggests that children could be using a combination of strategies in each phase when learning and reading different words. For example, a child may be able to form full grapheme-phoneme connections for shorter words but only partial mappings for longer ones in the alphabetic phases. Nevertheless, we cannot draw an explanation from this account of why there are differences between learning shorter and longer words, and also between individuals. In addition, it is very difficult to distinguish between each phase at either the word or at the reader level. That is, different words may involve different reading strategies for the same reader. A reader is also unlikely to remain for a fixed period in a particular phase and use the same strategies in reading all words. For example, a child may be able to read some high-frequency words by sights, but will still need to phonologically decode some unfamiliar low-frequency words.

Reading development: the self-teaching hypothesis

In contrast to the phase theory, Share's (1995) self-teaching hypothesis addresses how phonological decoding functions in orthographic learning from an item perspective. The rationale is that new words are constantly encountered and added into the readers' lexicon. Whether readers attempt to read a particular word by phonological decoding does not depend on which phase they are in, but on whether this word is familiar or novel. Because readers of all levels encounter new and low-frequency words, phonological decoding is used throughout life, rather than only for early stages of reading acquisition. Share (1995) postulates that specified orthographic representations that are necessary for fast and automatic word recognition are largely self-taught. Phonological decoding acts as a self-teaching device that provides learners the opportunity to attend to the word-specific orthographic details, and thus contributes to establishing an entry in the orthographic lexicon. When children encounter an unfamiliar word, they will use their knowledge of GPC rules to generate the pronunciation of that word. In doing so, their attention is drawn to its orthographic details. Each decoding attempt strengthens the bonding between the word's orthography and phonology. Thus, they are able to establish orthographic representation of the word.

Another argument for the self-teaching hypothesis is that it explains how children are able to learn many new words without explicit instruction. A fifth grader encounters as many as 10,000 new words a year on average (Nagy & Herman, 1987). Most learning takes place outside of school and without parental assistance. Another mechanism could be contextual guessing. However, it is unlikely that this is how children learn new words, because contextual information is often ambiguous and unreliable (Share, 1995). Nevertheless, context can supplement partial or incomplete phonological decoding when the novel word is irregular or when the reader has poor phonological decoding skills. Indeed, Wang, Nickels & Castles (2013) found that contextual information facilitated orthographic learning of irregular words but not of regular words. Taken together, self-teaching via phonological decoding is still the primary mechanism to acquire new written words.

Share (1999) tested the self-teaching hypothesis with a novel self-teaching paradigm. In this study (Experiment 1), second grade Hebrew-speaking children were asked to read aloud short stories unassisted where the target made-up words occurred four to six times. Three days later, they were assessed on how well they learned the new words with three measurements: naming speed, spelling to dictation and orthographic choice. The orthographic choice task was a novel measurement in that the children were to choose from the target (e.g., *yait*) and three visual distractors: a homophonic foil where some letters were replaced with homophonic alternatives (e.g., *yate*), a letter substitution where one letter was replaced with a similar one (e.g., *yoit*) and a transposition where two adjacent letters in the target word were transposed (e.g., *yiat*). The rationale for such a task as a measurement of orthographic learning is that only when the reader can identify a word without interference from its competing neighbors, the learning qualifies as successful orthographic learning (Castles & Nation, 2006). On average, children chose the target more often than the other distractors, suggesting that they had established specified orthographic representations of these words. Critically, another group was asked to repeat a pseudo-word "DUBBA" while reading the target words (in Experiment 2). In this condition, phonological processing of the target words was suppressed by the concurrent articulation. Posttest results of Experiment 2 were significantly worse than in Experiment 1, where phonological decoding was not suppressed. These results show that children are able to learn to read new words via self-teaching, and that phonological decoding enables orthographic learning. Reduced orthographic learning was also observed when phonological decoding was suppressed by concurrent articulation during reading in Dutch (de Jong, Bitter, van Setten, & Marinus, 2009) and in English (Kyte & Johnson, 2006). In addition, to exclude the possibility that the influence of the concurrent articulation on orthographic learning was a general effect of an extra task, de Jong et al. (2009) introduced another condition where the children tapped with the hand. The participants showed worse performance in the concurrent condition compared with the tapping condition, indicating that it was the suppression of phonological decoding rather than an extra task that hampered orthographic learning.

Self-teaching through phonological decoding also takes place during silent reading. To examine whether children also acquire orthographic knowledge without reading aloud, Bowey and Muller (2005) asked Grade 3 English-speaking children to read stories with target pseudowords silently. Next, the children were given an orthographic choice task and a word naming task to measure orthographic learning. It was found that the children not only chose more target words than homophonic and visual distractors, but also named the target items significantly faster. This effect established that phonological decoding had taken place and mediated the acquisition of orthographic representations. Dutch children in Grade 3 also showed strong orthographic learning when asked to read texts silently (de Jong & Share, 2007).

Given its emphasis on phonological decoding, a key prediction of the self-teaching hypothesis is the presence of a regularity effect in word learning. As regular words (e.g., *hint*) entirely conform to GPC rules whereas irregular words (e.g, *pint*) do not, decoding the former should be easier and more likely to be successful (e.g., Rack, Hulme, Snowling, & Wightman, 1994; Waters, Seidenberg, & Bruck, 1984). The regularity effect has been used to show reliance on phonological processing, and has been observed in children's word naming (e.g., Laxon, Masterson, & Coltheart, 1991) and lexical decision tasks (e.g., Schmalz, Marinus, & Castles, 2013). Hence, orthographic learning should also manifest the regularity effect, if phonological decoding is indeed the driving force behind it. Wang, Castles, and Nickels (2012) trained a group of 3rd year English-speaking children to read regular and irregular pseudowords and assessed their orthographic learning. They designed a novel paradigm, where phonology and meanings of the target items were taught to the children prior to orthographic exposure. This allowed for the manipulation of regularity. In addition, this simulated a more natural self-teaching environment, because when children are learning to read new words, many of them are already in their spoken vocabulary. A week after the learning, Wang et al. (2012) found that the regular words indeed gained stronger orthographic representations than the irregular ones, suggesting phonological decoding contributes directly to orthographic learning.

The importance of phonological decoding is also supported by studies showing a positive correlation between correct phonological decoding and successful orthographic learning (Bowey & Miller, 2007; Cunningham, 2006; Cunningham, Perry, & Stanovich, 2002; de Jong et al., 2009; Kyte & Johnson, 2006; Nation, Angell, & Castles, 2007). However, using item-level analyses, Nation et al. (2007) and Wang et al. (2013) demonstrated that successful decoding of a word does not directly translate into orthographic knowledge for this specific word. As Share (2008) contends, successful decoding does not guarantee orthographic learning, but only provides opportunities for it. Other factors, such as orthographic knowledge (Cunningham, 2006; Cunningham, Perry, Stanovich, & Share, 2002), pre-existing vocabulary knowledge (Gene Ouellette & Fraser, 2009) and contextual information (Wang, Castles, Nickels, & Nation, 2011), also influence the integration of the novel words into the orthographic lexicon. Nevertheless, how phonological decoding provides such learning opportunities is still not clear. Even though the self-teaching hypothesis posits that it functions by focusing the readers' attention on the words' orthographic details, researchers have not been able to directly test this hypothesis.

Orthographic learning across languages

The self-teaching hypothesis and the role of phonological decoding have not only been tested with orthographic learning studies in English (Bowey & Muller, 2005; Cunningham, 2006; Cunningham et al., 2002; Kyte & Johnson, 2006; Nation et al., 2007; Ricketts et al., 2011), but also in transparent languages such as Dutch (de Jong et al., 2009; de

Jong & Share, 2007), Spanish (Suárez-Coalla, Álvarez-Cañizo, & Cuetos, 2016) and Hebrew (Share, 1999, 2004). The results are largely consistent across languages. However, first graders learning pointed Hebrew did not exhibit orthographic learning (Share, 2004) as their English peers did (Cunningham, 2006).

An explanation provided for this difference was that Hebrew has a shallow orthography on the continuum of orthographic depth (Share, 2004). Because shallow orthographies have more consistent print-to-sound mappings and fewer GPC rules than deep orthographies, words will be easier to decode (Katz & Frost, 1992). In contrast, reading in a deep orthography requires both phonological and visual–orthographic processes (Seymour, Aro, & Erskine, 2003). Hence, readers of English, the deeper orthography, have to pay closer attention to visual-orthographic details and have to show more explicit orthographic learning than readers of pointed Hebrew, who can be relatively insensitive to words' orthographic details. A recent correlational investigation on 2nd grade children of Finnish, Hungarian, Dutch, Portuguese, and French showed that the effect of phonological awareness, the ability to perceive and manipulate speech units, as a predictor on word reading was indeed stronger in shallow than in deep orthographies (Ziegler, Bertrand, Tóth, & Csépe, 2010), suggesting that phonological skills may be more important for learning to read in transparent languages. However, there is also evidence showing that phonological awareness is equally important in English and Dutch (Patel, Snowling, & de Jong, 2004), English and Czech (Caravolas, Volín, & Hulme, 2005), and Hungarian, Dutch and Portuguese (Vaessen, Bertrand, Tóth, & Csépe, 2010) despite their variances in orthographic depth. Thus, it is not clear yet whether phonological decoding skills have greater impact on word learning in some languages than others.

Another cross-linguistic difference that has been observed is the durability of orthographic learning effect. Hebrew third graders showed no significant decline in orthographic memory thirty days after initial exposure, compared with a three-day delay (Share, 2004). In contrast, the orthographic learning effect was most robust one day after exposure for English-speaking children, with significant decay after six (Bowey & Muller, 2005) or seven (Nation et al., 2007) days. These findings suggest that strong associations between speech and print may require more repetition and consolidation in deep orthographies than in shallow orthographies.

Despite the cross-linguistic variations in the function of phonological decoding and in the effects of orthographic learning, Share (1999) maintains that "any script which is functionally decodable in context, and sufficiently encapsulated to permit identification of specific lexical items should permit functional self-teaching" (p.124). In orthographies such as Chinese and Japanese *kanji* (which also uses Chinese characters), the pronunciation of the reading units cannot be accessed by systematic phonological analysis of its constituents in the way that they can be in alphabetic languages. There is a lack of direct and reliable connection between print and sound. Therefore, learning to read in these languages may require high sensitivity to the orthography in order to establish word-specific knowledge. The effect of orthographic learning via self-teaching should also be strong in the non-alphabetic orthographies. A recent study has demonstrated initial evidence of fast orthographic learning in Chinese. Zhou, Duff, & Hulme (2015) taught Chinese first and second grade children to read new words. They found that teaching their pronunciations facilitated learning, while exposure to the meanings further improved learning. However, it is not clear how exposure to phonological information contributed to learning in this study. Specifically, whether it is the process of phonological decoding or merely the activated phonology that enhanced the learning is yet to be determined. Before we start discussing plausible answers to these questions, we need to first look at how phonological and semantic information is represented in Chinese.

Chinese characters and the radicals

Characters are the basic reading units in Chinese. Each character maps onto an entire spoken syllable rather than smaller phonological units such as phonemes. An estimated 80%-90% of modern Chinese characters are compounds, containing a semantic radical and a phonetic radical (Hoosain, 1991; Kang, 1993). There are about 200 semantic radicals and 1,000 phonetic radicals in Chinese (Hanley, 2005). The semantic radical (e.g., 氵, "liquid") often denotes the semantic category of the character (油, "oil"), and the phonetic radical (由 |you2|) normally provides cues for the sound of the character (油 |you2|). Many semantic and phonetic radicals themselves can be stand-alone characters with sound and meaning (e.g., 由 |you2|, "by").

Radicals can be in different positions within a compound character. The semantic radical can be on the left (e.g., 氵 in 油); on the right (e.g., 羽|yu3| in 翔 |xiang2|)；on the top (e.g., 宀 in 宙 |zhou4|); at the bottom (e.g., 貝|bei4| in 費|fei4|); enclosing the phonetic radical (e.g., 口|kou3| in 圓|yuan2|); half enclosing the phonetic radical (e.g., 辶 in 迪|di2|). Similarly, phonetic radicals can also occur in different positions. For example, 工|gong1| can be on the right as in 紅|hong2|; on the left as in 攻|gong1|; on the top as in 貢|gong4|; and at the bottom as in 空|kong1|. Although there is positional flexibility, for most radicals, 57% semantic radicals and 17% phonetic radicals have fixed position in compound characters

(Shu et al., 2003). Left-right structure is the most common configuration, namely, 72% of the 3,027 most frequently used compound characters. Ninety percent of these left-right characters have their phonetic radicals on the right (Hsiao & Shillcock, 2006). In Chinese elementary textbooks, the phonetic radical of compound characters also appears far more often on the right than in other positions (Lui, Leung, Law, & Fung, 2010; Shu, Chen, Anderson, Wu, & Xuan, 2003).

Chinese children are sensitive to the subcomponents of characters and make use of them in reading Chinese. They start develop awareness of the internal character structure early in elementary school (Anderson et al., 2013; Chan & Nunes, 1998; Ho, Ng, & Ng, 2003). Anderson et al. (2013) asked 50 Chinese children in 2nd grade to perform a delayed character copy task, where they wrote down briefly presented characters. These children, although varying in reading proficiency, performed better when the radicals appeared in familiar positions than in unfamiliar positions. The advantage even held for made-up characters. When the targets were made-up characters with arbitrary strokes, they could not reproduce them. Even kindergarteners have been found to be aware of the positional constraints of some radicals and produce more made-up characters with left-right structure. Furthermore, this ability improves steadily across grade levels (Li & McBride, 2014; Yin & McBride, 2015).

The reliability of information from the semantic or the phonetic components varies greatly. Shu et al.'s (2003) analysis of Chinese elementary textbooks revealed that among the 88% compound characters, 65% are semantically transparent, meaning that the character is directly related to the semantic category of its semantic radical. The phonological information provided by the phonetic radicals is much more unreliable. Only 39% of the compound characters sound exactly the same as their phonetic radicals (e.g., 油|you2| and 由|you2|). We will refer to them as regular characters. On the other hand, 41% of them sound totally differently (e.g., 油|you2| and 笛|di2|), and are known as irregular characters (Shu et al., 2003). The unreliable print-to-sound mappings in the Chinese script makes it harder for readers to use phonological decoding. They will have to compensate with using more visual-orthographic and semantic processing in learning new characters.

Phonological awareness and other cognitive predictors of Chinese reading development

Although the print-to-sound connections are unreliable in Chinese, phonological skills have still been found to play an important role in learning to read Chinese. First of all, a large number of cross-sectional and longitudinal investigations in both Taiwan, Hong Kong and mainland China have shown that phonological awareness is a predictor of character reading (Chan, 2013; Ho & Bryant, 1997; Hu, 2012; Hu & Catts, 1998; Huang & Hanley, 1997; Li, Shu, McBride, Liu, & Peng, 2012; Shu, Peng, & McBride, 2008). Secondly, Chinese dyslexic children have also been found to have much poorer phonological skills than their age-matched controls (for a review, see Peng, Wang, Tao, & Sun, 2016).

It should be noted that phonological awareness refers to sensitivity to several levels of speech units. Among them, syllable awareness is the strongest predictor of character reading, in contrast to English word reading, where phoneme awareness is the most crucial one (McBride, Bialystok, Chong, & Li, 2004; McBride, Tong, & Shu, 2008). This difference supports Ziegler and Goswami's (2005) *grain size hypothesis* that languages vary in phonological structure and in the consistency with which sound is represented in print. As such, the grain size of lexical representations and children's phonological knowledge differ across languages. English print-to-sound mappings can be described as existing at multiple grain sizes with phoneme processing being the basic level, whereas in Chinese, the conversion is entirely at the syllable level. This also suggests that phonological decoding in Chinese is likely a process of translating print to syllables in sounds without further decomposing the characters into smaller units.

Although phonological awareness explains some variance in children's reading ability, studies have been unable to demonstrate that enhanced phonological processing directly contributes to reading ability in Chinese. Zhou, McBride, Fong, Wong and Cheung (2012) compared the effect of phonological or morphological training on character reading. Eighty-eight kindergarteners were assigned to training either on morphological awareness (including lexical compounding and homophone awareness) or on phonological awareness (including syllable, lexical tone and rhyme sensitivity) for two months. Morphological awareness refers to the ability to identify and manipulate the basic meaningful units, the character (Kuo & Anderson, 2006). The lexical compounding task involved generating words with the target morpheme. An example in English is "Basketball is a game in which we throw a ball through a basket. What would we call a game in which we throw a ball onto a sofa?", and the answer should be *sofaball* (p. 480). Compared with a control group, word reading showed greater improvement in the lexical compounding group, whereas, phonological awareness training elicited no reading or vocabulary enhancements.

Over the last three decades, a number of other cognitive skills connected to reading ability in Chinese have been identified, including rapid automatised naming (RAN) (Chow, McBride, & Burgess, 2005; Ho & Lai, 1999; Tong, McBride-Chang, & Shu, 2009), visuo-orthographic processing (Ho & Bryant, 1999; Li et al., 2012) and morphological awareness

(Li et al., 2012; Tong, McBride-Chang, & Shu, 2009). RAN concerns serial naming speed of digits. Visuo-orthographic skills refer to the ability to process visual representations such as shapes and lines (Li et al., 2012). Given that the orthography-to-phonology mappings are rather arbitrary in Chinese, the skills concerning sensitivity to orthographic details and morphological combinability are considered crucial in word reading. Deficits in these abilities are also more common than phonological deficits in Chinese developmental dyslexia (Ho, Chan, Lee, Tsang, & Luan, 2004; Shu, McBride, Wu, & Liu, 2006; Wu, Packard, & Shu, 2009). For example, Ho et al. (2004) found that while 29% of the dyslexic children in their study had phonological deficits. Deficits in rapid digit naming (57%) and orthographic processing (42%) were even more prominent. Wu et al. (2009) also found that as much as 96% children with dyslexia have morphological deficits.

Moreover, phonological awareness may not be equally relevant for reading all types of characters. Lau, Leung, Liang and Lo (2015) tested 246 Grade 3 children with a range of tasks on phonological, orthographic, morphological processing, RAN, we well as naming regular, irregular and non-phonetic characters. They found that only phonological awareness is important for reading regular characters, while all the cognitive abilities are important for reading irregular and non-phonetic characters. The difference in processing regular and irregular Chinese characters is also supported by an ERP study (Yum, Law, Su, Lau, & Mo, 2014). This suggests that reading regular characters depends more strongly on phonological processing than is the case for irregular characters. These findings are line with the fact that the phonology of regular characters is represented directly by the phonetic radicals and thus allows a high reliance on phonological decoding. For irregular and non-phonetic characters, on the other hand, the print-to-sound conversion is so unreliable that reading needs to depend on other mechanisms. Further investigation is required to determine whether such differences affects orthographic learning.

It should be noted that the definition of regularity in Chinese and in English is only conceptually similar in that in both languages, it indexes whether a word's pronunciation follows certain rules. However, there are qualitative differences in how the rules are defined in the two languages. In English, even irregular words have some reliable cues, because irregularity is largely restricted to vowels (Treiman, Mullennix, Bijeljac-Babic, & Richmond-Welty, 1995). For example, in the irregular word *yacht*, the consonants [y] and [t] can still be decoded by using letter-sound translations. However, in Chinese, the pronunciation of an irregular character can be completely unrelated to its phonetic radical. In other words, the character-to-sound mappings can be entirely arbitrary in irregular characters, making it far more unreliable to decode them than to decode irregular English words. Nevertheless, they are so common that children must use some methods to derive their pronunciations from the printed form. Some researchers have suggested that decoding irregular characters involves making an analogy to neighbour characters with the same phonetic radicals (Chen, Anderson, Li, & Shu, 2014; He et al., 2005; Ho, Wong, & Chan, 1999). This proposal will be discussed in the next section. By examining how irregular characters are decoded, as well as by comparing phonological decoding for regular and irregular characters, we will be able to determine the nature of phonological decoding in Chinese.

Phonological decoding in Chinese: the "internal approach"

The direct approach of phonological decoding in Chinese is to derive the pronunciation of the character directly from the phonetic radical. There is ample evidence suggesting that children use phonetic radicals to read characters. In particular, children rely on the phonetic radicals to generate analogical sound cues in naming and reading unfamiliar words. Ho and Bryant (1997) reported that first and second grade Hong Kong children read regular characters more accurately than irregular characters, indicating that they took advantage of the reliable phonological information afforded by the phonetic radicals. Shu, Anderson, and Wu (2000) found similar results with mainland Chinese second, fourth and fifth graders. Even four-year-old kindergartners who haven't received formal reading instruction can detect the phonetic regularity of characters. Also, when these children were tested a year later, their reading and writing abilities were found significantly correlated with their sensitivity to phonetic regularity a year ago (Yin & McBride, 2015).

Phonetic radicals that contain reliable phonological information can help children to read new characters. Anderson, Li, Ku, Shu, and Wu (2003) taught children from Beijing and Hong Kong to read unfamiliar characters of four types: regular, tone-different, onset-different and phonetic-unknown. The participants learned to read more regular, tone-different and onset-different characters than characters with unknown phonetic radicals. This suggests that knowledge of the phonetic radicals is important for character learning. He, Wang, and Anderson (2005) replicated the study in Taiwan and found similar results. Kindergartners also learned to read more pseudo-characters if phonetic cues were available (e.g., 忄人 , where 人 |ren2| is pronounceable) than pseudo-characters without such information (e.g., 氵丂 , where neither 氵 nor 丂 is pronounceable) (Yin & McBride, 2015).

In addition to the evidence that phonetic radicals are used for word reading and learning in Chinese, two strategies have been proposed regarding how phonological decoding takes place via the radicals, the "internal approach". They are the phonetic strategy and the analogy strategy. By using the phonetic strategy, a character’s phonology is accessed directly via the phonetic radical. Alternatively, children can infer a character’s sound by making analogy to its orthographic neighbours with the same phonetic radical (Chen, Anderson, Li, & Shu, 2014; He et al., 2005; Ho, Wong, & Chan, 1999). Chen et al., (2014) investigated whether children use known characters to name novel ones via direct mapping from phonetic radicals or via analogy. In their study, the children first learned to read a character (e.g., 胥|xu4|), and were then asked to name an unknown character with the learned character as its phonetic radical (e.g., 揟|xu4|). In the other condition, children first learned a compound character (e.g., 溍|jin4|), and were then asked to name an unknown character that shared the same phonetic radical (e.g., 縉|jin4|). The performance of the children did not differ between the two conditions, indicating that they used both analogy and direct decoding via the phonetic radical to name unfamiliar characters. They also found that as their print experience grows, the children develop a tendency to adopt analogy over the phonetic strategy.

Phonological decoding in Chinese: the “external approach”

Another approach to phonological decoding is by using an external aid: Zhuyin symbols. Given how unreliable phonetic radicals are in providing cues to the sounds of characters, children are taught to read Chinese with this external phonological coding system. An alternative aid used in mainland China is Pinyin, whose function is similar. Zhuyin consists of 37 symbols, making one-on-one representations of the onsets and rimes of spoken Chinese. It is introduced in the first 10 weeks of Grade 1, and children in Taiwan normally master this phonetic transcription system before they start learning characters (Cheung & Ng, 2003). It always occurs alongside novel characters in elementary textbooks and storybooks, helping children to sound out any unknown character (see Figure 1.1. for an example).

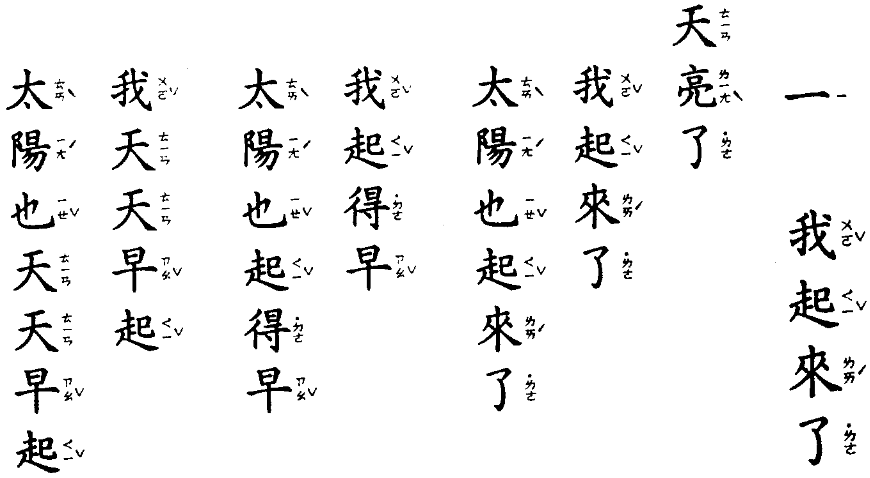

Figure 1.1. An extract from the Chinese language textbook for 1st-graders in Taiwan. The Chinese characters appear on the left with the smaller Zhuyin symbols to the right, arranged vertically. The symbols that sometimes appear on the right of the Zhuyin indicate the lexical tone in which the word is spoken. (Source: Huang & Hanley, 1997, p.251)

Learning Zhuyin/Pinyin may promote character reading and learning. For instance, knowledge of Zhuyin/Pinyin has been found to be a predictor of character recognition. Lin et al. (2010) showed that representations of Pinyin uniquely predicted Chinese kindergartners' character reading a year later. In another longitudinal study, Pinyin knowledge reliably predicted character recognition from kindergarten through Grade 5 (Pan et al., 2011). However, a recent study did not find additional benefit on reading and writing in kindergartners from training on Pinyin and copying skills, compared with training on copying only (Wang & McBride, 2016). The only extra gain was improvement in an invented Pinyin spelling task, as a measurement of children's phonological coding ability of Pinyin knowledge. In this task, the children were encouraged to write down orally presented words in Pinyin, with all Pinyin alphabets shown on another sheet for their reference. This finding suggests that there is no direct effect of Zhuyin/Pinyin proficiency on learning to read character. The predictive value of it on character reading may only reflect that children who can easily learn Zhuyin/Pinyin are also good at character learning.

There are two ways that Zhuyin/Pinyin likely improves reading and learning. Firstly, learning these external aids improves children's phonological awareness. Children in Taiwan and mainland China have consistently demonstrated an advantage in phoneme and onset/rime awareness over children with the same level of schooling in Hong Kong, where they do not learn Zhuyin or Pinyin (Chen & Yuen, 1991; Cheung & Chen, 2004; Cheung, Chen, Lai, Wong, & Hills, 2001; Huang & Hanley, 1995; Zhang & McBride, 2011). Poor readers also performed significantly worse in the invented Pinyin spelling task than average and good readers (Ding, Liu, McBride, & Zhang, 2015), suggesting it can be effective as a screener for children who might struggle with learning to read in Chinese. Secondly, Zhuyin, as well as Pinyin, may function as a highly efficient self-teaching tool (Lin et al., 2010), since it is reliable at all phonological levels, representing the exact sound of a given character. In fact, children who are learning Chinese as a second language have been found to learn characters better with Pinyin transcriptions and English translations presented together (Chung, 2002). Similar facilitating effects from Zhuyin may also manifest with first language learners.

However, Zhuyin/Pinyin may also inhibit orthographic learning. Since Zhuyin only occurs beside characters, it can potentially distract the children's attention from focusing on the orthography, and thus impede the formation of orthographic representations. Also, decoding via Zhuyin is comparable to reading in shallow orthographies. Therefore, when Zhuyin is available, readers may only resort to phonological processing and pay little attention to the visual-orthographic details (Share, 2004). In addition, the print-and-sound connections built via Zhuyin can be highly susceptible to homophonic interference, since

Zhuyin ensues correct decoding but may limit orthographic processing. For instance, if children's attention is largely on Zhuyin when learning the character 油|you2|, they might have more difficulty later in distinguishing the target from its homophones like 游|you2| and 鈾|you2|. Thus, the presence of Zhuyin may result in a weak and unspecified association between the phonology and the orthographic form. This could be particularly problematic for learning to read Chinese, where there is a high level of homophony.

Summary

Previous studies on orthographic learning have established that phonological decoding helps to establish orthographic representations of novel words. While the developmental account of written word acquisition acknowledges the pivotal role of phonological decoding, how it contributes to learning specific words is less clear. The self-teaching hypothesis proposes a description of the underlying mechanism: decoding provides opportunities to establish specified orthographic knowledge of given words. This hypothesis has been tested and confirmed in several languages, although beginning readers of Hebrew showed a difference from their peers learning to read other languages, especially in the efficiency of fast orthographic learning and its durability. In general, the cross-linguistic difference seems to be a result of differences in the extent to which the orthography of a language allows for reliable phonological decoding. The contribution of phonological decoding to orthographic learning has not been examined in a non-alphabetic language.

Although the print and sound translation in Chinese is indirect and unreliable, phonological awareness, the ability to perceive and manipulate speech units, is one of the cognitive predictors of reading in Chinese. In addition, a recent study showed that reading regular and irregular characters may draw on different cognitive skills (Lau et al., 2015). This difference might affect orthographic learning as well.

Before we can test the self-teaching hypothesis in Chinese, we first need to better understand the mechanism of phonological decoding in Chinese. Based on the analysis of the language and education practice outlined in this review, an internal and an external approach may be proposed. The internal approach is decoding via phonetic radicals. Previous research has shown that Chinese children use phonetic radicals to generate characters' pronunciations (Ho & Bryant, 1997; Shu, Anderson & Wu, 2000), and that their ability to use phonetic radicals is an effective predictor on reading (Yin & McBride, 2015). Specifically, children might use both phonetic strategy (direct mapping from the phonetic radicals to sounds) and analogy strategy (analogous mapping from orthographic neighbours to sounds). The external approach is decoding via Zhuyin/Pinyin. Formal reading instruction in Chinese elementary school offer these external phonological decoding systems. They are highly transparent and enable children to sound out any unknown characters. Therefore, it is speculated that Zhuyin/Pinyin could be an efficient self-teaching tool for orthographic learning.

Based on the review of findings about phonological decoding and its contribution to orthographic learning in different languages, as well as on the analysis of Chinese characters and the phonological decoding aid, two questions can be proposed. They are 1) what is the mechanism of phonological decoding in Chinese? And, building on this question, 2) does phonological decoding contribute to orthographic learning in Chinese? The next section proposes future directions about how these questions could be examined.

Future directions

It has been discussed that there might be two approaches of phonological decoding in Chinese, one internal and one external. Whether they are indeed the mechanisms of phonological decoding can be investigated by two different manipulations in reading aloud experiments. To examine the use of phonetic radicals, experimental items can be manipulated such that the phonetic radicals in some character provide reliable phonological information, whereas in others, there are no available phonological cues to use. To further distinguish the use of the phonetic and the analogy strategy via using the phonetic radicals, a manipulation can draw on Chen et al. (2014). Test items can be selected such that in one condition, only the phonetic strategy is available for reading the items, while in another condition, only analogy is available, with a third control condition, where neither strategy can be used. To distinguish the use of Zhuyin in phonological decoding, a manipulation of reading with and without Zhuyin is needed. Comparisons between conditions can be conducted with reading accuracy and reading speed.

Investigating the role of phonological decoding in Chinese orthographic learning can draw on the self-teaching paradigm widely used in alphabetic languages. In particular, the experimental design of Wang et al. (2012) provides a promising avenue to manipulate character regularity to examine orthographic learning as a function of phonological decoding. Importantly, by comparing decoding accuracy and orthographic learning outcomes between reading with and without Zhuyin, we might be able to answer whether phonological decoding indeed functions via drawing readers' attention to the orthography. If this is true, the orthographic learning effect should be lower when there is Zhuyin, which potentially distracts the reader from the orthography of the characters.

Chapter 3

Examining Phonological Decoding in Orthographic Learning in Chinese

Abstract

According to Share’s self-teaching hypothesis (1995), phonological decoding is fundamental to learning to read, as it gives opportunities to build up orthographic representations of novel words. To date, most studies on orthographic learning have been conducted in alphabetic languages. Here, we examined whether and how Chinese children use the phonetic radical, an internal phonological aid, and Zhuyin, an external aid, to decode and to build up orthographic representations of novel characters. Seventy-three Grade 2 children were taught the sound and meaning of twelve pseudo-characters, and were then exposed to their written forms in short stories. The characters were assigned three different pronunciations – one identical to its phonetic radical (regular), one identical to a neighbour with the same phonetic radical (irregular), and one unrelated sound (unrelated). Zhuyin (with, without) was also manipulated. Spelling and orthographic choice tasks were conducted immediately after learning and 5 days later. The results suggest that 1) although Chinese children use Zhuyin in reading, it does not influence orthographic learning; 2) they use both phonetic radicals and neighbours to generate a novel character’s sound, but phonological decoding via phonetic radicals contributes to better orthographic knowledge than via neighbours.

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 process of acquiring the orthographic knowledge about the written form of novel words (Castles & Nation, 2006) is dependent on converting print to speech sounds, or phonological decoding. This hypothesis has been tested and supported in some languages (e.g., English: Cunningham, 2006; Dutch: de Jong et al., 2009; Hebrew: Share, 2004), which are all alphabetic. 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. Here, we test this hypothesis in a non-alphabetic language, Chinese. In addition, we investigate the underlying mechanism of phonological decoding in reading Chinese, by examining both the use of the phonetic radical, the internal phonological aid, and Zhuyin, the external phonological aid. This will be the first study to explore the role of phonological decoding in Chinese orthographic learning.

According to the self-teaching hypothesis, phonological decoding draws a child's attention to the orthographic details of novel words. Thus, phonological decoding provides opportunities to build up word-specific orthographic knowledge. To test this hypothesis, Share (1999) exposed second grade Hebrew-speaking children to novel pseudo-words in story context. It was found that orthographic learning, measured with spelling, naming speed and orthographic choice, was significantly better when phonological decoding took place without suppression. This suggests that phonological decoding contributes directly to orthographic learning. de Jong et al. (2009) and Kyte and Johnson (2006) replicated this experiment in Dutch and English respectively, and found similar results.

The importance of phonological decoding is also supported by studies showing a positive correlation between correct phonological decoding and successful orthographic learning (Bowey & Miller, 2007; Cunningham, 2006; Cunningham et al., 2002; Kyte & Johnson, 2006). However, using item-level analyses, Nation et al. (2007) and Wang et al. (2013) both noticed that correct reading of a word does not directly translate into successful acquisition of orthographic knowledge of that word. This seems to suggest that the exact mechanism of how phonological decoding assists orthographic learning is not clear.

The reliance on phonological decoding in orthographic learning can also be revealed by the regularity effect. In alphabetic languages, regular words are processed faster and more accurately, as has been shown in children's word naming (Laxon, Masterson, & Coltheart, 1991) and lexical decision tasks (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 et al. (2012) investigated this aspect of phonological decoding in the self-teaching paradigm. They trained Grade 3 children to read regular (e.g., *ferb,* pronounced as "ferb") and irregular pseudo-words (e.g., *cleap,* pronounced as "clape"). Ten days later, orthographic learning was assessed with a spelling and an orthographic decision task. In the orthographic decision task, the children were asked to choose the correct one when the target (e.g., *ferb*) was presented simultaneously with a phonological foil (e.g., *furb*) and two visual distractors (e.g., *ferd* and *furd*). It was indeed found that regular items gained stronger orthographic representations than irregular ones, suggesting that orthographic learning is less effective when there is only partial decoding, as in the irregular words.

Phonological decoding in Chinese is by nature different from in English. As the precise mechanism of phonological decoding is still unclear, this study adopts Share's (1995) definition of it being an "umbrella term" to refer to the processes of deriving speech information from print (p. 152). Two major aspects make this process different in Chinese from English. First, there are no grapheme-phoneme correspondences (GPCs) in the writing system. Instead, a character, the basic reading unit in Chinese (see discussion in Li & McBride-Chang, 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. Second, only a subcomponent of a character contains phonological information. An estimated 80%-90% of modern Chinese (Kang, 1993) and 72% of elementary textbooks (Shu et al., 2003) are compound characters with a semantic and a phonetic radical (e.g., 油 |you2| is composed of a semantic radical 氵 on the left and a phonetic radical 由 |you2| on the right). Only the phonetic radical represents phonological information (e.g., 由 |you2|). As such, phonological decoding is always "partial" in Chinese. Nevertheless, Chinese children are sensitive to the radicals as subcomponents of compound characters. They can copy more made-up characters 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 radicals' function and use it in character naming (Ho & Bryant, 1997; Shu et al., 2000) and learning characters' pronunciations (Anderson et al., 2003; Chen et al., 2014; He et al., 2005; Yin & McBride-Chang, 2015). Yet, whether the phonetic radical is used as a way of "phonologically decoding" an unfamiliar character to achieve orthographic learning is not clear.

In contrast to English, in which regularity is defined according to whether a word conforms to GPC rules, regularity of Chinese characters is defined based on whether a character has identical pronunciation to its phonetic radical as a stand-alone character (Fang, 1986; Hue, 1992; Lee, 2005). For example, 油 (|you2|) is regular, while 袖(|xiu4|) is irregular, despite having the same phonetic radical 由 (|you2|). If phonological decoding in Chinese is to establish direct mapping from the phonetic radical to the character's sound, children should learn regular characters better than irregular ones.

However, it has been found that children also use analogy to decode and read unfamiliar characters (Chen, Anderson, Li & Shu, 2014; He et al., 2005; Ho, Wong, & Chan, 1999). That is, children can infer a character's sound by making analogy to its orthographic neighbours with the same phonetic radical (Chen et al., 2014; He, Wang, & Anderson, 2005; Ho, Wong, & Chan, 1999). Chen et al. (2014) investigated whether children use known characters to name novel ones via direct mapping from phonetic radicals or via analogy. In their study, the children first learned to read a character (e.g., 胥|xu4|), and were then asked to name an unknown character (e.g., 揟|xu4|) where the first character was they learned functioned as the phonetic radical. In another condition, the learned and unknown characters shared the same phonetic radical (e.g., 溍|jin4| and 縉|jin4|). The performance of the children did not differ between the two conditions, indicating that they used both analogy and direct decoding via the phonetic radical to name unfamiliar characters.

If children indeed use analogy in phonological decoding, regularity may not affect orthographic learning in Chinese the way it does in English. That is, an irregular novel character can be as easily decoded and learned as a regular one, if the children know its irregular neighbours and use analogy to decode it. Therefore, irregular characters should be further divided into those that can be decoded by using analogy and those that cannot. In this study, only the former type will be hence referred to as “irregular”, and the latter as “unrelated”. If children use the phonetic radical to decode and learn novel characters, either via direct mapping or analogy, it should be easier for them to acquire orthographic representations of both regular and irregular characters than of unrelated characters.

It has also been proposed that phonological decoding in Chinese can take place via Zhuyin or Pinyin. These are external phonological decoding systems used in Taiwan (Zhuyin) and mainland China (Pinyin). Both 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 translations, children can use them to reliably sound out any unfamiliar character. From the self-teaching perspective, it could be argued that reading with Zhuyin/Pinyin permits more successful decoding, which should allow for better conditions to set up entries in the orthographic lexicon. Therefore, it might be that these external aids are used to decode and to build up orthographic representations of new words (Lin et al., 2010; Share, 1995).

Importantly, investigating whether Zhuyin facilitates orthographic learning will help us understand exactly how phonological decoding contributes to orthographic learning – whether it functions by providing the correct phonological form of the words or by drawing the readers’ attention to the words’ orthographic representations via the act of decoding. On one hand, as Zhuyin is highly transparent, it would enable correct decoding. If phonological decoding is about activating the phonology, then Zhuyin should facilitate learning. On the other hand, Zhuyin only acts as an external aid; therefore, decoding via Zhuyin potentially reduces readers' attention on the characters and interfere with the establishing of specified orthographic representations. If phonological decoding is more about attending to the orthographic details, then Zhuyin should hinder orthographic learning.

The present study investigated whether and how children use the internal phonological aid – the phonetic radical – and the external phonological aid – Zhuyin, to decode in reading and acquiring novel Chinese characters. We exposed Grade 2 children to novel written words in a version of self-teaching paradigm developed by Wang, Castles, Nickels, & Nation (2011). In contrast to previous orthographic learning studies, we carried out spoken vocabulary training prior to orthographic exposure. This way, a novel written word could be presented as "irregular" to the children.

To investigate the function of the phonetic radicals, we manipulated character regularity in subsequent orthographic exposure by creating three types of characters: regular, irregular and unrelated. A regular character had the same pronunciation as its phonetic radical. An irregular character had the same pronunciation of a known irregular neighbour that shares the same phonetic radical. An unrelated character had a pronunciation unrelated to its phonetic radical or any neighbour. We expected that orthographic learning would be stronger when the target characters' phonetic radicals had related pronunciations (as in the regular and irregular conditions) than when they were unrelated (as in the unrelated condition), suggesting children use the phonetic radicals both for phonological decoding and orthographic learning. Meanwhile, as younger children tend to resort to the "phonetic strategy" as opposed to the "analogy strategy" (Chen et al., 2014), we expected that regular targets would be learned better than irregular targets. Alternatively, a non-significant difference between learning regular and irregular characters would suggest that the children used the analogy approach only. Finally, if learning the three types of characters do not differ significantly, this would suggest that phonetic radicals are not used for orthographic learning.

We also manipulated the presence of the external aid, Zhuyin. Half of the children read the stories with Zhuyin and half of the children read without Zhuyin. If the target items were learned better when Zhuyin was present than when it was not, this would suggest Zhuyin plays a facilitative role in decoding and learning novel characters. If, on the other hand, target items were learned less well with Zhuyin's presence, Zhuyin might be distracting children from attending to the orthographic details of the targets during reading, and hence hinder orthographic learning. Finally, if there was no significant difference between the two conditions, it would suggest that Zhuyin does not influence orthographic learning. In this case, however, we would still expect higher reading accuracy during the orthographic exposure with Zhuyin than without.

In addition, we measured the orthographic learning effects twice – immediately after orthographic exposure and five days later. We expected that there would be a decline in the orthographic knowledge of all the trained items.

Method

Participants

Seventy-nine Grade 2 children (47 boys and 32 girls) aged between 7.4 and 8.7 years (*M* = 8.1, *SD* = 0.35) participated in the study. Six children (1 boy and 5 girls) 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 are likely to have developed awareness of the internal radical structure of Chinese characters (Anderson et al., 2013), and are 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 *Chinese Word Recognition Test* (Huang, 2001). This test has been widely used to assess Taiwanese children's word reading ability (e.g., Wang, Hung, Chang & Chen, 2008). 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 or wrote incorrect Zhuyin for 20 characters. The internal consistency reliability for this test is .99 (Cronbach's α). 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, $p < .001$. A likely explanation is that these children were recruited from a school in central Taipei and were from middle-class families, they were on average better readers than the sample in the norm. In addition, a shortened version (100 items) of the *Peabody Picture Vocabulary Test-Revised* in Chinese by Lu and Liu (1994) was administered to assess the participants' receptive vocabulary. *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 both measures.

Materials

Twelve pseudo-characters were created (M strokes = 11; see Appendix A). All target characters had a semantic radical on the left and a phonetic radical on the right (e.g., 糸羊). Although Chinese semantic-phonetic compound characters can also appear in top-bottom structures, left-right structures are far more common. Specifically, 72% of the 3,027 most frequently used compound characters in Taiwan have left-right structure (90% have phonetic radicals on the right, Hsiao & Shillcock, 2006). In elementary textbooks, the phonetic radical of compound characters appear on the right far more often than in other positions (Lui, Leung, Law, & Fung, 2010; Shu, Chen, Anderson, Wu, & Xuan, 2003). Therefore, all the targets were designed in the most familiar left-right structure to maximize the likelihood of the children making use of the phonetic cues in the characters.

The chosen phonetic radicals were all high in frequency as stand-alone characters based on the *Chinese Character Frequency - A trans-regional diachronic survey* (He, 1998). We selected phonetic radicals that are inconsistent and therefore can form both regular and irregular compound characters. A regular character has the same pronunciation as its phonetic radical, while an irregular character is different from its phonetic radical in either onset or rime (Fang, Horng, & Tzeng, 1986; Hue, 1992; Lee, Tsai, Su, Tzeng, & Hung, 2005). For example, despite having the same phonetic radical 羊|yang2|, the compound characters 洋|yang2| and 佯|yang2| are regular, while 詳|xiang2| and 祥|xiang2| are irregular.

The 12 novel target characters were all assigned three different pronunciations: regular, irregular and unrelated. Take the novel word 𦍋 for example: the regular pronunciation was |yang2|, which was the same as its phonetic radical 羊|yang2|; the irregular pronunciation was |xiang2|, which was not the same as its phonetic radical, but based on an existing character that contains this phonetic radical 詳 |xiang2|; the unrelated pronunciation |tao2| was not related to its phonetic radical or any existing characters that contained this phonetic radical. The neighbours were all high-frequency characters based on the *Chinese Character Frequency - A trans-regional diachronic survey* (He, 1998). We also made sure that the unrelated pronunciation differed from the phonetic radical in its initial and final phoneme. Unlike some previous studies, which categorized character regularity regardless of lexical tone (e.g., Fang et al., 1986; Hue, 1992; Shu et al., 2003), we consider a character regular when its tone is also the same as its phonetic radical's. 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. In addition, to increase the children's focus on the phonetic radicals of the target words, we used semantic radicals that are 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 to us that during the first learning session, many participants were not able to identify or write these radicals. Therefore, in order to ensure that the focus could stay on the phonetic radicals and that the task was not too difficult, in the following session, the other six items had only two semantic radicals, with one item from each condition (regular, irregular, unrelated) sharing the same semantic radical.

The 12 target characters were grouped into three sets, which were matched on the frequency of the phonetic radicals and visual complexity (number of strokes). The three sets were counterbalanced in regular, irregular and unrelated conditions for the three groups of participant (see Table 3.1.). 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 characters over others.

The target characters were embedded in three-character word phrases for the invention names for the children to learn. We did so because Chinese words are often composed of two to three characters. Half of the words are in the form of 電___機

|dian4__ji1| “super __ machine” and the other half 超__機 |chao1____ji1| “electronic ___machine”, with the target character inserted in between the two characters (e.g., 超 鋰 機 and 電糹羊 機). Many electrical 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 one 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.

Table 3.1. *Conditions of characters presented to the participants.*

		Group 1	Group 2	Group 3
Zhuyin		+/-	+/-	+/-
Character type	Set A	Regular	Irregular	Unrelated
	Set B	Irregular	Unrelated	Regular
	Set C	Unrelated	Regular	Irregular

Note. + refers to orthographic exposure with Zhuyin, - refers to without Zhuyin.

Procedure

The procedure was similar to the paradigm developed by Wang et al. (2011), which consists of three phases, taking place over a period of 15 days. The first and third phases were conducted at group level, while the second was carried out individually. The three phases are described in detail below.

Oral vocabulary learning phase (Session 1 - 4, over 7 days). Participants were taught vocabulary knowledge of the 12 new words via pictures and oral explanations (see Appendix B for an example), adapted from Wang et al. (2011, 2012). 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 on Day 1 and the other half on Day 2. On Day 4 and 7, all twelve items were trained together. The children received training for 20 minutes each day. The training procedure was as follows:

1. The experimenter showed the children the picture and the name of the invention (e.g., This is a 電絆機 |dian4 yang2 ji1|. The children repeated the name.
2. The experimenter described the semantic features of the invention (e.g., 電絆機 |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 Session 3 and 4, the children were also asked to complete twelve sentences like "If I had a 電絆機 |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 (Session 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. Then the child was asked to read aloud the stories with the target words in it. No feedback was provided. Before they started reading, they were instructed to use what they had learned earlier about the invention names to help with the reading. The children were exposed to six stories in Session 5 and to another six in Session 6. The children were randomly assigned to either stories with or without Zhuyin.

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 preexposure phase. After reading each story, the child completed two comprehension questions. Immediately after the story-reading, each child was assessed with the spelling task and the 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 correct one. The four options were the target word, a phonological foil and two visual distractors (see Appendix C). The phonological foil and visual distractors were pseudo-characters or extremely low-frequency characters. One visual distractor had a different semantic radical, and the other had a different but similar-looking phonetic radical to the target character. The phonological foil had the same semantic radical as the target. Its phonetic radical was either a homophone of the targets' phonetic radical or differ from it only in tone. 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. Its phonological foil in the irregular condition **(**絴|xian1|) was 緣, whose phonetic radical was 象 |xiang4|, similar to 詳 |xiang2|, whose sound the irregularly spelled target was based on. Its phonological foil in the unrelated condition **(**絴|tao2|) was 綯**,** where the phonetic radical 匋 |tao2|'s pronunciation was unrelated to either the target's phonetic radical nor any compound characters it can comprise.

Delayed testing phase (Session 7, over 1 day). Five days after orthographic exposure, the children were administered a spelling and an orthographic choice task to measure how well the learning had been retained. The assessments were conducted at a group level. The experimenter gave instructions to the three groups separately. In addition, each child was individually assessed on picture naming task and target word reading. This was to measure how much vocabulary knowledge they had retained. Target word reading accuracy was also a measure of orthographic learning and needed individual testing as it required verbal responses.

Results

The present study aimed to answer two primary questions. First, do children use phonetic radicals to establish orthographic representations of novel Chinese characters; and if they do, do they use it to directly generate the sound of the characters (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 characters? In the following section, we first report results on oral vocabulary learning, followed by the effect of Zhuyin and character type on phonological decoding, Next, the overall orthographic learning effects are evaluated. Finally, we report the effect of Zhuyin on orthographic learning.

Oral vocabulary learning

For the twelve invention names, mean picture naming accuracy was 70% (*SD* = 28%) immediately prior to orthographic exposure, and maintained at 72% (*SD* = 26%) on the orthographic testing day. This indicates that the children had acquired a substantial vocabulary knowledge of the target words, and that this knowledge was retained throughout the experiment.

Effect of Zhuyin and character type on phonological decoding

During orthographic exposure phase, the target characters were read in story contexts, either with or without Zhuyin. Reading accuracy was scored as a measure of phonological decoding (see Table 3.2.). The mean proportion of target characters that were decoded correctly was .93. Although this proportion was reasonably high, there was a moderate level of variation (*SD* = .13, range = .42 - 1.0). A repeated measures analysis of variance (ANOVA) was conducted with character type (regular, irregular, unrelated) as the within-subjects variable, and Zhuyin (with Zhuyin, without Zhuyin) as the between-subjects variable.

Table 3.2. *Mean proportions of reading accuracy by character type and by with (+)/without (-) Zhuyin during orthographic exposure.*

	+Zhuyin	-Zhuyin	Total
Regular	1.00 (.00)	.94 (.14)	.97 (.10)
Irregular	.98 (.07)	.92 (.19)	.95 (.15)
Unrelated	.97 (.09)	.78 (.27)	.88 (.22)
Total	.98 (.04)	.88 (.17)	.93 (.13)

Note: Standard deviation in parentheses.

Effect of Zhuyin. There was a main effect of Zhuyin, $F(1, 70) = 11.45$, $p = .001$, η_p^2 =. 14. Reading accuracy was almost at ceiling (M = 98.15%, SD =4.04%) when Zhuyin was presented, compared with when it did not appear beside the characters (M = 88.19%, SD = 17.18%), indicating that Zhuyin helped with generating the correct sounds of novel characters.

Effect of character type. There was a significant interaction between character type and Zhuyin, $F(2, 140) = 7.3$, $p = .001$, $\eta_p^2 = .94$. Therefore, analyses of simple main effects were performed. There was a statistically significant difference between character types in reading accuracy for the without Zhuyin condition, $F(2, 70) = 12.797$, $p < .001$, $\eta_p^2 = .27$, but not for the with Zhuyin condition, p =.064. There was also a main effect of character type, $F(2, 140) = 15.25$, $p < .001$, $\eta_p^2 = .18$. Because the difference between character types was only significant when Zhuyin was not presented, pairwise comparisons were run for the without Zhuyin condition. Mean reading accuracy was significantly higher for regular than unrelated items, $t(35) = 4.12$, $p < .001$, $d = .69$, and for irregular than unrelated items, $t(35) = 4.30$, $p < .001$, $d = .72$. There was no significant difference between regular and irregular items, $p = .38$. This shows that the phonetic radicals were used for phonological decoding during the story-reading.

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 3.3. 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.

Table 3.3. *Mean proportions of accuracy of orthographic learning measured immediately after learning and in the delayed test.*

		Spelling	Orthographic choice	Delayed word reading
	Immediate	.22 (.14)	.74 (.19)	n/a
Session	Delayed	.13 (.11)	.57 (.20)	.59 (.17)

Note: Standard deviation in parentheses.

Spelling accuracy in both the immediate and the delayed testing sessions was not high. However, given that spelling is a quite challenging task for Grade 2 children, and that the children could 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 characters.

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%). To further examine the effect of orthographic learning, the mean differences among the proportions of targets, phonological foils and visual distractors chosen in the immediate and delayed orthographic choice tasks were compared. Sixteen percent (*SD* = 14%) and 20% (*SD* = 14%) 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. This tendency of favouring the targets over the phonological and visual distractors suggests that the children acquired considerable orthographic knowledge of the target characters.

Orthographic learning was also measured by reading accuracy in the delayed test. Given that the target words were presented as a list without context or Zhuyin support, the reading performance (*M* = 59%, *SD* = 17%) suggest that the children had established substantial orthographic representations of the trained characters.

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.

Effect of Zhuyin and character type on orthographic learning

Two repeated measures ANOVAs were conducted separately for spelling and orthographic choice results. Zhuyin (with Zhuyin, without Zhuyin) was the between-subjects variable. Character 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, where Zhuyin was the between-subjects factor and character type was the within-subjects factor. The results are reported in Table 3.4. Below, we first present results on the effect of Zhuyin, and then the effect of character type on orthographic learning.

Effect of Zhuyin on orthographic learning

Spelling. There was a significant three-way interaction between Zhuyin, character type and testing session (see Table 3.4.). Pairwise comparisons were carried out for all two-way interactions at each level of the third variable. The only significant interaction was found for character type and session in the without Zhuyin condition, $F(2, 70) = 8.86$, $p < .001$, $\eta_p^2 = .20$. The interaction between character type and session will be discussed in later sections. However, as we had not made any predictions on this effect, we are cautious in providing an interpretation about this result before it is replicated. There was also no significant main effect of 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 character 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 only effect of Zhuyin was found in the three-way interaction with character type and testing session in spelling. However, in the other two measures of orthographic learning – orthographic choice and delayed word reading accuracy, Zhuyin had no significant main effect or interactions with the other factors.

Table 3.4. *ANOVA summary for orthographic learning by Zhuyin, character 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	0.23	.630	.003	1	1.36	.248	.019	1	0.20	.654	.003
Character type	1.78	33.31***	.000	.322	2	42.83***	.000	.380	2	221.98***	.000	.760
Session	1	14.52***	.000	.172	1	60.36***	.000	.463	n/a			
Zhuyin × Character type	1.78	0.92	.393	.013	2	0.67	.513	.009	2	0.14	.867	.002
Zhuyin × Session	1	.02	.433	.009	1	0.34	.564	.005	n/a			
Character type × Session	1.93	6.14**	.003	.081	2	14.92***	.000	.176	n/a			
Zhuyin × Character type × Session	1.93	3.94*	.022	.053	2	1.24	.296	.017	n/a			

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

Effect of character type on orthographic learning

Spelling. There was a significant two-way interaction between character type and testing session, $F(1.93, 134.88) = 6.14$, $p = .003$, $\eta_p^2 = .08$, indicating different patterns for the three types of characters. In the immediate session, regular characters elicited significantly more correct spelling than unrelated characters, $t\ (73) = 5.74$, $p < .001$, $d = .67$. Irregular items also had higher spelling accuracy than unrelated ones, $t\ (73) = 3.51$, $p = .001$, $d = .41$. In the delayed session, the advantage of regular over unrelated characters ($t\ (74) = 7.56$, $p < .001$, $d = .87$), as well as that of irregular over unrelated characters ($t\ (74) = 3.52$, $p = .001$, $d = .41$), were also significant. However, the difference between correct spelling of regular and irregular characters was only significant in the delayed test, $t\ (74) = 5.16$, $p < .001$, $d = .60$, but was not significant in the immediate test, $p = .50$. Spelling accuracy was significantly lower in the delayed session than in the immediate session for irregular, $F(1, 73) = 18.89$, $p < .001$, η_p^2 = ,21, and unrelated items, $F(1, 73) = 16.38$, $p < .001$, $\eta_p^2 = .18$. However, the difference between sessions for regular characters was not significant ($p = .916$). These results indicated that orthographic representations of regular and irregular characters initially did not differ. However, orthographic knowledge of irregular and unrelated characters decayed over time, while representations of regular characters remained unchanged (see Figure 3.2.).

Orthographic choice. There was no significant three-way interaction. However, similar to the results from the spelling measure, the two-way interaction between character type and session was statistically significant. The simple effect analyses results were in accord with the spelling outcomes. The difference between character types was significant in both the immediate session, $F(2,73) = 14.88$, $p < .001$, $\eta_p^2 = .29$, and in the delayed session,

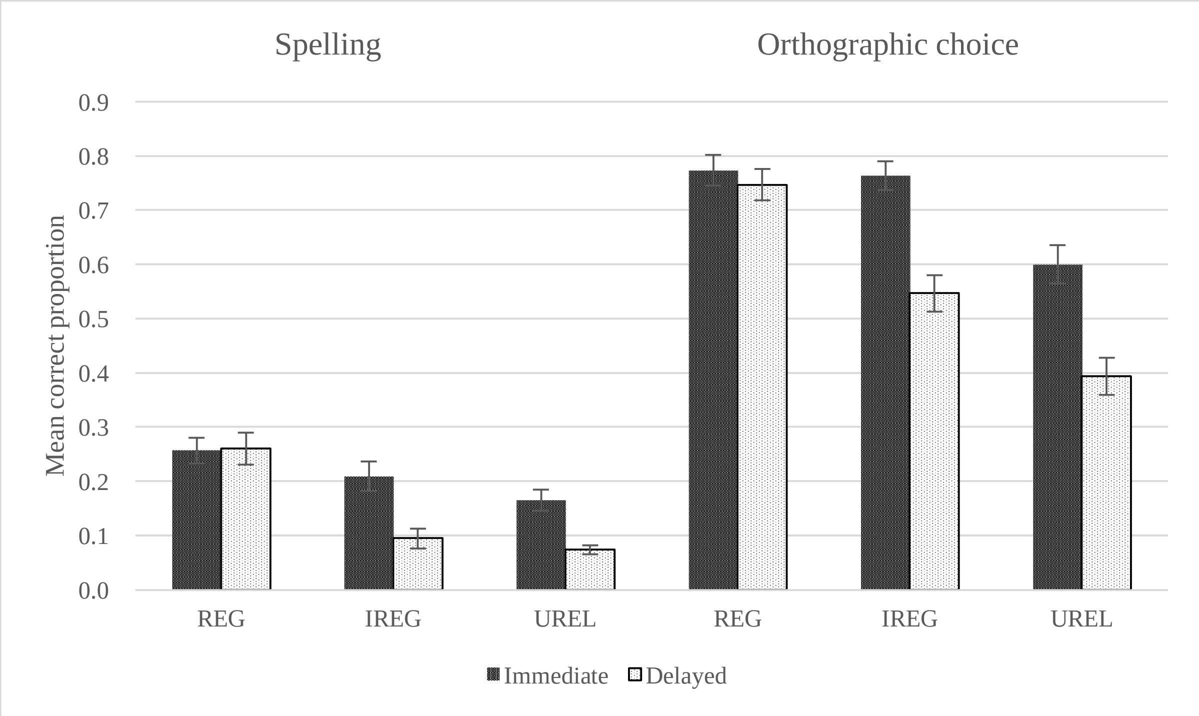

Figure 3.2. *Mean proportions of accuracy of spelling and orthographic choice by character type in the immediate and delayed sessions (with the error bars indicating standard errors).*
Note. REG = regular. IREG = irregular. UREL = unrelated.

$F(2,73) = 59.02$, $p < .001$, $\eta_p^2 = .62$. In the immediate session, the proportion of correct choices was significantly higher for regular than unrelated characters ($t(74) = 4.57$, $p < .001$, $d = .53$), and for irregular than unrelated characters ($t(74) = 5.22$, $p < .001$, $d = .60$). In the delayed session, there was also more correct choices of regular than unrelated items ($t(74) = 10.74$, $p < .001$, $d = 1.24$), and of irregular than unrelated items ($t(74) = 3.87$, $p < .001$, $d = .45$). However, correct choices made for regular and irregular characters did not differ significantly in the immediate session ($p = .75$), but the difference was significant in the delayed test $t\ (74) = 5.58$, $p < .001$, $d = .64$. Also, orthographic knowledge of regular characters remained unchanged over time ($p = .37$), but not for irregular and unrelated characters (*p*s < .001).

Delayed word reading. There was no significant two-way interaction between character type and Zhuyin. However, the main effect of character type was significant. Word reading accuracy was higher for regular than irregular, $t(74) = 7.18$, $p < .001$, $d = .83$, and irregular than unrelated characters, $t(74) = 13.41$, $p < .001$, $d = 1.55$, as was shown by the post hoc comparisons.

These results showed that character type had an effect on orthographic learning. Regular and irregular characters were learned better than unrelated characters. Regular items also gained stronger orthographic representations than irregular ones, although this advantage only became obvious in the delayed testing session.

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 in Chinese. Specifically, we examined whether and how Chinese children use the phonetic radical, the internal phonological aid, and Zhuyin, the external phonological aid, to decode and acquire orthographic knowledge of novel characters.

Findings in this study provided strong evidence that orthographic learning took place via self-teaching. The effect of character 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 measurements both showed advantages for regular and irregular characters over characters in the unrelated condition. Although regular items did not gain more successful phonological decoding than irregular items, they were learned better. There was also a decline in orthographic memory of irregular and unrelated characters five days after initial exposure. However, orthographic knowledge of regular character was almost fully retained. Zhuyin's presence during orthographic exposure enabled higher reading accuracy, but had no effect on subsequent orthographic learning.

The role of phonetic radicals

During orthographic exposure without Zhuyin alongside the characters, there was no significant difference in reading accuracy of regular and irregular items, where the phonetic radical provided cues to the pronunciation of the target word. In contrast, reading accuracy was significantly lower for the items in the unrelated condition, where the phonetic radical was not related to the pronunciation of the character. This effect suggests that children use the phonetic radicals for phonological decoding when there is no external aid to rely on. While the phonetic radicals of regular and irregular items entailed phonological cues that can be used for phonological decoding, the phonetic radicals did not support decoding of the items in unrelated condition. As such, it was possible to use the phonetic radicals to phonologically decode regular and irregular items, but not the items where the pronunciation for the novel words and the phonetic radicals were unrelated. These results suggest that children used phonetic radicals to assist them to phonologically decode unfamiliar Chinese characters.

Orthographic learning, which was measured with spelling, orthographic choice and word reading, consistently showed that learning was more efficient for the regular items compared to the irregular items, with unrelated items showing the least amount of learning. The results supported our prediction that using the phonetic radicals facilitates orthographic learning through the mechanism of phonological decoding. It should be noted that the difference between regular and irregular orthographic learning was not significant when learning was measured immediately after orthographic exposure. The advantage of the items being regular only became apparent in the delayed test.

The experimental design also allowed us to look at the nature of phonological decoding in Chinese. During orthographic exposure, there was no significant difference between the regular and the irregular characters in reading accuracy. This suggests that the children used both direct mapping and analogy as strategies of phonological decoding. For regular characters, children could use the "phonetic strategy" to establish direct mappings between the character and the sound of the phonetic radical. For irregular characters, children could use the "analogy strategy" to connect the character to the sound of an irregular neighbour.

According to Chen et al. (2014), younger children tend to favour direct mapping over analogy, because their ability to name characters via analogy is limited due to lack of knowledge of characters sharing the same phonetic radicals. If the "phonetic strategy" had priority over the "analogy strategy" for young children, phonological decoding at the first attempt should have always failed when the character is irregular. In this case, a lower reading accuracy should have been found in the irregular than in the regular condition in the present study. As a result of lower reading or decoding accuracy, subsequent measurements on orthographic learning should have also demonstrated a difference. However, we did not find evidence to support this proposal during or immediately after learning had taken place. Instead, we found that regular and irregular characters, although demanding the use of different decoding strategies, were decoded equally well, indicating 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, difference between using the two decoding strategies diminishes. In addition, we ensured that the irregular items were based on high-frequency neighbours that children are familiar with. As such, children have the orthographic knowledge to use the analogy strategy.

Interestingly, the advantage of regular over irregular characters only became significant five days after initial orthographic exposure. Compared with the immediate test outcomes, while the children's orthographic knowledge of the regular items remained intact, that of irregular and unrelated characters had decayed significantly. This indicates that although analogy is as effective as direct mapping for phonological decoding, it seems not as effective in building up orthographic representations. This may be because when an irregular character has many neighbours with different pronunciations, decoding by analogy allows mapping onto several competing sounds. Therefore, the orthography and the phonology are only loosely connected for characters decoded this way. In contrast, the "phonetic strategy" maps orthography directly onto the phonetic radical's sound. Therefore, the association is much more direct and specified.

Previous studies have shown that character consistency may have great impact on phonological decoding. Consistency refers to the degree in which characters with the same phonetic radical are pronounced the same (Xing, Shu, & Li, 2004). 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 some evidence that consistency affects children's choice of decoding strategy. In their study, Grade 4 and Grade 6 children were taught to read a character and two irregular compound characters in which the first character was the phonetic radical. Next, they were asked to name another novel neighbour. The trained characters' consistency was manipulated such that in one condition, the two learned compound characters were consistent in pronunciation, and in another condition, they were inconsistent. In the consistent condition, the children tended to name the novel neighbour using the irregular sound, i.e., via "analogy strategy". In the second condition, the novel neighbour was named more often with the phonetic radical's sound, i.e., via "phonetic strategy". Importantly, this tendency was more pronounced in sixth graders than in fourth graders, suggesting an increasing influence from the children's implicit use of consistency on decoding strategy as their print experience grows.

From the present study, however, we cannot draw any conclusions about the influence of consistency on orthographic learning. Its influence, as well as its interaction with regularity, on phonological decoding and orthographic learning needs to be addressed in future research, which will be very challenging to manipulate in a training study, because there are probably large individual differences in the perception of consistency.

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 98.15% correct), which was significantly higher than the without Zhuyin condition (on average 88.19% correct). This indicates that Zhuyin helps to generate the correct sound of the novel characters.

However, the facilitation in reading did not translate into better orthographic learning. Spelling accuracy and correct orthographic choice did not differ between the two conditions in the immediate and in the delayed tests. Delayed word reading accuracy also showed no significant difference. Although we found that Zhuyin mediated the interaction between character type and testing session in spelling, the other measures consistently suggest 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 phonology or via enhancing readers' attention on the orthography. Share (2004) found that first graders learning pointed Hebrew, a highly transparent script, did not exhibit much orthographic learning effects. He proposes that this is because the one-to-one relationship between print and sound allows children to overtly rely on phonology, and thus makes them insensitive to the orthography. Therefore, phonological decoding contributes to orthographic learning by drawing attention to the orthography. In this sense, Zhuyin should impede orthographic learning, because as an external phonological aid, it can distract the children's attention from the orthography, although it provides correct pronunciation for the character. The results did not support this prediction. We did not find that the Taiwanese children relied on the transparent Zhuyin so much that their orthographic learning was less effective than when Zhuyin was not available. Instead, the results suggested that the two conditions did not produce any difference in learning outcomes. One possible explanation for our findings is that the distraction canceled out the facilitation from correct phonology. That is, getting the correct sound and attending to the characters' orthography are both important components of phonological decoding in the orthographic learning context. The presence of Zhuyin enhances the former while attenuates the latter. That being said, it is still possible that Zhuyin did not interfere with the children's attention on the characters. After all, the children had learned and practiced using Zhuyin for almost two years by the time of the experiment. They could be so experienced with it that they did not need to spare much effort to analyse Zhuyin and could still focus on the characters. If this is true, it would suggest that phonological decoding contributes to orthographic learning via enhancing attention on the word, but not via providing the correct sound of the word. Future eye-tracking research could explore this possibility by measuring the children's visual attention during character reading with Zhuyin.

Although it did not enhance character learning in this study, it would be too strong to conclude that Zhuyin, as well as other phonological aids like Pinyin, are not helpful tools in learning to read. It can be beneficial in two ways. First, it helps children to reliably sound out characters without available phonological cues. This is especially helpful for children with limited radical or character knowledge. In one study (Chung, 2002), Pinyin has been found to effectively promote character learning for twelve-year-old non-native speakers. Second, it enhances children's sensitivity to phonological units, including syllables, phonemes, rimes and tones (Cheung et al., 2001; Huang, & Hanley, 1997; Lin et al., 2011), which is known to be an important predictor of children's character recognition (Li et al., 2012; Shu et al. 2008).

Conclusion

This study is the first one to consider the mechanism of phonological decoding and its role in orthographic learning in Chinese. Although longitudinal and cross-sectional studies have acknowledged the importance of phonological skills in learning to read Chinese (Chan, 2013; 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 study how it contributes to orthographic learning. We found that there are two approaches or strategies in phonological decoding, namely, the direct mapping and analogy. Children use both to acquire character-specific orthographic knowledge, but when there is direct mapping between phonetic radical and the character, learning is more effective than using analogy.

In addition, while Zhuyin helps children to sound out unfamiliar characters, there is no effect on orthographic learning. In contrast to our prediction, Zhuyin neither facilitated nor impeded orthographic learning. An explanation is that the effects of better reading accuracy and distraction from the orthography, both of which are the result of Zhuyin's presence, canceled each other out. If this is true, it would suggest that phonological decoding via Zhuyin not only provided the correct phonology, but also drew the readers' attention away from the orthography.

Our findings have pedagogical implications. First, explicit instruction on the two phonological decoding strategies may improve Chinese character acquisition. Yin and McBride (2015) demonstrated that even kindergartners' sensitivity to phonetic regularity and positional patterns was related to word reading a year later. Currently in schools, children are only taught to decompose characters into subcomponents and to observe that regular characters and their phonetic radicals shared the same pronunciations (Wu, Li, & Anderson, 1999). If we also teach them to explicitly use the two decoding strategies, especially analogy, it might help them with learning irregular characters as well. Second, the role of Zhuyin, as well as Pinyin, as a phonological aid should be specified for teachers and students early. Despite its great usefulness in generating novel characters' pronunciations, this study has shown that it does not promote orthographic learning. In fact, we observed that some children rely on Zhuyin heavily in the spelling tasks. Instead of writing down the target characters, 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.

In summary, there are two major findings from this research. First, Chinese children use both direct mapping and analogy in phonological decoding and orthographic learning. Second, Chinese children use Zhuyin to read novel characters, but Zhuyin does not affect orthographic learning.

Chapter 4

General Discussion

Although phonological decoding has been widely accepted as important for orthographic learning in alphabetic languages, its contribution has never been directly tested in a non-alphabetic script. Against this background, this thesis sets out to clarify the nature of phonological decoding in learning to read in Chinese, and to examine whether it is indeed universal in its role in acquiring novel written words. Building on a broad review of the theories and findings in alphabetic languages, this thesis proposes how the function of phonological decoding can be investigated in learning to read in Chinese. Next, in an empirical study, two approaches to phonological decoding were examined and their effects on orthographic learning in Chinese were measured.

The study demonstrated that orthographic learning via self-teaching is possible in Chinese, and that phonological decoding makes a direct contribution in the process. There are two approaches to phonological decoding in Chinese. Internally, the phonetic radical supports decoding via either direct mapping or analogy with neighbours. Externally, the phonological aid, Zhuyin, is used to generate the correct sounds of characters. However, based on the findings, it seems that only the internal decoding approach directly contributes to orthographic learning in Chinese.

In the next sections, the theoretical implications of the findings will be discussed, and suggestions for future research will be provided.

Theoretical implications

The empirical study in this thesis provided evidence that phonological decoding facilitates orthographic learning in Chinese. This finding adds to the current orthographic learning literature that has been focused on alphabetic writing systems. It supports the self-teaching hypothesis as an orthography-general theory and shows that in non-alphabetic languages, orthographic knowledge can be obtained via phonological decoding.

The findings indicated that the phonetic radical contributes to orthographic learning via the mechanism of phonological decoding in Chinese. Specifically, a phonetic strategy and an analogy strategy appeared to be used for phonological decoding.

The external aid, Zhuyin, has been found to be of limited help in the formation of character-specific representations. This finding supports the view that activating the correct phonological form does not necessarily lead to orthographic learning of the specific item (Nation et al., 2007; Wang et al., 2013). Although it has been found that Zhuyin benefits the growth of Chinese children's phonological sensitivity and awareness (Chen & Yuen, 1991; Cheung & Chen, 2004; Cheung et al., 2001; Huang & Hanley, 1995; Zhang & McBride, 2011), and that Zhuyin knowledge predicts children's character recognition (Lin et al., 2010; Pan et al., 2011), findings in this study do not support that it helps with character learning. As such, the positive correlation between Zhuyin and reading ability might be less direct and reflect a broader ability in learning to read.

Overall, the spelling accuracy was low across conditions, suggesting that phonological decoding may not be sufficient for orthographic learning in Chinese. The writing system represents phonological information in a much less consistent way than alphabetic scripts do. Phonological decoding in alphabetic languages is a serial analysis on a word's orthography using knowledge of letter-sound rules. In any unknown word, the letters and letter clusters are still mostly familiar to the reader. In fact, there is evidence that even before seeing a word, English speaking children may have already generated an "orthographic skeleton" of the word from their vocabulary knowledge (McKague, Pratt &

Johnston, 2001; Wegner, Wang, de Lissa, Nation, Ribidoux & Castles, submitted). Subsequent learning is, therefore, more like filling up the gaps in between the skeleton and forming a representation of the whole word. Conversion between phonology and orthography is possible and reliable for alphabetic readers in that they can sound out new written words and also make predictions as to what a spoken word might look like. However, in Chinese, where the connection between print and sound is much less fine-grained and reliable, such an "orthographic skeleton" is almost impossible. This is because, firstly, many characters have unpronounceable components such as the semantic radicals, for which phonological decoding has no contribution in that respect. As a result, the correct sound of a character only provides a partial connection to the orthography. Secondly, characters often have many homophones. This is supported in our study by the finding that even for regular characters, spelling accuracy was low. For instance, the sound of the syllable |yi4| can correspond to 69 characters (Chang, Hsu, Tsai, Chen, & Lee, 2015). In this case, it will be impossible for the reading system to form or reliably predict an "orthographic skeleton". Sounding out a character is not adequately constraining on any written form (Perfetti, Liu, & Tan, 2005). Therefore, phonology may not help much with reinforcing a specified entry in the orthographic lexicon prior to the written form is seen.

Orthographic learning in Chinese may rely more on other mechanisms such as semantic processing. In English, item-specific vocabulary knowledge has been found to improve orthographic learning (Ouellette, 2010; Ouellette & Fraser, 2009). However, word meaning in English needs to be explicitly taught, while the semantic components of Chinese characters allow decoding for meaning. For example, a child cannot derive any semantic information from an unknown English word like *soup* without instruction. In contrast, when a

Chinese child encounters an unknown character 湯(|tang1| “soup”), as the semantic radical 氵 is often related with liquid as in 海(|hai3| “sea”), 油(|you2| “oil”) and 游(|you2| “swim”), s/he can infer the semantic category of this character. This is because the semantic radical is often consistently related to the character’s meaning. According to Shu et al.’s (2003), in 80% of the characters, the semantic radical has a direct connection to the character’s meaning. In addition, some characters do not have a phonological component, but many of them are pictographs or have a semantic component. When a character contains some semantic information in the semantic radical, children can use this information for orthographic learning, rather than relying purely on rote memory. Learning to read such characters might depend on semantics, while phonology has a minor contribution.

Future directions

Previous studies have shown that character consistency may have great impact on phonological decoding. Consistency refers to the degree in which characters with the same phonetic radical are pronounced the same (Xing, Shu, & Li, 2004). 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 some evidence that consistency affects children’s choice of decoding strategy. Importantly, its impact was more pronounced in sixth graders than in fourth graders, suggesting an increasing influence from the children’s implicit use of consistency on decoding strategy as their print experience grows. The influence of consistency, as well as its interaction with regularity, on phonological decoding and orthographic learning needs to be addressed in future research.

Another important issue that needs to be investigated is the function of other components in orthographic learning in Chinese. In the unrelated condition of our study, even without feasible methods to decode, the children managed to acquire some orthographic knowledge. This is most likely because the children had acquired the vocabulary knowledge so well that they were using it to learn the novel characters, with support from the story context. This suggests that there are likely other important contributors to learning to read Chinese in addition to phonological decoding, such as visuo-orthographic processing and semantic information.

To begin with, preexisting orthographic knowledge is likely to be crucial for Chinese orthographic learning. Knowledge and memory of radicals have been found to predict word reading and spelling in Chinese (Yeung, Ho, Chan, & Chung, 2016). Visuo-orthographic skills are also strongly associated with Chinese character reading (for a review, see McBride & Wang, 2015). Share (2004) suggested that in opaque languages, the mappings between print and sound only permit a low level of phonological decoding, and hence more sensitivity to the orthography is required. This is probably why orthographic learning was more salient in English first graders than in their Hebrew peers. Considering that Chinese is even more opaque than English, it is reasonable to propose that orthographic knowledge is even more important for orthographic learning in Chinese. Also, orthographic knowledge is particularly important for learning Chinese because of the many homophones. It would require considerable sensitivity to the orthographic details of characters to build up specified orthographic representations with minimal homophonic interference.

Secondly, orthographic representations of novel characters might also be established via semantic information, since many characters have components with character-specific explicit semantic knowledge (e.g., 氵, the semantic radical of 油 "oil", means "liquid"). In English, the association between phonology and semantic knowledge of a word is arbitrary and vocabulary knowledge is often associated with learning irregular words only (Ouellette, 2006; Ricketts, Nation, & Bishop, 2007; Wang et al., 2013), where phonological decoding is less effective. In contrast, longitudinal studies have shown that vocabulary knowledge explains an equal amount of variance in learning to read Chinese as phonological skills (Song et al., 2015; Zhang et al., 2013). Zhou et al. (2015) also found that while teaching first and second graders the sounds of novel Chinese words helped them to learn to read, teaching the meanings further improved their learning. The target items in our study all had semantic radicals that provide minimal semantic information to ensure that learning was focused on phonological processing. It would be interesting to see if orthographic learning is boosted when there is explicit semantic information and whether a combination of semantic and phonological processing will result in stronger learning effects.

It should be noted that semantic processing does not equal vocabulary knowledge, which has been found to improve orthographic learning in English (Ouellette, 2010; Ouellette & Fraser, 20009; Wang et al., 2013) and in Chinese (Zhou et al., 2015). However, in these studies, vocabulary knowledge refers to the words' meaning that is explicitly provided either prior to or during orthographic exposure. Semantic processing, however, is to directly derive semantic information from the orthography without having to be explicitly taught the meaning. This processing is possible in Chinese because of the semantic radicals in characters. Given the high level of homophony in Chinese, compared with phonological decoding, semantic processing may help with forming a direct link between print and meaning that enables a more specified representation. Future research could examine this issue by manipulating the semantic radicals of the experimental characters, and by comparing orthographic learning of characters whose semantic radicals contain information varying in reliability. This factor can also be examined together with phonetic radicals. A prediction from the lexical quality hypothesis (Perfetti, 2002) is that semantic processing becomes more crucial when phonological decoding is compromised. Therefore, semantic processing might mostly compensate for orthographic learning of the unrelated characters.

Semantics may play a more important role in learning to read Chinese than in English. Computational simulations of reading have already revealed a heavier reliance on semantic inputs in the Chinese than in the English model (Yang, McCandliss, Shu, & Zevin, 2008). Orthographic learning may exhibit a similar pattern. However, this hypothesis would be very challenging to test. To begin with, it is difficult to decide the extent of engagement of the components in orthographic learning. Take phonological decoding as an example, although it has been measured with reading accuracy, item-level analyses have established that successful decoding of a word is not associated with orthographic learning of that specific word (Nation et al., 2007; Wang et al., 2013). Therefore, reading accuracy cannot reliably measure the reliance on phonological decoding in orthographic learning. Secondly, it is hard to compare the results of orthographic learning across languages. Even for studies within the same language, discrepancies in the results have often been found across different measures of orthographic learning (e.g., Nation et al., 2007; Ouellette & Fraser, 2009). Currently, reading accuracy (Landi, Perfetti, Bolger, Dunlap, & Foorman, 2006), reading speed (e.g., Share, 1999), spelling (e.g., Ouellette & Fraser, 2009), orthographic choice (e.g., Cunningham, 2006) and orthographic decision tasks (Wang et al., 2011, 2012, 2013) have all been used to measure orthographic learning outcomes.

To address this issue, a better method to measure orthographic learning and a consensus on it may be needed. To begin with, the *prime lexicality effect* (Forster & Veres, 1998) provides a promising avenue to tap whether a novel word has been acquired. Masked priming studies have shown that presenting a nonword briefly has a strong facilitation effect on the lexical decision time of an existing neighbour, whereas a word has a null or inhibitory effect (Davis & Lupker, 2006; Forster & Veres, 1998; Qiao & Forster, 2013). If a novel word starts to show the same priming effects as a word, it would suggest that its orthographic representation has been acquired. This method is in line with the definition of orthographic learning – having established an orthographic representation that allows for rapid and automatic recognition. Therefore, it might be a better way to measure orthographic learning. There are already research using the prime lexicality effect to index children's orthographic learning (Tamura, Castles, & Nation, 2015), although it should be noted that because the word recognition system of developing readers is less precise and finely tuned, they can demonstrate stronger priming effects than skilled readers do (Castles, Davis, Cavalot, & Forster, 2007). Another method is to evaluate changes in the neural representations of novel words after learning with EEG recordings. For example, previous studies have shown that words elicited higher power in the theta (4–8 Hz; e.g., Krause, Grönholm, Leinonen, & Laine, 2006) and in the gamma bands (> 30 Hz; e.g., Krause, Korpilahti, Pörn, & Jäntti, 1998) than nonwords. Changes in the oscillations could be used as indicators of consolidated orthographic representations of newly learned words.

Concluding remarks

Orthographic learning is an important component in reading development. The last two decades of research has established the pivotal role of phonological decoding in acquiring word-specific orthographic knowledge. However, previous studies have focused on alphabetic languages, ignoring that fact that the nature and function of phonological decoding might be different in a morphosyllabic language like Chinese. This thesis addresses this gap in orthographic learning research, and provides empirical evidence to support an orthography-universal theory of phonological decoding being an important contributor to orthographic learning. In addition, findings from this thesis suggest potential difference in learning to read in Chinese compared to English that can be investigated in future work. In conclusion, this thesis has furthered our understanding of phonological decoding and its role in orthographic learning, with implications for theory and practice in learning to read.

Chapter 5

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Appendix

Chapter 3

Appendix A.

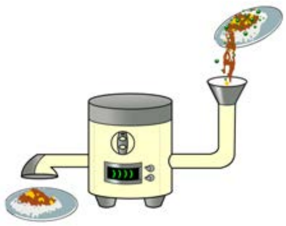
Target characters and pronunciations (with Pinyin transcriptions)

	Target character	Regular pronunciation		Irregular pronunciation		Unrelated pronunciation	
		Zhuyin	(Pinyin)	Zhuyin	(Pinyin)	Zhuyin	(Pinyin)
Set A	秹	ㄓㄨˇ	(zhu3)	ㄨㄤˇ	(wang3)	ㄎㄢ	(kan1)
	岌	ㄐㄧˊ	(ji2)	ㄒㄧ	(xi1)	ㄊㄠˊ	(tao2)
	僜	ㄉㄥ	(deng1)	ㄔㄥˊ	(cheng2)	ㄆㄧㄢˋ	(pian4)
	鉼	ㄆㄧㄥˊ	(ping2)	ㄔㄥˋ	(cheng4)	ㄉㄜˊ	(de2)
Set B	袯	ㄐㄧㄠ	(jiao1)	ㄧㄠˇ	(yao3)	ㄎㄢ	(kan1)
	絴	ㄧㄤˊ	(yang2)	ㄒㄧㄢ	(xiang2)	ㄊㄠˊ	(tao2)
	鋰	ㄌㄧˇ	(li3)	ㄇㄞˊ	(mai2)	ㄆㄧㄢˋ	(pian4)
	㐀止	ㄓˇ	(zhi3)	ㄔㄜˇ	(che3)	ㄉㄜˊ	(de2)
Set C	埥	ㄑㄧㄥ	(qing1)	ㄘㄞ	(cai1)	ㄎㄢ	(kan1)
	僑	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 preexposure phase, and a story used in the orthographic exposure phase

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 |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.)



<table>
<tr><th>+ Zhuyin</th><th>-Zhuyin</th></tr>
<tr><td>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。</td><td>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 。</td></tr>
<tr><td colspan="2">English translation: Xiaoming was eating his lunch. He saw peas in his bowl and he does not like them. He poured his lunch in the 電絴機 |dian4 yang2 ji1|. Then he pressed the buttons on the 電絴機 |dian4 yang2 ji1|. The food went into the tube of the 電絴機 |dian4 yang2 ji1|, and came out from the other end with no peas in it. Xiaoming washed the 電絴機 |dian4 yang2 ji1| and put it away.</td></tr>
</table>

Appendix C.

Items in the orthographic choice task

	Target Character	Visual Distractor 1	Visual Distractor 2	Phonological Foil		
				Regular	Irregular	Unrelated
Set A	禾主	牜主	禾王	秼	禾亡	禾看
	立及	王及	立久	立己	立西	立匋
	亻登	牜登	亻癸	亻等	亻成	亻片
	金平	彳平	金米	金屏	金呈	金得
Set B	衤交	禾交	衤父	衤角	衤要	衤看
	糸羊	糸羊	糸羔	紻	緘	綯
	鋰	錁	扌里	金离	金買	金片
	亻止	亻企	木企	侄	俥	亻得
Set C	埥	王青	土背	土頁	埰	土看
	傐	槁	亻嵩	俈	亻考	亻匋
	伷	王由	亻甲	佑	亻秀	亻片
	鉡	阝半	金未	鍛	鎊	金得

Appendix D. Ethics Approval

Fhs Ethics

To: Professor Anne Castles

Cc: Dr Peter De Lissa, Dr Hua-Chen Wang, Miss Luan Li, Ms Julianne Pascoe, Ms Signy Victoria Wegener

RE: HS Ethics Amendment 4 - Approved (Ref No. 5201500098)

Dear Professor Castles,

RE: 'Making words stick: Lexical consolidation effects in learning to read ' (Ref: 5201500098)

Thank you for your recent correspondence regarding the amendment request.

The amendments have been reviewed and approved.

In the reviewers' view the research is innocuous enough to contain little risk to the participants. The passive consent process is a pragmatic approach that when combined with the verbal consent the researchers are obtaining from the children individually should suffice. The verbal address of the participants also outlines the option to opt out at any point. What is possibly lacking is a record that the child themselves agrees. Some reviewers suggest that the student researcher, Ms Luan Li, keep some record of agreement from children. Please see below.

This approval applies to the following amendments:

1. To change the form of consent from the Taiwan elementary school, as described in Section 5, 6 and 7;

2. Supporting documents - attached and noted

Attachment 1) Research Plan & Passive Consent Form (Chinese)
Attachment 2) Research Plan & Passive Consent Form (English translation)
Attachment 3) Plain Language Statement for Children (Chinese)
Attachment 4) Plain Language Statement for Children (English translation)
Attachment 5 & 6) Email correspondences between the Taiwan elementary school representative and Dr Wang (with English translation)

Please note that this approval is subject to one condition:

1. Please obtain some record of agreement from children.

Please accept this email as formal notification that the amendments have been approved. Please do not hesitate to contact us in case of any further queries.

All the best with your research.

Kind regards,

FHS Ethics
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