# ABSTRACT

Title of Document: THE INFLUENCE OF ORTHOGRAPHIC EXPERIENCES ON THE DEVELOPMENT OF THE FUNCTIONAL PHONOLOGICAL UNIT IN SPOKEN WORD PRODUCTION

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The current dissertation project examined the influence of orthographic experiences on the development of the functional phonological unit in spoken word production in native Mandarin-speaking children. Functional phonological unit refers to the first selectable phonological unit after lexical selection in the planning of spoken word production. Previous research has shown that the acquisition of orthographic knowledge restructures literate speakers' phonological representation and in particular, the acquisition of alphabetic orthographic knowledge improves children's phonological awareness at the phonemic level. However, few studies have investigated the influence of orthographic experiences on phonological retrieval and encoding in spoken word production. The goal of this dissertation is to fill this gap. Four experiments were carried out to conduct the investigation. Participants consisted of native Mandarin speakers from four age groups with different orthographic experiences, including 1) Grade 1 children, who were comparatively more exposed to alphabetic Pinyin and had very limited Chinese character knowledge, 2) Grade 2 and Grade 4 children, who had better character knowledge and more exposure to characters, and 3) adult readers, who had the highest level of character knowledge and the most exposure to characters. Experiment 1 investigated whether the onset served as the functional phonological unit in producing monosyllables; Experiment 2 investigated whether the role of the onset in phonological retrieval and encoding was sustained when producing disyllabic words; Experiment 3 examined the role of the syllable segment (i.e., a syllable whose tone is indeterminate or an atonal syllable) in producing disyllabic words; Experiment 4 examined the role of the tonal syllable (i.e., tonal information is also included) in producing disyllabic words. Results showed that only Grade 1 children selected the onset as the functional phonological unit regardless of the word length during spoken word production and that additionally, they might process the rime segment and tone as a cohesive unit. By contrast, Grade 4 children and adults selected the syllable segment as the functional phonological unit. Grade 2 children were in their transitional stage of development, and they selected tonal syllable as the functional phonological unit. The different orthographic experiences of the four groups might contribute to the above differences. The current dissertation has important theoretical and pedagogical implications. The aforementioned findings help us better understand the mechanism of phonological processing, and as a result, may help educators develop more efficient pedagogical approaches to improve children's phonological processing ability.

# THE INFLUENCE OF ORTHOGRAPHIC EXPERIENCES ON THE DEVELOPMENT OF THE FUNCTIONAL PHONOLOGICAL UNIT IN SPOKEN WORD PRODUCTION

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# Chapter 1 - Introduction

Spoken word production involves the operation of a series of cognitive mechanisms. Speakers start from message or concept encoding (e.g., identify an object in a picture), then select the corresponding lexical item, retrieve and encode the phonological information, and finally articulate the sounds (Ferreira, 2010). Phonological retrieval and encoding is an indispensable component among these mechanisms. How do speakers retrieve and encode the phonological information? For example, if a speaker wants to say the word “paper,” does he or she retrieve and encode the spoken word /peipɚ/ as an integral unit, retrieve the constituent syllables /pei/ and /pɚ/ separately, or /p/, /ei/, /p/, and /ɚ/ as four independent phoneme units? In this dissertation, the term “functional phonological unit” is used to refer to phonological units that are used to plan spoken word production after the stage of lexical selection (Kureta, Fushimi, & Tatsumi, 2006). Literature also used the terms “proximate unit” to refer to the same concept (e.g., Chen & Chen, 2013; O’Seaghdha, Chen, & Chen, 2010; O’Seaghdha, 2015).

O’Seaghdha et al. (2010) showed that adult native English speakers are more likely to retrieve and encode the phonological information as individual phonemes (e.g., they retrieve and encode /p/, /ei/, /p/, and /ɚ/ as four independent units when planning to say the word “paper”). In other words, the functional phonological unit is phoneme segment in literate adult native English speakers. Yet, it remains unclear what the functional phonological unit is for children, how children develop sensitivity to these units, and how orthographic experiences (e.g., learning to read and write) influence this development. The current dissertation research aims to answer these research questions. This work has important theoretical implications as its results can lead to a better understanding about the mechanism of spoken language production, the development of phonological processing during spoken word production, and how the literacy experiences affect this development. This work also has significant pedagogical implications as the findings may help educators develop better educational methodology to improve children's abilities of phonological processing, thus facilitating the improvement of their speaking proficiency.

In order to examine and explain the mechanism or procedure of spoken word production, a few models such as the WEAVER++ (Word Encoding by Activation and VERification) have been put forward (Levelt, Roelofs, & Meyer, 1999). According to WEAVER++, there are five stages in the network. The first stage is conceptual preparation at the conceptual level, which contains concept nodes and conceptual links. A subset of these concepts consist of *lexical* concepts, which are connected to lemma nodes in the second level. The lemma level involves the semantic and syntactic information of a word, and the second stage is the retrieval of lemma and syntactic environment (e.g., number, tense, and aspect). After lemma selection, word production proceeds to the third level, the word form level or lexeme level, at which the morphemes of the lemma are accessed, followed by the retrieval of phonological information (i.e., segmental and metrical properties). At the final stage, phonetic encoding occurs and phonetic gestural scores are executed during articulation. At the fourth stage, the retrieval of phonological information at the beginning may differ in terms of the size of phonological unit, and the units which are selected to retrieve phonological information at the beginning of processing at word form level is defined as the functional phonological unit in this dissertation. Chen and Chen (2013) used the term "proximate unit" to refer to the same concept in their model. They suggested that the retrieval and encoding of proximate units occurred after lexical retrieval, and "non-proximate units", if there is any, iterate and can be manipulated. For example, syllable segment is the functional phonological unit or proximate unit in Mandarin Chinese, and native Mandarin speakers plan their spoken words in syllables after lexical retrieval is finished (i.e., syllable segment is the first unit they select during the planning of spoken words). The functional phonological units are deployed sequentially in the context of metrical properties (e.g., tone in Chinese, stress in English) after being retrieved and encoded. Yet, smaller units such as phoneme segments are still selectable and Mandarin speakers are able to manipulate them, although phoneme segments are the non-proximate units. Non-proximate units are smaller than proximate units/functional phonological units. The functional phonological unit used for phonological retrieval and encoding during spoken word production has been investigated among adult speakers with different language backgrounds. In languages in which phoneme segment is the functional phonological unit, non-proximate units in Chen and Chen's model (2013) is not applicable.

Previous research suggested that the functional phonological unit differs across languages (Chen, Chen, & Dell, 2002; Kureta, et al., 2006; Meyer, 1990, 1991; O'Seaghdha, et al., 2010). Native speakers of alphabetic languages such as Dutch (Meyer, 1990, 1991) and English (O'Seaghdha et al., 2010) have been shown to plan the production of spoken words phoneme by phoneme, suggesting that the primary functional phonological unit in these alphabetic languages is the phoneme segment. For non-alphabetic languages, Chen et al. (2002) and O'Seaghdha et al. (2010) showed that the functional phonological unit is the whole syllable segment in Mandarin Chinese, and Kureta et al. (2006) suggested that the CV (consonant + vowel) mora is the functional phonological unit in Japanese. In Chinese, a syllable may consist of 1) a consonant and a vowel, 2) a vowel only, 3) a consonant, a vowel and a final consonant, or 4) a vowel and a final consonant. In Japanese, a mora represents a timing slot for any part of a syllable other than the onset (Hyman, 1985). For example, a syllable nucleus represents one mora in the case of a short vowel regardless if it contains an onset or not, and two morae in the case of a long vowel or a short vowel plus a coda.

Returning to the studies that investigated the functional phonological unit across languages, the results showed that the functional phonological units in the aforementioned three languages (i.e., English, Mandarin, and Japanese) are also consistent with the orthographic form of these languages. For languages with alphabetic orthographies such as Dutch and English, each phoneme represents a grapheme. For Mandarin, which has a morphosyllabic writing system, each character represents a syllable and a morpheme. For Japanese, each mora maps onto a grapheme in hiragana and katakana. This close relation between phoneme-grapheme correspondence and the functional phonological unit may lead to the question that is it possible that the different orthographic forms contribute to the different functional phonological units across languages. If so, how does learning a specific orthographic form of a language influence children's selection of the functional phonological unit?

Previous literature has shown that orthographic experiences have an impact on various aspects of language development, including vocabulary growth (Ricketts, Bishop, & Nation. 2009), orthographic awareness (Stanovich & West, 1989), phonological awareness (Ziegler & Goswami, 2005), phonological memory (Nation & Hulme, 2011), and spoken word recognition (Ziegler & Muneaux, 2007). The acquisition of orthographic knowledge improves children's ability on the first four aspects, and literate listeners showed that their phonological representation might be restructured due to the learning of orthographic knowledge. For example, simply being exposed to orthography is able to facilitate children in learning the meaning of pseudo-words (Ricketts, et al., 2009), and correlation analysis suggested that orthographic exposure can account for the development of orthographic awareness (Stanovich & West, 1989). The acquisition of orthographic knowledge also improves children phonemic awareness (Ziegler & Goswami, 2005) and their ability to recall a sequence of nonword (Nation & Hulme, 2011). In terms of spoken word recognition, advanced readers showed significant Orthographic Neighborhood Effect (i.e., faster reaction time during spoken word recognition if the word has more orthographic neighbors) in an auditory lexical decision task (Ziegler & Muneaux, 2007). However, few studies have focused on the development of phonological retrieval and encoding skills. In addition, most of previous studies have focused on monolingual speakers who are only exposed to one orthography (e.g., English alphabets). As a result of rapid globalization, more and more children will be exposed to multiple orthographies and languages. However, very few studies have investigated the consequences of learning multiple orthographies on children's phonological development. As a result, the present dissertation was conducted to address this issue. This dissertation project is guided by the following research questions:

1. What is the developmental trajectory of the functional phonological unit during spoken word production?
2. How does the experience with orthographies influence the development of the functional phonological unit?

In order to tease apart the influence of spoken language difference and orthographic difference, Mandarin Chinese was selected as the target language as it provides a good opportunity to investigate a language with multiple orthographies. Native Mandarin-speaking children in Mainland China are an ideal population since they are exposed to two types of orthographies in the same language—the alphabetic Pinyin and the morphosyllabic characters. Li, Wang, & Idsardi (2015) suggested that when native Mandarin-speaking adults were asked to memorize same Chinese word pairs written in Pinyin and characters, they selected different functional phonological units when recalling the target words. Onset was selected as the functional phonological unit when the materials were presented in Pinyin but not in Chinese characters. The researchers interpreted that the explicit orthographic information presented in Pinyin may encourage speakers to select a small unit (onset) for retrieving and encoding the phonological information. However, it remains unclear whether the acquisition of orthographic knowledge may have an influence on the selection of functional phonological units when orthographic information is not explicitly represented in a conceptually driven language production task. Since literate adults were recruited in Li et al. (2015), it is possible that the long-term orthographic experiences have affected their phonological representation and processing, thus affecting the selection of functional phonological units in spoken word production. This dissertation research examined the development of native Mandarin-speaking children's functional phonological unit and the influence of their multiple orthographic experiences (i.e., Pinyin and character) on this development when orthographic information is not presented explicitly. This dissertation is organized as follows: Chapter 2 is a review of the literature on the topic of the development of phonological processing skills and the influence of orthographic experiences. Particularly, previous literature about the explanation of the influence of orthographic experiences is reviewed. Chapters 3-6 are detailed description of the four experiments, respectively. Chapter 7 is the general discussion based on the four experiments and addresses the limitation and future directions of the current dissertation. This dissertation is among the first projects that investigates the functional phonological unit in children from a developmental perspective. Its findings will benefit our understanding of the phonological representation and processes from a developmental perspective in general and help enrich the current models of spoken word production and phonological representation by taking into consideration the role of orthographic experiences.

# Chapter 2 – Literature Review

The ability to process phonological information (i.e., the sounds of one's language) is critical in language and literacy development. Phonological processing involves different components, such as phonological awareness – the awareness of the sound structure of language (Wagner & Torgesen, 1987), phonological memory – coding and temporary storage of sound-based representations in working memory (Baddeley, 1987; Torgesen, 1996), and phonological retrieval and encoding in spoken word production (Mann, 1991). Phonological processing skills have been shown to be important for reading development. In turn, literacy experience promotes phonological processing skills. One source of evidence is that the acquisition of orthographic knowledge (i.e., the understanding that the sounds in a language are represented by written or printed symbols) has been shown to be important for the development of awareness of phonological units (see Ziegler & Goswami, 2005, for an overview). For example, literacy experience makes it easier for children to count the number of phonemes in a word (Liberman, Shankweiler, Fischer, & Carter, 1974). Phoneme is the smallest sound unit of speech that can be used to distinguish between two words. For example, the initial sounds /k/ and /b/ allow listeners to differentiate between *kid* and *bid*. Orthographic knowledge may also influence phonological memory (Pattamadilok, Lafontaine, Morais, & Kolinsky, 2010; Nation & Hulme, 2011). Orthographic information is automatically involved in coding phonological units during the memorization and recall of spoken words (Pattamadilok, et al., 2010). For example, it may be easier for listeners to remember an address if they see the spelling of the street name. To date, very limited research has investigated how orthographic knowledge influences phonological retrieval and encoding in spoken word production. One of the goals of this proposed dissertation is to fill this gap by examining the relationship between the development of functional phonological unit and orthographic experience.

This chapter is divided into three sections. The first section will review previous studies that have investigated the development of phonological processing skills and discuss how orthographic experience influences phonological processing, with a focus on phonological awareness and phonological memory. Since very few studies have examined the development of phonological retrieval and encoding units in spoken word production among children, the second section will review literature on adults' preference of functional phonological units across different languages. Finally, the characteristics of Chinese language and the orthographic features of two Chinese writing systems will be introduced to provide the rationale why native Mandarin-speaking children in Mainland China are selected for this proposed dissertation.

## The Development of Phonological Processing Skills

Phonological processing refers to the use of phonological information or phonological structures in processing spoken or written languages (Wagner & Torgesen, 1987). Previous research on the development of phonological processing skills included a large number of studies that investigated the development of phonological awareness, phonological recoding in lexical access in written words and for maintaining information in working memory (Anthony & Francis, 2005; Carroll, Snowling, Stevenson, & Hulme, 2003; Goswami, Ziegler, Dalton, & Schneider, 2001; Ho, & Bryant, 1997; Mark, Shankweiler, Liberman, & Fowler, 1977; Palmer, 2000; Vandervelden & Siegel, 1995; Wagner & Torgesen, 1987). These phonological processing abilities have been shown to be highly related to literacy and language development among young children (Dufva, Niemi, & Voeten, 2001; Wagner, Torgesen, & Rashotte, 1994; Wagner, et al., 1997). In this review, the focus will be on the processing of phonological information in spoken languages, including phonological awareness, phonological memory, and phonological retrieval and encoding in spoken word production.

**The Development of Phonological Awareness**

Phonological awareness involves the ability to detect and manipulate phonological units within a word, such as phonemes (e.g., /s/ in the word *skip* /skɪp/), onsets (e.g., /sk/ in *skip*), rimes (e.g., /ɪp/ in *skip*), and whole syllables (e.g., /skip/) (Gillon, 2004). Phonological awareness develops in a similar hierarchical pattern across languages—syllables awareness first, followed by onset-rime level awareness, and finally phoneme-level awareness (Stanovich, 1992; Anthony & Lonigan, 2004; Anthony, Lonigan, Driscoll, Phillips, & Burgess, 2003). According to Treiman and her colleagues' Linguistic Structure Hypothesis (e.g., Treiman, 1995; Treiman, Mullennix, Bijeljac-Babic, & Richmond-Welty, 1995), the syllable is at the top of the hierarchical structure since it is the largest and most accessible unit. The phoneme is at the bottom of the hierarchical structure since it is the smallest unit and develops later for children. Between syllables and phonemes lie the intermediate onset and rime units.

In Anthony et al. (2003), around 1,000 native English-speaking children with a wide age range (2-6 years old) were assessed and results showed that the awareness of phonological units develops from large to small units. A series of tests on phonological awareness at different levels were conducted, such as the *blending* and *elision multiple-choice tasks*. A *blending multiple choice task* requires children to combine auditory syllables, onsets and rimes, or phonemes to form a word and to choose a picture out of three candidates that represents the word (e.g., to blend /k/ and /æt/ together and to point to a picture of *cat*). An *elision multiple choice* task requires children to remove a phonological unit from an auditory word (e.g., to remove the phoneme /f/ from /fɑɚm/ and to point to a picture of *arm*). Both tasks were used to measure children's phonological awareness at all levels, thus minimizing the variances from task complexity and difference. Hierarchical loglinear analyses (HLA) were used to examine the order of acquisition of phonological awareness. Results suggested that the acquisition of phonological awareness of larger units precede that of smaller units (i.e., syllable→ onset/rime→ phoneme). Similarly, preschool children learning other languages with alphabetic scripts also showed better syllable awareness than phoneme awareness, although the variations are great in terms of the global levels of phonological awareness attained (Cossu, Shankweiler, Liberman, Katz, & Tola, 1988, for Italian; Harris & Giannouli, 1999, for Greek; Demont & Gombert, 1996, for French). For example, preschool Turkish children have shown a high level of syllable awareness (Durgunoglu & Oney, 1999), whereas native English learning children without formal literacy instruction performed at chance level in task measured syllable awareness (Liberman, et al., 1974). This difference may be related to the syllable structure of the languages (Ziegler & Goswami, 2005). For example, compared with Turkish, English has more complicated syllable structure that allows various types of consonant clusters. Therefore, the acquisition of syllable structure is more challenging for English-speaking children.

Previous literature has suggested that phonological awareness of different units are reliable predictors of later reading abilities. Beginning readers or children who are more capable of attending to and manipulates different sound units can more rapidly map written symbols onto sound units and, therefore, are more likely to be successful in decoding and reading. The above positive relationship between phonological awareness and decoding has been shown in research with readers of both alphabetic languages (e.g., Bradley & Bryant, 1983; Nithart & Demont, 2011; Schneider & Naslund, 1999; Soltani & Roslan, 2013; Wagner et al., 1994, 1997) and non-alphabetic logographic languages (e.g., Ho & Bryant, 1997;Muter, Hulme, Snowling, &

Stevenson, 2004; Siok & Fletcher, 2001), although the relationship is modulated by orthographic depth, that the correlation is stronger in languages with less transparent orthographies (Ziegler et al., 2010). Also, the awareness of some units may be a stronger predictor for some languages than others (for reviews see Adams, 1990; Brady & Shankweiler, 1991; Goswami & Bryant, 1990; McBride-Chang, Tong, Shu, Wong, Leung, & Tardif, 2008; Wagner & Torgesen, 1987). For example, syllable awareness has been suggested to be predictive of future reading ability across different languages such as English, Greek, and Chinese, whereas phoneme awareness is a good predictor for reading development in English and Greek but not in Chinese (Adinis & Nunes, 2001; McBride-Chang, et al., 2008). An explanation of this difference is that the syllable is salient and the simplest unit within a word (Treiman & Zukowski, 1991) and it is a universal phonological unit of language processing (e.g., Boysson-Bardies, 1999), whereas phoneme is not salient in some orthographies like the logographic Chinese characters.

However, the development of Chinese-speaking children's phonological awareness also follows the hierarchical pattern from large units to small units. For example, Shu, Peng, and McBride-Chang (2008) examined phonological awareness among native Mandarin-speaking children in preschool and primary schools, and found that children in the first grade performed significantly better (accuracy rate about 70%) than preschool children at ages 3–5 years (accuracy at 50%) in detecting phoneme onsets. The researchers suggested that children's experience of learning to read in Pinyin, an alphabetic script in Chinese, has significant influence on this development. In the following session, previous research that investigated this orthographic influence will be reviewed.

## The Influence of Orthography on Developing Phonological Awareness

The relationship between phonological awareness and reading is reciprocal. Phonological awareness of different sized units predicts future reading performance. In turn, the experience of learning to read promotes the development of phonological awareness (for reviews see Castle & Coltheart, 2004; Ziegler & Goswami, 2005). Researchers suggested that it is possible that learning to read guides beginning readers to attend to relevant phonological segments in a language (Ehri, 1989; Morais, Alegria, & Content, 1987). For example, the orthography of alphabetic languages such as English, French, and German may make beginning readers aware of the phoneme units, because a letter or letter clusters represent phonemic information in these languages. One source of supporting evidence comes from a series of studies which demonstrated that phonemic awareness only develops after children have been taught to read and write, irrespective of the age at which these skills are taught (see Goswami & Bryant, 1990; Castle & Coltheart, 2004, for reviews). Mann and Wimmer (2002) found that American kindergartners outperformed age-matched German kindergartners on phonemic tasks, although both groups' native languages (i.e. English and German) are alphabetic. This difference was explained by their different orthographic experiences in which American kindergartners were taught to read alphabetic letters prior to schooling, whereas their German counterparts were not. In addition, alphabetic languages with more transparent orthographies promote children's access the phonemes, thus boosting their development of phonemic awareness (see Goswami, Ziegler, & Richardson, 2005). As a result, the transparent orthography facilitate children to reach ceiling in terms of their phonemic awareness at early primary grades, thus explaining why phonological awareness, phonemic awareness in particular, is a stronger predictor of reading performance in languages with less transparent orthographies than those with more transparent orthographies.

Other supporting evidence comes from studies on illiterate adults, who were found to lack phonemic awareness (Lukatela, Carello, Shankweiler, & Liberman, 1995). Native speakers of Serbo-Croatian were categorized according to their ability to identify Cyrillic alphabets. The group with lower reading ability performed significantly worse on phoneme deletion and phoneme counting tasks but not on syllable counting or picture vocabulary tasks. Particularly, illiterate individuals performed significantly worse on phonemic awareness tasks than age-matched adults who had been illiterate as adults but had subsequently learned to read. It is difficult for illiterate Portuguese adults to add or remove a phoneme at the beginning of a non-word. However, their counterparts with similar environment (most of them were working in the textile industry when the study was conducted) and childhood experiences (all of them were peasant origin) who had been illiterate as adults but had subsequently learned to read are able to perform the same task easily (Morais, Cary, Alegria, & Bertelson, 1979). Similarly, compared with their counterparts who have similar education level and can read both Chinese characters and Pinyin, Chinese adults who had not learned to read Pinyin performed significantly worse in adding and deleting phonemes (Read, Zhang, Nie, & Ding, 1986). These results suggested that the acquisition of orthographic knowledge of alphabetic scripts plays a critical role in the development of phonemic awareness.

A third source of evidence comes from research that has shown the acquisition of orthographic knowledge changes the way children segment phonological units in spoken language (Ehri & Wilce, 1980; Inagaki, Hatano, & Otake, 2000). Native English speaking fourth-grade children tended to report that there were more phonemes in a word with more letters such as *pitch* than in another word such as *rich*, although the rimes (/ɪtʃ/) and the number of phonemes in both words were the same (Ehri & Wilce, 1980). In light of the fact that four letters are used to represent the rime in *pitch*, whereas only three are used to represent the rime in *rich*, children conceptualized the phonetic element [t] as a separate phonemic unit when segmenting *pitch*. This result suggested that learning to read may change the phonological representation among children. Inagaki et al. (2000) showed that Japanese children's spoken word segmentation skill develops from being a mixture of syllable- and mora-based to being predominantly mora-based as they acquired kana knowledge. Kana is a mora-based writing system. A group of 4- to 6-year old Japanese-learning children were asked to make dolls jump along colored circles in time with their articulation of familiar words. The critical manipulation was that, the auditory words differ in terms of the number of syllables and morae. For example, the word *kureyon* (crayon) should be segmented into three syllables (i.e., ku/re/yon) but into four morae (i.e., ku/re/yo/n), and it is written as クレヨン with four kana letters. Japanese children with minimal kana knowledge segmented the target words based on syllable in half of the trials and based on mora in the other half. Children with intermediate or high level kana knowledge were more likely to segment the words based on mora. In other words, the way older children segment the phonological units of a word is consistent with its orthography or spelling.

In summary, three sources of evidence consistently suggested that the acquisition of orthographic knowledge influences the way that literate speakers process phonological units. Learning to read alphabetic orthographies (e.g., English) improves children's ability to detect and manipulate phoneme units, and learning to read moraic orthographies (e.g., Japanese Kana) encourages children to manipulate sounds using mora-based strategies. In addition, children tend to match the representation of phonemes with their spellings (e.g., *-itch* is represented as three phonemes whereas *–ich* is represented as two). Finally, illiterate adults without literacy experience in alphabets hardly detect or manipulate phonemes, whereas their counterparts who were instructed to read alphabets after childhood were able to develop phoneme awareness.

**The Development of Phonological Memory**

Phonological memory, the ability to code and store sound-based representations temporarily in working memory, is another important aspect of phonological processing (Wagner, Torgesen, & Rashotte, 1994). An important component of working memory is phonological loop, in which auditory memory is stored and articulatory rehearsal was adopted to make the memory traces active (Baddeley & Hitch, 1974; Baddeley, 1986). Therefore, individuals with better phonological memory may also have a better developed phonological loop system. Typical measurement of children's phonological memory is a repetition or recall task: children may be asked to repeat/recall non-words or sequences of digits/words which have been presented aurally (Dufva, et al., 2001; Gathercole & Baddeley, 1990; Gathercole, Hitch, & Martin, 1997; Nation & Hulme, 2011). High accuracy rate in a nonword repetition task or large span in a digital or word span task indicates high level of phonological memory. Phonological memory is developed dramatically during childhood (Nicolson, 1981; Hulme, Thomson, Muir, & Lawrence, 1984). This development is attributed to the increased rehearsal rate (i.e., more phonological items can be stored in the phonological loop).

Researchers suggested that phonological memory may play a role in reading development, hypothesizing that after decoding visual symbols (e.g., alphabetic letters) into phonological units (e.g., phonemes), beginning readers need phonological memory to store these phonological units before they can blend them into a word (Baddeley 1982; Wagner & Torgesen 1987). Early studies have found an association between deficient phonological memory and reading difficulties (for reviews, see Gathercole & Baddeley, 1993a; Hulme & Mackenzie, 1992).

Another source of supporting evidence comes from the research that showed phonological memory of preliterate children is predictive of their future word recognition in the school years (Gathercole & Baddeley 1993b). In a longitudinal study, 80 native English-speaking children were tested four times at the ages of 4, 5, 6, and 8 years. Their phonological memory skills at age 4 were significantly related to their reading performance at age 8. However, a limitation of these studies is that they failed to take into consideration the influence of phonological awareness, a powerful predictor of children's reading development. Dufva et al. (2001) recruited 222 native Finnish-speaking children in their longitudinal study, and measured their phonological processing skill, including phonological awareness and phonological memory, and their reading performance. The researchers found that the relationship between preschoolers' phonological memory and their word recognition performance at Grade 1 is mediated by phonological awareness. The mediation of phonological awareness can be explained by the fact that better memory of certain phonological units facilitates the manipulation of the units in children's working memory (e.g., blending and moving the location of the units).

**The Influence of Orthography on Phonological Memory**

Orthography contributes to the development of phonological memory (Pattamadilok, et al., 2010; Nation & Hulme, 2011). According to the working memory model (Baddeley & Hitch, 1974; Baddeley, 1986), orthographic information is not needed in the "phonological loop" since all the items are being rehearsed in an auditory manner in the loop. In other words, phonological memory does not require orthographic information. However, once readers learn to read and acquire orthographic knowledge, they may make use of this knowledge to memorize phonological information automatically, thus affecting their phonological memory. Pattamadilok et al. (2010) found that orthography is involved in the use of phonological memory among literate adults. When speakers were asked to recall auditory word lists with seven items in each list, their performance was significantly interfered by phonological similarity between items. However, if the phonologically similar items were orthographically dissimilar, the influence of phonological similarity was reduced.

In a longitudinal study, Nation and Humle (2011) showed that the acquisition of orthographic knowledge has significant influence on children's performance on pseudo-word repetition, which requires phonological memory. In the study, native English-speaking children's reading skills, oral language skills (i.e., vocabulary, recalling sentences and sentence structure), phonological awareness, and nonword repetition abilities were assessed at the ages of 6 (Time 1) and 7 (Time 2). An important finding was that reading skills at Time 1 made significant contribution to nonword repetition performance at Time 2, independent of oral language skills and phonological awareness at Time 1. These results suggested that learning to read promotes children's phonological memory. As children learn to read, the acquired orthographic information is available to influence on-line performance when children listen to and repeat novel words or pseudowords. Vandewalle, Boets, Ghesquiere, and Zink (2012) found that children diagnosed with Special Language Impairment (SLI) have delayed literacy development and they performed significantly worse than typically developing children on verbal short-term memory (vSTM) tasks. Participants' vSTM performance was measured by digit span and nonword repetition tasks, in which children were asked to recall or repeat the digits or nonwords presented from a CD. These findings provided indirect evidence that learning to read and write may be related to phonological memory development.

**The Phonological Restructuring Hypothesis**

According to the Phonological Restructuring Hypothesis, the process of learning to read and write provides an opportunity for orthographic experience to alter the nature of phonological representation, (Castro-Caldas, Petersson, Reis, Stone-Elander, & Ingvar, 1998; Pattamadilok, Knierim, Kawabata Duncan & Devlin, 2010; Muneaux & Ziegler, 2004; Perre, Pattamadilok, Montant, & Ziegler, 2009; Taft, 2006, 2011; Ziegler & Goswami, 2005). The process of acquiring orthographic knowledge introduces the mapping between phonemes and graphemes, thus adding a visuographic dimension to the internal representational system of phonology. A supporting evidence of this explanation is that the orthographic inconsistency effect, which refers to readers' different response to orthographically consistent and inconsistent words, is localized in the brain areas that are in charge of phonological processing.

In some languages, words differ in the degree of their sound-to-spelling consistency (Stone, Vanhoy, & Van Orden, 1997; Ziegler, Montant, & Jacobs, 1997). For example, the phonological rimes of some words can only be spelled in one way (e.g., (/-ʌk/ can only be spelled as –uck in English), whereas those of other words can be spelled in multiple ways (e.g., /-aɪt/ can be spelled as –ight/-ite/-yte). The latter type of words (i.e., the orthographically inconsistent words) was found to take readers longer to process compared with the former type (i.e., the orthographically consistent words) in a lexical decision task and a semantic categorization task (e.g., Peereman, Dufour, & Burt, 2009; Perre & Ziegler, 2008; Ventura, Morais, Pattamadilok, & Kolinsky, 2004; Ziegler & Ferrand, 1998). Listeners also showed different event related potential (ERP) patterns when hearing orthographically consistent and inconsistent words—significantly larger negative wave was shown for inconsistent words (Perre & Ziegler, 2008). The different response patterns to orthographically consistent and inconsistent words (e.g., different response latency and ERP patterns) are referred to the orthographic consistency effect.

Pattamadilok, et al. (2010) showed that this orthographic consistency effect is localized in the phonological brain areas but not orthographic or visual areas. In this study, transcranial magnetic stimulation (TMS) was used to selectively interfere with either phonological or orthographic processing. The hypothesis was that, if the orthographic consistency effect results from phonological restructuring, the stimulation of the left supramarginal gyrus (SMG)—an area involved in phonological processing—would reduce the effect. In contrast, if the orthographic consistency effect is due to the co-activation of visual information, then stimulation of the left ventral occipitotemporal cortex (vOTC)—an area involved in orthographic processing—would reduce the effect. If both SMG and vOTC stimulation affect the orthographic consistency effect, it means that both reconstruction and co-activation contribute to the effect. The result supported the first hypothesis and suggested that the orthographic consistency effect was due to the reconstruction of phonological representation, which might be a result of the acquisition of orthographic knowledge, instead of the direct activation of orthographic information. This result is consistent with earlier findings in Petersson, Reis, Askelöf, Castro-Caldas, and Ingvar (2000) that the brain activities of literate and illiterate speakers differ in a pseudoword repetition task. For example, literate speakers showed larger activation in the Broca's area and the posterior-midinsula bridge between Wernicke's and Broca's area. These results were explained as a result of the modulatory influence from orthographic knowledge on sublexical phonological processing, which contributes to the phonological loop and phonological memory.

Perre, Pattamadilok, Montant and Ziegler (2009) reached a similar conclusion by having listeners' ERP patterns measured. A lexical decision task was conducted on a group of native

French speaking adults. All the real words were disyllabic French words and the second syllable was also consistent (i.e., only have one way to spell). For the real words whose first syllable can be spelt in multiple ways (i.e., inconsistent words), participants showed  a larger ERP pattern in two time windows (300-380ms and 410-550ms) compared with the consistent words after the onset of the target. Employing the standardized low resolution electromagnetic tomography (sLORETA), Perre, et al. showed that the aforementioned orthographic consistency effect was clearly localized in a classic phonological area (left SMG), whereas no clear activation occurred in the posterior cortical areas coding orthographic information, such as the visual word form area in the left fusiform gyrus.

In summary, the acquisition of orthographic knowledge may reconstruct phonological representation, thus influencing literate individuals' phonological awareness, phonological memory, and subsequently, spoken word recognition which requires the mapping between phonological information and lexical information. However, few studies have investigated the influence of orthographic knowledge by examining phonological processing skills from the perspective of phonological retrieval and encoding in spoken word production. This limitation makes it difficult to build a comprehensive understanding of the interaction between orthographic experiences and phonological processing abilities. Another limitation is that research seldom examines the influence of multiple orthographic experiences. In modern times, children are increasingly frequently exposed to different orthographies due to rapid globalization. Learning multiple orthographies simultaneously may introduce different mappings between phonemes and graphemes, which may lead to complex changes in phonological representation. Therefore, this dissertation project aims to fill these gaps by investigating the functional phonological unit – the way speakers retrieve and encode phonological information – among speakers across different age groups who have experiences with multiple orthographies.

## Investigation on Functional Phonological Units

Few studies have been conducted to investigate the development of the functional phonological unit in children. Nevertheless, the selection of the functional phonological unit among adults with different language backgrounds has been studied extensively. This section will review literature about the functional phonological unit in adults, particularly focusing on the experimental designs and paradigms used to examine this issue. How the paradigms will be conducted with children accordingly will also be discussed.

### The Form Preparation Paradigm

The form preparation paradigm, also known as implicit priming in production, has been frequently used to investigate the functional phonological unit in spoken word production (Chen, et al., 2002; Cholin, Schiller, & Levelt, 2004; Kureta, et al., 2006; Meyer, 1990, 1991; O'Seaghdha, et al., 2010). The classic form preparation paradigm includes two sessions—an associate learning session and a test session. In the associate learning session, participants are asked to memorize some prompt-response word pairs that are printed on index cards. The test session is conducted immediately afterwards and participants are asked to say the response word as quickly and accurately as possible when the corresponding prompt is unpredictably presented. The rationale of this paradigm is that, in the *homogeneous* context, when the response words always begin with the same ingredients, the fore-knowledge of the ingredient allows the participants to prepare their spoken words in advance, thus facilitating their naming latency. For example, the response words may always begin with the onset /d/, such as *day, dew* and *dough*. In contrast, in the *heterogeneous* context, the response words do not share the same onset (e.g., *day*, *pea*, and *bow*). In the *homogeneous* context, participants keep repeating words that begin with /d/, thus they are able to prepare to say /d/ in advance. If speakers benefit from the fore-knowledge of a phonological unit (e.g., the phoneme onset /d/), that particular phonological unit is considered as the functional phonological unit in planning spoken words.

Early literature provides several key findings about the functional phonological unit using the form preparation paradigm. Firstly, the functional phonological unit does not differ within a language when words with different length are produced. Native Dutch speakers benefited from the fore-knowledge of the onset of a set of words regardless of whether the words were short (e.g., monosyllabic words) or long (disyllabic words) (Meyer, 1990, 1991).

Secondly, the fore-knowledge of the later shared components of a set of word cannot elicit facilitation (Meyer, 1990, 1991). As a result, the form preparation paradigm can only be used to investigate whether a phonological unit that serves as the beginning component of a word (e.g., initial phoneme and initial syllable) is selected as the functional phonological unit, whereas the later component (e.g., coda and rime) are not examined. When the set of words shared the same rime but different onsets, native Dutch speakers did not respond faster in the homogeneous condition compared with the heterogeneous condition (Meyer, 1991). The null effects of later components were the same for both monosyllabic and disyllabic words. Similarly, the fore-knowledge of the first syllable can speed the production of disyllabic words whereas the fore-knowledge of the second syllable cannot (Meyer, 1990). An explanation for this finding is that phonological preparation may require the sequential assembly of phonological units, so that only the shared initial components are able to show a facilitative effect and other components cannot be prepared until the initial phonological unit has been produced. However, a recent study among native Mandarin-speaking adults showed different results. The shared rime of a set of monosyllabic Chinese word elicited a significant interference effect (Li, et al., 2014). The interference effect was explained as a result of lexical competition between rhyme neighbors.

A possible explanation for the inconsistency of the rime effects in Chinese and Dutch lies in the cross-linguistic differences and the selection of stimuli in the two studies. On one hand, Mandarin does not allow consonant clusters in a syllable whereas Dutch has a much richer set of onsets. In fact, words with consonant clusters as the onsets were included in Meyer (1991), such as *snoek* (pike) and *vloek* (curse). However, only single consonants are allowed as the onsets in Chinese. When words like *snoek* are involved in the task, the consonant clusters take two time slots instead of one before speakers proceed to the rime, which might allow them to have longer time for speech motor control between syllables.  On the other hand, the features of the onsets selected in the two studies may also contribute to the differences. Researchers (e.g., Bouchard, Mesgarani, Johnson, & Chang, 2013) suggested that consonants are categorized into three groups from the perspective of motor control: front-of-the-tongue sounds (e.g., /s/), back-of-the-tongue sounds (e.g., /g/) and lip sounds (e.g., /m/), and that consonants belong to the same category would lead to difficulty of speech motor control. Out of the three onsets in Li et al., two of them belonged to the same consonant category (i.e., /ʂ/ and /t/ are both front-of-the-tongue sounds). Therefore, speakers were likely to be influenced by the similarity of the consonants. In contrast, the five onsets selected in Meyer (1991) in the same rime list were /b/, /d/, /s/, /v/, and /h/, which belonged to all three onset articulation categories (i.e., lips, front-of-the-tongue, and back-of-the tongue). As a result, the variance among consonant sets in that study may have minimized the interference effect. Although Li et al. showed a rime effect, the interpretation of this effect lies in at the lemma level instead of the stage of phonological retrieval and encoding. Therefore, the results still do not imply that the rime is selected as the functional phonological unit for the native Mandarin speakers.

Thirdly, the benefit from the fore-knowledge of shared unit in the form preparation paradigm is driven by shared segmental information but not phonological features (Roelofs, 1999). When the initial phonemes of a set of words shared the same place of articulation and manner but differed in voicing (e.g., the three response Dutch words were ***p**auw,* ***b**ijl,* and ***b**oek*), participants did not show the significant facilitative effect. Similarly, no facilitation was observed when the initial phonemes of a set of words were the same in terms of manner and voicing but differed in the place of articulation (e.g., the three response words in Dutch were ***z**etel,* ***v**enus,* and ***v**ezel*). These results suggested that all the features of the segmental information are activated in a parallel fashion, and that the form preparation effects can be observed only when all the features of the initial segment are the same, namely the exact same segments.

Fourthly, the fore-knowledge of longer consecutive beginning segments of a set of words is able to increase the effect size of facilitation in a production task with the form preparation paradigm (Meyer, 1991). For example, a stronger facilitative effect was observed among native Dutch speakers when disyllabic words share the same initial syllable than when the words only shared the onset of the first syllable.

Lastly, the fore-knowledge of metrical properties alone such as number of syllables, primary stress location, or tonal information cannot benefit the preparation of spoken word production, although variability in these properties may reduce or minimize the benefits from the advance knowledge of initial segmental units (Chen, et al., 2002; Roelofs & Meyer, 1998). Nevertheless, the influence of these properties depends on exact property in the language. For example, knowing the number of syllable or the position of stress alone cannot benefit Dutch speakers' speech planning, but when a set of word shared the initial consonant but differ in the number of syllables within a word, Dutch speaker did not show significant facilitation (Roelofs & Meyer, 1998). In contrast, compared with the case in which the entire initial syllable was shared, native Chinese speakers showed smaller facilitative effect size when the initial syllable shared the same segments but differed in tone, but they still showed significant facilitation because of the fore knowledge of the initial syllable segment even if it is without a shared tone (Chen, et al., 2002). In summary, although the fore-knowledge of metrical properties led to different results across languages, there is a consensus in the literature that metrical properties are processed after functional phonological units are retrieved. Speakers fit phonological information to the metrical properties after phonological retrieval and encoding. Although the fore-knowledge of some metrical properties (e.g., lexical tone in Mandarin) may facilitate spoken word production, metrical properties are not independent planning units, and the benefit of this fore-knowledge occur after the stage of phonological retrieval and encoding (See O'Seaghdha, et al., 2010 and O'Seaghdha, 2015 for more discussion).

**The Influence of Orthography in the Form Preparation Paradigm**

Previous literature using the form preparation paradigm has suggested that the functional phonological unit differ across languages among literate adults. Native adult speakers of languages with alphabetic orthographies such as Dutch (Meyer, 1990, 1991) and English (O'Seaghdha et al., 2010) have been shown to benefit from the fore-knowledge of the initial phoneme, suggesting that the primary functional phonological unit in spoken word production in alphabetic languages is the phoneme segment. Native Japanese adult speakers benefit from the same initial consonant-vowel (CV) mora but not the same phoneme segment (Kureta et al., 2006), suggesting that CV mora may be the primary functional phonological unit in Japanese. Chen et al.

(2002) and O'Seaghdha et al. (2010) showed that native Mandarin adult speakers benefit from the same initial syllable segment but not from the same initial phoneme. Therefore, it is possible that the functional phonological unit is the syllable segment instead of the phoneme segment in Mandarin.

Interestingly, the functional phonological units in the aforementioned three groups of languages (i.e., English/Dutch, Mandarin, and Japanese) are also consistent with the orthographic forms of these languages. The phoneme segment is adopted in planning spoken words in languages with alphabetic writing systems, syllables are selected form languages with morphosyllabic systems, and mora is selected in languages with its moraic orthography. Here a natural question may be asked: Is it possible that the different orthographic forms contribute to the different functional phonological units across languages? Orthographic knowledge is not required in production, but it is possible that orthographic information influences spoken word production in literate speakers (Damian & Bowers, 2003). In order to investigate whether the explicit orthographic information in the form preparation paradigm influences the selection of the functional phonological unit, Chen and Chen (2013, Experiment 1) compared native Mandarin speakers' performance when the materials were presented in written form (i.e., visual Chinese character) or spoken form (i.e., auditory stimuli). Even when the stimuli were presented in spoken form which avoided the explicit orthographic information, participants still fail to show any benefit from the fore-knowledge of onset. Therefore, it is possible that retrieving and encoding phonological information in syllables is not due to the morphosyllablic feature of the visual character. However, Li et al. (2015) suggested that manipulation the orthographic form of the stimuli may change the selection of the functional phonological unit among native Mandarin speakers. Li et al. investigated the functional phonological unit among native Mandarin adult speakers when the Chinese words were written in different orthographic forms-the morphosyllabic Chinese character and alphabetic Pinyin, a Roman alphabetic system that transcribes the pronunciation of Chinese characters. Similar to Chen et al. (2002), O'Seaghdha et al. (2010), and Chen and Chen (2013), Chinese speakers did not benefit from knowing the onset of a set of words when the words were written in Chinese characters, but they showed a significant onset facilitation when the materials were written in Pinyin. These results suggested that the functional phonological unit might be influenced by the orthographic form in which the words are written: if the words are written in an alphabetic writing system, the functional phonological unit during the recall of these words may be small units such as phoneme onsets; if the words are written in a morphosyllabic writing system, the functional phonological unit may be syllables. Kureta, Fushimi, Sakuma and Tatsumi (2015) showed a similar pattern with Japanese speakers who demonstrated significant phoneme facilitation when participants learned materials in romaji (i.e., a phonetic system to write Japanese using the Latin alphabet). However, this phoneme preparation effect was not shown when materials were presented in an auditory task. The above results suggested that presenting visual materials in an alphabetic writing system may encourage speakers to attend to subsyllabic units that are explicitly represented in the orthography (see O'Séaghdha & Frazer, 2014 for the attentional theory), thus encouraging them to prepare spoken words in smaller units (i.e., the phoneme). Taken together all these findings, orthographic forms may serve as cue to encourage literate speakers to select different phonological units to construct a spoken word. It is likely that the native Mandarin-speaking adults prefer to retrieve and encode the phonological information in syllables in spoken word production as a default. However, the skilled readers are able to encode the phonological information flexibly since they have acquired knowledge of multiple orthographic systems (i.e., Pinyin and characters). In Pinyin, the explicit phonological information, sub-syllabic unit in particularly, allows the readers to shift their preference of larger units (e.g., syllable) to smaller units (e.g., onset segment) in planning spoken words.

Although the form preparation paradigm has been frequently used to investigate functional phonological units during spoken word production, it has several limitations. Firstly, as Li et al. (2015) suggested, the orthographic form of the visual materials may influence the selection of the functional phonological unit. Secondly, even without explicit orthographic information, it is not clear how participants associate the prompts and targets in the associate learning session. Although prompts and targets are usually semantically related words (e.g., *fruit* serves as the prompt while *melon* serves as the response word) in the classic form preparation paradigm, participants may make associations not only at the lemma level which involves semantic processing, but also at the lexeme level which involves phonological and orthographic processing. The associate-learning session may encourage participants to use orthographic feedback to facilitate memorization (Alario, Perre, Castel, & Ziegler, 2007). Using the form preparation paradigm with an associate learning session, Damian and Bowers (2003) showed that, the *Homogeneous Condition* in which the response words had both overlapped initial phoneme and the same initial letter (e.g., ***c****amel,* ***c****offee,* ***c****ushion*) produced significantly larger facilitation in comparison to the *Inconsistent Condition* in which the response words only shared the same initial phoneme but not the initial letter (e.g., ***k****ennel,* ***c****offee,* ***c****ushion*). In fact, the *Inconsistent Condition* did not show any significant facilitation at all. The difference in facilitation was also observed when the materials were presented aurally (i.e., no orthographic information was presented in either the learning session or the test session). These results suggested that orthographic information is automatically involved in the production task. However, in a picture naming task with the form preparation paradigm (i.e., the names of the pictures may be homogeneous or heterogeneous), the aforementioned difference between the *Homogeneous Condition* and the *Inconsistent Condition* disappeared (Alario, et al., 2007). In other words, the *Inconsistent Condition* also elicits significant phoneme onset facilitation with an effect size similar to that of the *Homogeneous Condition*. The discrepancy between the two studies suggested that speakers may take into consideration the spelling of words in the associate learning session to facilitate memorization, but not in a simple picture naming task which does not require memorization.

Nevertheless, this discrepancy may not provide evidence about whether orthographic form influences the functional phonological unit when it is not explicitly presented. In order to exclude the influence from associate learning session, Chen and Chen (2013, Experiment 2) used a simple picture naming task with the form preparation paradigm in which the associate learning session was removed, and showed that native Mandarin-speaking adults still could only benefit from overlapped initial syllable segment but not initial phoneme segment. Therefore, the researchers argued that syllable segment is the functional phonological unit in Chinese and this is an intrinsic property of the production system. In other words, the selection of syllable segment as the functional phonological unit is a consequence of the nature of the spoken language but is not influenced by the orthographic feature of Chinese.

**Other Related Paradigms**

In another study in which a picture naming task without the form preparation paradigm was used, it was shown that phoneme also plays a role in phonological retrieval and encoding during spoken word production (Qu, Damian, & Kazanina, 2012). Native Mandarin-speaking adults were instructed to name colored line drawings of objects using color adjective-noun phrases. The researchers examined participants' performance on producing a character after they have produced a prime which shares the same initial phoneme with the target character. In the picture naming task, the color and object name either shared the initial phoneme (e.g., ***h**uang2-**h**e2zi* 'yellow box', the number denotes the tone) or were phonologically unrelated (e.g., ***lü**4-**h**e2zi* 'green box'). Compared with the phonologically unrelated condition, participants showed more positive ERPs in the posterior regions 200–300ms and more negative ERPs in the anterior regions 300–400ms after picture onset when the color and object name shared the initial phoneme. The posterior ERP amplitude in the 200-300ms time window was explained as a result of facilitation due to phoneme repetition during phonological encoding, and the anterior ERP effect in the in the 300-400ms time window was interpreted as a result of internal speech monitoring which aims to avoid speech error. Participants did not show significant faster naming latency in the phonological related condition, and this is explained as a result that the negative effect in the self-monitoring stage cancelled off the facilitative effect due to phoneme repetition. In alphabetic language such as English, the phoneme-based facilitation may be very pervasive and is much stronger than the inhibitory effects due to self-monitoring, so that speakers still show facilitation as an overall effect.

In summary, Qu et al. (2012) suggested that the phoneme segment may play a fundamental role in phonological retrieval and encoding during spoken word production in Mandarin, although it does not mean that phonemes plays the exact same role during spoken word production in Mandarin and English. Nevertheless, one explanation of participants' sensitivity of phoneme is their experience with the alphabetic Pinyin orthography. All the aforementioned studies that investigated the functional phonological unit were conducted on adults who have rich orthographic experiences, and it is difficult to identify the influence of these orthographic experiences. Therefore, the current dissertation research will be conducted among children with different orthographic experiences and aims to investigate whether the different orthographic experience of alphabetic Pinyin and morphosyllabic Chinese character may influence the contribution of phonemes to spoken word production.

Another paradigm which can be used to investigate the functional phonological unit is the picture—word interference paradigm. Using this paradigm, Wong and Chen (2009) found that the phonological unit used in spoken word planning in Cantonese Chinese was smaller than syllable segment. Native Cantonese speakers were asked to name a series of pictures. The names of all the pictures were Cantonese mono-syllabic words with a consonant + vowel + consonant (CVC) structure (e.g., /sing1/, star), and the distractors were all visually presented with the target pictures. A syllable with CVC structure (e.g., cat) can be divided into onset /k/ and rime /æt/. Rime /æt/ can be further divided into two constituents, a nucleus /æ/, and a coda /t/. The combination of onset and the nucleus, /kæ/, is called body. Compared with the control condition (e.g., 阁, /gok3/), participants' picture-naming responses were faster when the target (e.g., /sing1/, star) and the distractor shared the same syllable segment (e.g., 城, /sing4/, "city"), the same body (e.g., 食, /sik6/, "eat"), or the same rime (e.g., 境, /ging2/, "region"). These results indicate that an effective phonological unit in Cantonese spoken word planning lies between phoneme and syllable segment. The findings in Cantonese may not be able to be applied to Mandarin. However, the study informed us that it might be necessary to employing a paradigm without an associate learning session among native Mandarin speakers to investigate their functional phonological unit.

The masked primed naming paradigm has been used to investigate functional phonological units as well (Chen, Lin, & Ferrand, 2003; Verdonschot, et al., 2011; You, Zhang,

& Verdonschot, 2012). In Verdonschot et al. (2011), when the primes (e.g., クイ, ***ku***-*i*) written in katakana overlapped in the whole initial mora with target words (e.g., くに, ***ku***-*ni*) written in hiragana, it significantly sped up native Japanese speakers' naming latency of the target words compared with the control condition (e.g., when ルイ, ***ru***-*i*, served as the control prime). Note that orthographic overlap was avoided since the shared mora was printed in hiragana for targets but in katakana for primes. However, the facilitation was not shown when only the initial phoneme was shared between the primes (e.g., かみ, ***k****a-mi*) and targets (e.g., くに, ***k****u-ni*). In addition, the facilitation was absent even when romaji (i.e., a phonetic system to write Japanese using the Latin alphabet) was used to present the visual stimuli (the primes were presented in romaji, and the targets were either presented in hiragana or romaji). You, et al. (2012) showed significant syllable facilitation in native Mandarin speakers in both word and picture primed naming tasks. Taken together, the aforementioned studies yielded consistent results similar to those that the form preparation paradigm, that mora and syllable are the functional phonological units in Japanese and Mandarin, respectively. However, inconsistent with Kureta et al., (2015) that showed significant onset phoneme facilitation in the form preparation paradigm when the stimuli were presented in romaji, Verdonschot et al. (2011) failed to show onset phoneme facilitation even when both primes and targets were presented in romaji. The difference might be due to the task difference. The masked primed naming task is a hybrid of perception and production task. Even though participants may not be aware of the masked prime, they still perceive it. Compared with the form preparation task, it requires participants to perceive the matching between primes and targets implicitly. Under time pressure for the perceptual matching, native Japanese speakers may fail to benefit from the overlap phonemes. In contrast, the form preparation paradigm is more like a true production task without the requirement of the perceptual matching, at least at the testing or naming session.

**Limitations and Improvements**

The discussion of aforementioned literature yield to a conclusion that, different paradigms and different tasks can be used to investigate the functional phonological unit in a language, and the results from these different paradigms have not reached an agreement about the role of different phonological units in phonological retrieval and encoding when planning spoken word production. Particularly, it is still not clear whether and how orthography influences phonological retrieval and encoding during spoken word production. Different task demands may lead to the various results. Even within the same paradigm such as the most frequently used one-the form preparation paradigm, some confound variables might be introduced depending on the participants or the design of a study. On one hand, in an associate naming task with the form preparation paradigm that involves explicit orthography, it is difficult to tease apart of the influence of orthography per se and attention. On the other hand, given that most of previous literature focused on adult participants only, it is challenging to exclude the influence of orthographic knowledge and experience on phonological retrieval and encoding. Skilled readers with extensive orthographic experiences may allow orthographic knowledge to reconstruct their phonological representations. It is possible that even a task that does not involve explicit orthographic information or require orthographic strategies (e.g., a simple picture naming task) still fail to prevent the influence of orthography on phonological encoding and retrieval. If the acquisition of orthographic knowledge restructure phonological representation, it is possible that it changes the functional phonological unit as well. Particularly, considering that skilled readers retrieve and manipulate the phonological unit of visual words when comprehending and memorizing print materials (see Crowder, 1982; Mann, 1986; Perfetti & McCutchen, 1982, Stanovich, 1982, for reviews), it is plausible that adults tend to select the phonological unit that is consistent with the orthography they are extensively exposed to (e.g., choose syllable for morphosyllabic writing system) even during spoken language processing which does not require orthographic knowledge.

In summary, it is still not clear whether and how orthography influence phonological retrieval and encoding during spoken word production, and particularly, studies on adults cannot exclude the possibility that the extensive orthographic experiences have already reconstructed speakers' phonological representation thus affecting their phonological retrieval and encoding, even in a production task which does not require orthographic knowledge. This observation motivates this dissertation, which aims to fill these gaps by examining the development of functional phonological units among participants from different age groups who have different orthographic experiences. Considering that the associate learning session in a classic form preparation paradigm may 1) encourage participants to use orthographic codes or strategies to facilitate memorization, and 2) be challenging for children because of its demands for short-term memory, a simple picture naming task without the associate learning session in the form preparation paradigm was utilized in the present dissertation. Since Chinese is selected as the target language, a discussion of its phonological and orthographic characteristics will be provided in the following section.

## The Characteristics of Chinese Phonology and Orthography

Unlike many languages such as English and Dutch that employ only one type of writing system, there are two different writing systems used in Mandarin Chinese. The Chinese character is morpho-syllabic, meaning each character corresponds to a morpheme and a syllable (e.g., the character 早 is a morpheme meaning early and only have one syllable /zɑʊ̯/), and phonological information is not explicitly represented in the orthography. Mandarin Chinese has a simple syllable structure. There are only two legal codas /n/ and /ŋ/, and consonant clusters such as /gl/ and /st/ which are common in English are not allowed. Re-syllabification does not occur in Mandarin Chinese. For example, the sound /s/ changes from a coda to an onset of the next syllable when the word *me**ss*** changes to its adjective form *messy* in English, but this phenomenon does not occur in Mandarin Chinese. There are only four possible syllable structures in Chinese: consonant + vowel (CV, such as /mā/, the symbol above the vowel is a tone marker, and the whole symbol is the Pinyin alphabets in Chinese, which will be introduced in details in the following paragraph), vowel only (V, such as /ā/), consonant + vowel + consonant (CVC, such as /mān/), and vowel + consonant (VC, such as /ān/). The analysis of the consonant + glide (CG) structure (e.g., [mjæ̃n], which means noodle) is controversial. Although it resembles a consonant cluster, it differs from the consonant cluster in English. For example, the [sw] sound is quite different in English (as in [swei], sway) and Mandarin Chinese (as in [swei], age), because [sw] sounds like two separate sounds in English whereas it sounds like a single sound, due to the fact that the rounding of [w] starts at the same time as [s] (Duanmu, 2007). Therefore, Duanmu (2007) suggested that the CG structure only takes one onset slot and should be written as $C^G$. Hence, a syllable with the $C^GV$ structure is included in the CV group in this review and the current study.

As a tonal language, the tone bearing unit in Chinese has been investigated by a number of researchers, and there is much debate on this topic in previous literature. Some researchers argued that tone is associated with rime (Chen, 1999; Ho & Bryant, 1997); Duanmu (2007) proposed that tone is associated with mora; and Xu (1998, 2004) suggested that tone spreads over the whole syllable. We believe that both adults and children tend to associate tone with the vowel rather than the entire syllable based on the recent literature that provided evidence that it is more difficult for participants to judge the tone of different syllables when the vowels differed (e.g., *ba2* and *bu4*) than when onsets differed (e.g., *ba2* and *ma4*) (Tong, Francis, & Gandour, 2008; Lin, Wang, & Shu, 2013).

Different from the scripts of alphabetic languages such as English, Chinese characters are logograms which are made up of strokes instead of letters (e.g., 大 (dà, *big*) is a character with three strokes). Strokes are combined to form radicals, which may signify the general semantic information (i.e., semantic radicals) or phonetic information (i.e., phonetic radical) of a character. A number of characters are phono-semantic compounds which are composed of a semantic radical and a phonetic radical. For example, in the character 湖 (hú, *lake*), the left radical 氵 is the semantic radical suggesting that this character is related to water, and the right radical 胡 (hú) serves as the phonetic radical to indicate the pronunciation. However, not all phono-semantic compounds are pronounced same as their phonetic radicals. For example, in the character 河 (hé, *river*), the phonetic radical 可 is pronounced as "kě" but not "hé". 江 (jiāng, *river*) and 红 (hóng, *red*) share the same phonetic radical 工, but the pronunciation of the two characters are very different. Therefore, phonetic radical is not always a good indicator of the pronunciation of a character. Previous literature suggested that the predictive accuracy of the pronunciation of a phono-semantic compound character from its phonetic radical is only about 40 percent (Shu, Chen, Anderson, Wu, & Xuan, 2003). In addition, numerous characters are pictograms or ideograms which do not have phonetic radicals. For example, 日 (rì, *sun*) is a pictogram which is derived from the picture of the sun. 上 (shàng, *up*) is a simple ideogram whose original shape is a dot above a line, and 休 (xiū, *rest*) is a compound ideogram refers to the situation that a person leans on a tree (it composes of the pictogram人, *person* and 木, *tree*). For these characters, it is difficult to deduce the pronunciation based on its orthography.

Pinyin is a Roman alphabet that transcribes the pronunciation of Chinese characters. Pinyin is a transparent system in which phonological information such as onsets, rimes, and tones are explicitly represented. In addition, Pinyin has strictly one-to-one letter-sound correspondence. All children in Mainland China in the first 10 weeks of Grade 1 (6-7 years old) are taught to read Pinyin before learning Chinese characters (Hanley, 2005). For example, the character "早" (early) is represented by Pinyin with the spelling "zăo." Its onset is "z," the rime is "ao," and the tone is marked above the vowel "ă." Children are instructed to articulate a syllable by pronouncing the onset and rime separately, and then combining them together (Wang & Gao, 2011). For example, children are taught to pronounce the syllable *mā* by repeatedly spelling it as: *m-ā-mā*. After acquiring Pinyin knowledge, children then receive instruction in characters with Pinyin printed on top of them, such as zǎo 早. In Pinyin instruction, when learning rimes with a nasal coda such as "ang", children are not told that these sounds can be further segmented into a vowel and a final consonant (e.g., "a" and "ng"). Therefore, the Pinyin instruction encourages children to segment a CVC syllable into an onset and a rime instead of an onset, a vowel and a coda.

## The Development of Phonological Processing in native Mandarin Speakers

The previous investigation of the development phonological processing abilities mainly focused the development of phonological awareness and its relationship to reading (e.g., Ho & Bryant, 1997; Hu & Catts, 1998; Huang & Hanley; 1995; Huang & Hanley, 1997; McBride-

Chang, Bialystok, Chong, & Li, 2004; McBride-Chang, et al., 2008; McBride-Chang & Ho, 2000; Siok & Fletcher, 2001; So & Siegel, 1997). A general developmental trajectory is that, as mentioned earlier in this review, the development of phonological awareness follows a hierarchical pattern from larger units (e.g., syllable) to smaller units (e.g., onset and rime). Particularly, the acquisition of Pinyin was found to play a role in the development of phonological awareness at onset-rime level. In other words, Chinese children's sensitivity to onset and rime units is related to the experience of learning Pinyin. For example, McBridge-Chang et al. (2004) compared the phonological awareness of children in kindergarten and Grade 1 from Xian (a city in Mainland China), Hong Kong, and Toronto in Canada, and an important finding is that Hong Kong children who were not taught to read Pinyin performed significantly worse than the children in Xian on both syllable and phoneme onset deletion tasks. This contrast suggested that Pinyin training that was given to children in Xian promoted the development of phonological awareness, and importantly, promoted the development at the level of a small phonological unit (e.g., onset). This is consistent with previous research that showed that Chinese children in Taiwan who were taught to use another phonological coding system (i.e., Zhu-yin-fu-hao which has an onset-rime division in its orthography) were significantly better at deleting phonemes from Chinese syllables than Hong Kong children (Huang & Hanley, 1995). A more recent study further showed that, in Mainland China, native Mandarin-speaking children's awareness of the onset phoneme improved significantly after Grade 1, largely due to children's exposure to Pinyin instruction (Shu, et al, 2008). Recall that an earlier study found that native Chinese-speaking adults who had not learned to read Pinyin performed significantly worse in adding and deleting onset phonemes compared with their counterparts who have learned Pinyin (Read, et al., 1986).

In summary, previous literature suggested that learning Pinyin can facilitate Chinese children to attend to phonological units smaller than syllable. Therefore, it is possible that the experience of learning Pinyin may encourage children to represent and process phonological information in onsets and rimes. In contrast, due to the morpho-syllabic nature of Chinese characters, native Mandarin speakers who have not learned Pinyin may be more likely to represent and process phonological information in syllables. Due to the experience with different writing systems (i.e., Pinyin and characters), the relationship between phonological processing abilities and literacy experience in native Mandarin-speaking children may be more complex than that in children who have been exposed to only one writing system (e.g., English). Unfortunately, few studies have been conducted to investigate this potentially complex relationship from the perspective of the development of functional phonological units among children. For children have multiple orthographic experiences within one language-Mandarin Chinese, what is their development trajectory of functional phonological units? The present study aims to find an answer to this question.

## Summary

The acquisition of orthographic knowledge has been suggested to influence children's phonological processing across different orthographies. This influence includes improved sensitivity to small phonological units (e.g., phoneme awareness) and better phonological memory. Orthography also influences phonological processing among literate adults and the orthographic consistency effect during spoken word recognition provides strong support for this observation. Most importantly, the segmentation of auditory sounds in literate children is consistent with the orthographic form they acquired (Inagaki, et al., 2000), and orthographic information encourages literate adults to select the phonological unit which is consistent with the orthographic from as the functional phonological unit. One possible mechanism underlying the orthographic consistency effect is that the acquisition of orthographic knowledge reconstructs or influences individual's phonological representations. The present dissertation aims to investigate how experiences with multiple orthographies influence the development of children's phonological representations, thus influencing phonological retrieval and encoding (e.g., the functional phonological unit). Orthographic experience includes both orthographic knowledge/skills and orthographic exposure, and it is difficult to tease apart orthographic knowledge and exposure cleanly. For example, readers with more orthographic exposure usually have better orthographic knowledge. In the present dissertation, both orthographic knowledge and orthographic exposure was measured among all participants. A simple picture naming task with the form preparation paradigm was adopted. For native Mandarin-speaking children, all children in the first 10 weeks of their first grade are taught to read Pinyin before learning Chinese characters (Hanley, 2005). The ratio of the number of Pinyin symbols vs. Chinese characters is about 1:1 in children's Chinese textbook. Children have acquired Pinyin knowledge but have very limited character knowledge. In the Grade 4 curriculum, children no longer received training on reading Pinyin, and Pinyin is rarely printed on top of the characters due to the growth of children's print vocabulary. Grade 4 children receive extensive training on character reading and have developed better character knowledge than Grade 1 children. The ratio of the number of characters vs. Pinyin symbols is about 80:1. Grade 2 children do not receive training in reading Pinyin either, and they are in the transition period where the ratio of their exposure to character vs. Pinyin is between Grade 1 and Grade 4 children (about 20:1). Adults are rarely exposed to Pinyin and they are highly proficient in character reading. Hence, adults served as the control group. The comparison among these four groups allows us to examine the development of the functional phonological unit in natural, authentic learning contexts, thus enhancing the ecological validity of the study.

Considering that 1) the acquisition of orthography enhances phonological awareness, 2) phonological segmentation develops from larger units to smaller units, 3) the instruction of Pinyin contributes significantly to the awareness of phoneme onset, and 4) explicit Pinyin symbols encourage adults to select onset as the functional phonological unit when producing the symbols, it is reasonable to expect that Grade 1 children would select the smaller phonological unit (e.g., onset) as the functional phonological unit during spoken word production due to 1) extensive training and exposure to Pinyin, and 2) the lack of proficiency in character reading. On the other hand, given that skilled readers retrieve and manipulate the phonological unit of visual words when comprehending and memorizing print materials (see Crowder, 1982; Mann, 1986; Perfetti & McCutchen, 1982, Stanovich, 1982, for reviews), literate readers may use the phonological unit that is consistent with the writing systems which they have extensive exposure to in daily life. Li et al. (2015) and Kureta et al. (2015) have shown that the functional phonological unit is consistent with orthographic form in which the lexical items are represented (i.e., onset for Pinyin symbol but not for Chinese character; phoneme segment for ramaji but not for auditory stimuli). As a result, it is possible that Grade 4 children and adults will use a larger unit (e.g., syllable) due to extensive exposure to Chinese characters. Taken into consideration adults' higher proficiency on character reading than Grade 4 children, it was expected that adults would have more stable representation of syllable, thus they may show larger effect size in facilitation when the stimuli share the same initial syllable during spoken word production. Grade 2 children are at the transition period, so it is possible that their functional phonological unit is started to be transited from onset to syllable segment.

These hypotheses are made based on the possibility that readers' functional phonological unit is subject to the characteristics of the orthography they are extensively exposed to. If the orthography represents a large unit, then the large unit will be selected as the functional phonological unit. If the orthography represents a small unit, the small unit will be selected. An alternative hypothesis is that, a small phonological unit (e.g., phoneme onset) still plays a role in phonological retrieval and encoding among Grade 2 children, Grade 4 children and adults. Read et al. (1986) suggested that the influence of Pinyin on phonological awareness persists for years, because they found that Chinese adults who have learned Pinyin are able to manipulate phonemes even though they do not use Pinyin during reading and writing in their daily life any longer. The ERP data in Qu et al. (2012) also showed the importance of phoneme segment in spoken word production. Therefore, it is possible that the small unit serves as the functional phonological unit for older children and adults.

The current dissertation research has both significant theoretical and practical implications. Theoretically, an important contribution of this proposed project is that it investigates the development of phonological processing skills from the perspective of phonological retrieval and encoding, namely, the functional phonological unit during spoken word production. Few studies investigated this perspective. Secondly, we investigate how literate speakers incorporate orthography in spoken word production. For the studies that have examined the functional phonological unit across different orthographies, most of them focused on adults with rich orthographic knowledge. However, once the orthographic knowledge is acquired, speakers may reconstruct their phonological representations under the influence of orthography. The proposed project fills this gap by investigating the functional phonological unit among four age groups (i.e., Grade 1 children, Grade 2 children, Grade 4 children and adults) who have different orthographic knowledge and experiences, thus can lead to a better understanding of the mechanism of children's development of phonological retrieval and encoding in spoken word production, and the influence of multiple orthographic experiences.

Practically, based on the findings of this project, teachers and educators will be able to develop more efficient educational methodology to improve children's development of phonological processing by combining children's phonological training and their orthographic experience. In addition, findings of this dissertation research may be helpful to children with language difficulties, particularly to those with speech disfluency or other speech-related difficulties. Identifying the influences of orthographic information on speech production may help them overcome difficulties in speech planning. Finally, this project may promote future research on related topics among children who have experience with multiple orthographies. The rapid globalization will lead to an increasing number of children to be exposed to multiple orthographies and languages. A continuation of this dissertation project is an investigation of bilingual children's phonological processing abilities and the influence of multiple orthographic experiences on bilingual phonological development.

## Chapter 3 - Experiment 1: Onset as the Functional Phonological Unit in Monosyllabic Words

This experiment was designed to investigate the functional phonological unit in producing monosyllabic words in Mandarin. O'Seaghdha et al. (2010) showed that onset failed to be selected as the functional phonological unit among native Mandarin speakers regardless of the word length in an associative naming task. Since the length of the words may influence the size of the functional phonological unit, the present dissertation started with the shortest word-the monosyllabic word in Mandarin. In particular, given that Chinese children are instructed to spell Pinyin in the way of *onset-rime-whole syllable* for monosyllables, it is particularly interesting to investigate if such Pinyin experience encourages children to select sub-syllabic unit (i.e., onset) as the functional phonological unit.

### Participants and Orthographic Experience Measures

Four groups of participants with normal or corrected-to-normal vision were recruited, including 1) 20 Grade 1 children at 7 years of age (8 males), 2) 20 Grade 2 children at 8 years of age (9 males), 3) 20 Grade 4 children at 10 years of age (9 males), and 4) 18 adult participants whose age ranged from 22 to 23 (6 males, Mean Age=22.28, SD= .46). All participants were native speakers of standard Mandarin. Child participants were recruited from a primary school in Tianjin, China. Adult participants were graduate students from a Mid-Atlantic University but had been in the U.S. no longer than 1 month.

Both orthographic knowledge and orthographic exposure were measured for all participants. For orthographic knowledge, a Pinyin reading test (Appendix A) and a character reading test (Appendix B) were conducted. As no standardized Pinyin reading test is available in Mainland China, the Pinyin reading task consisted of 48 Pinyin symbols that was constructed for the present study. In the Pinyin test, all the symbols have corresponding real homophone characters. The test included all possible syllable structures in Mandarin (i.e., simple CV, simple CVC, V, VC, CGV, and CGVC). All the participants were instructed to read the symbols one by one while their accuracy was recorded. If a symbol was read correctly, participants were given one point, otherwise no point was given. Therefore, participants could score a total of 48 possible points on the Pinyin reading task.

For the character-reading test, we adopted the character reading task that has been used in previous research (Li, Shu, McBride-Chang, Liu, & Peng, 2012). According to Li et al. (2012), the first 40 characters of the test were judged by two kindergarten teachers who suggested that the items were orally familiar to the kindergarten children and are formally taught in the first grade. The remaining 110 characters were judged by two primary school teachers to be orally familiar to primary school children. The 110 characters included 20 characters selected from the textbooks from each grade level Grades 2 to 6 and another 10 characters not included in the textbooks. The difficulty of the characters increased continuously from the first one to the last one. All participants were asked to read from the beginning and stopped when they failed to read 15 consecutive items. Again, only reading a symbol completely correct was given one point, so there were 48 total possible points for the Pinyin reading task. The number of characters that could be read correctly by a participant was his/her final score on this test. Both tests were paper based and used 24 font size for both the Pinyin symbol and the characters in order to ensure that participants could see each item clearly.

For orthographic exposure, parents of the participating children as well as the adult participants completed a questionnaire about participants' weekly experience with different orthographies (i.e., Pinyin, character, and others if any). The questionnaire included questions about both reading and writing/typing to obtain participants' information about their orthographic exposure. Sample questions for parents in the reading session included: 1) How many types of writing systems is your child able to read? (e.g., Pinyin, Chinese, or English), what are they? 2) For the readings that involve multiple writing systems, how is time distributed to those writing systems? Likewise, sample questions in the writing session include: 1) How many types of writing systems can your child write or type? (e.g., Pinyin, characters, or alphabets), what are they? 2) For each writing system, how much time does your child spend on writing using that system in a typical week? How much time does your child spend typing in that system in a typical week? (See Appendix C for the full questionnaire in Chinese and Appendix D for the English translation). The adult participants were asked to answer the same questions. For example, they were required to answer: 1) How many writing systems are you able to read? (e.g., Pinyin, Chinese, or English), what are they? 2) How many types of writing systems can you write or type? (e.g., Pinyin, characters, or alphabets), what are they?

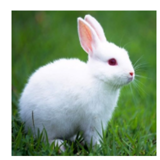
**Materials and Design**

A simple picture naming task with the form preparation paradigm was implemented. In the picture naming task, the names of all pictures were monosyllabic Mandarin words. During materials selection, ten native Mandarin-speaking adults were shown a total of 30 pictures and were asked to provide the first three monosyllabic names that came to mind to name a picture. Only those pictures that were named consistently using the same noun were selected as stimuli for the formal test (i.e., all the participants have the name in their list and at least seven of them used the same name as their first choice). Ten children from both Grade 1 and Grade 4 were also recruited to select picture names to ensure that children and adults did not name the pictures differently. In addition, this procedure also guaranteed that the final stimuli selected would be orally familiar to children by using the same criteria for selecting pictures among children as that used among adults. The final set of stimuli includes nine pictures, and individuals who were involved in picture selection did not participate in the formal experiment.

The names of the pictures consist of three sets of monosyllables with each having a different onset, the Pinyin symbol of each is *m* ([m]), *t* ([$t^h$]) and *sh* ([ʂ]), respectively. Each of the three onsets were selected such that they vary in both place and manner of articulation in order to minimize the possibility that the shared features of the onsets play a role in the form preparation effect. Each selected onset was used as the basis of a stimuli set that included three Items. The primary manipulation of the design, **Context**, is whether a list of pictures is homogeneous or heterogeneous. Each homogeneous list consists of three items that share the same onset, while each heterogeneous list consists of three items that share neither the onset nor the later component of the syllable (i.e., vowel + coda). There are three homogeneous lists and heterogeneous lists. For the items in a list, the tone is not controlled to be same or totally different across the three items (i.e., the three items in a list might carry totally different tones, or two out of the three shared the same tone while the remaining carried a different tone from them), considering that both adults and children tend to associate tone with the vowel rather than the entire syllable (e.g. Tong, et al., 2008; Lin, et al., 2013). In addition, in Pinyin presentation, because the tone marker is above the vowel, if Pinyin experience leads to an onset-rime division during the selection of functional phonological units, then the tone should be attached with the later component of the word that includes the vowel instead of the onset.

Each list of pictures had three presentation **Blocks**, in which the three picture items were presented four times (i.e., four **Repetitions**) in a random order. Table 1 shows the examples of homogenous list 2 with the onset *sh* and its corresponding heterogeneous list (see Appendix E for all the stimuli). Each list-pair consists of a homogenous list and a heterogeneous list, so the 6 lists compose 3 list pairs. Both the order of the three list pairs and the **Sequence** of contexts, a between-subjects factor, was counterbalanced across participants. Half of the participants in each age group received the homogeneous context first for each list pair, while the other half received the heterogeneous context first. Therefore, each participant received 216 trials in total (3 blocks × 2 contexts × 3 sets × 3 items × 4 repetitions).

*Table 1. Sample stimuli in Experiment 1*

| | | | |
|---|---|---|---|
| Homogeneous Condition | 蛇(shé, *snake*)<br> | 树(shù, *tree*)<br> | 勺(sháo, *spoon*)<br> |
| Heterogeneous Condition | 米(mǐ, *rice*)<br> | 勺(sháo, *spoon*)<br> | 兔(tù, *rabbit*)<br> |

*Note*. The first symbol in the parentheses is the Pinyin symbol of the corresponding character.

**Procedure**

Each participant was tested in a quiet room. Prior to the formal experiment, all of the picture stimuli were printed out and were shown to the participants. Participants were instructed to use monosyllabic words to name the pictures. If the name they provided was different from our target name, they were corrected, but these corrections occurred rarely. During the formal experiment, each trial began with a 1000-HZ warning tone and one fixation "+" presented at the center of the screen for 200ms. 600ms after the offset of the tone, the picture appeared at the center of the screen for 1,500ms or until a response was produced. The size of each picture was 300 × 300 pixels. Participants were instructed to name the picture aloud, as quickly and accurately as possible. The inter-trial interval was 200ms. The experimenter sat behind the participants and scored their naming accuracy. Throughout the experiment, participants received one point for every correct pronunciation and 0 point for an incorrect pronunciation or no response. There were six lists in the formal test, and participants had a break between every two lists. A practice session was conducted in which all nine items were presented twice in a random order (i.e., a total of 18 trials). The formal testing session began only after participants were familiar with the procedure and the materials (i.e., being able to provide the correct answer of each item within 1,000ms with no hesitation). Both the practice and formal test sessions were implemented using the DMDX software (Forster & Forster, 2003). The reading tasks and questionnaire were administered after the picture naming task.

**Hypotheses**

For orthographic knowledge, all four groups should show high accuracy rates in the Pinyin reading test. Grade 1 children are expected to show the lowest score in the character reading test, and the scores for Grade 2, Grade 4 children and adults are expected to increase successively. Regarding the orthographic exposure/experience (i.e., the questionnaire), Grade 1 children were expected to show much higher Pinyin:character ratio than other groups. For the picture naming task, Grade 1 children were expected to show onset facilitation, while Grade 4 children and adults were expected to fail to show any effect, since they have better character knowledge and are more exposed to characters. For Grade 2 children, if they have finished the transition from onset to syllable, they should also fail to show any onset effect; if not, they may also show onset facilitation. An alternative hypothesis is that all groups may show onset facilitation if the influence of Pinyin persists. Furthermore, Grade 1 children were expected to show a larger effect size of facilitation than Grade 2 children, while Grade 2 children were expected to show a larger effect size than Grade 4 children, who were expected to show a larger effect size than adults.

## Results

All analyses were carried out in R, an open source programming environment for statistical computing (R Development Core Team, 2008).

## The Picture Naming Task

The analyses for the picture naming task was carried out with the lme4 package (Bates, Maechler, Bolker, & Walker, 2013) and lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2013) for linear mixed effects modeling (LLM) and general linear mixed effects modeling (GLMM). Only response time (RT) data for correct responses were included in analyses. The data were removed if any of the following situations occured: hesitation, disfluency, or a correct answer failing to trigger the voice key. RT data that was smaller than 200 milliseconds were removed as well. Two Grade 2 children's data were removed from analyses due to high error rates in the picture naming task (higher than 30%). For the remaining subjects, all four groups achieved very high accuracy rates in the simple picture naming task: Grade 1 = 98.80%, Grade 2 = 99.30%, Grade 4 = 98.96%, and Adults = 99.77%. As a result of cleaning, the data that were removed from each of the four age groups were: 5.39% for Grade 1, 4.60% for Grade 2, 4.42 % for Grade 4, and 1.47% for Adults.

A statistically significant facilitative effect of the homogeneous context will be taken as evidence for using onset as the functional phonological unit during spoken monosyllabic word production because this result indicates that the speakers are able to benefit from the fore-knowledge of the unit. Context, Block and Sequence were entered in the model as fixed effects. Meanwhile, Subject and Item were entered as random slopes while Context was entered as the intercept. The interaction between Context and other variables will be taken as evidence that the form preparation effects are influenced by other factors (e.g., practice effect). Four models were constructed to examine the context effect in each of the four age groups. A new model was conducted when all participants' data were combined where a new model and Age Group was entered as a fourth fixed effect. For RT, all the data were log-transformed to improve normality. The linear mixed effect model entered in R for the analysis of RT for each age group was "LogRT ~ Context * Block* Seq + (1 +Context|Participant) + (1 +Context|Item)", and the more complicated model including for all participants was "LogRT ~ Context * Age * Block * Seq + (1 + Context|Participant) + (1 + Context|Item)". Sequence was labeled "Seq" and Age Group was labeled as "Age" in R for brevity. Accuracy rates were analyzed using a similar procedure to fit GLMM. The lmerTest could be applied to lmer model, so the results of the ANOVA approach (see Table 3 to Table 7) for the full models were provided for RT analysis. The full models were kept (i.e., no interaction terms were removed) to provide a comprehensive picture of the effects and a comparison among the four age groups. However, the lmerTest does not apply to the glmer model (the *p* values are not provided in the ANOVA test of a particular glmer model). In order to make the results easy to interpret, the interaction terms were removed one at a time from the full models until the models with the best goodness-of-fit using the Chi-square test.

***Accuracy Rate.*** Table 2 shows the mean naming latency and the standard deviations of different groups. For brevity, only the main effect of all fixed effects and the interactions between Context and other factors (e.g., Context and Block) are reported, considering that Context is the critical variable in the present study. When all groups are combined, the final reduced model was ACC~Age + Context + Block + Seq+ (1+Context|Participant) + (1+Context|Item). All children's groups showed a significantly lower accuracy rate than the adults group (For Grade 1 and Adults: $Z$= -3.809, $p$< .001; For Grade 2 and Adults, $Z$= -2.275, $p$= .023; For Grade 4 and Adults: $Z$= -3.000, $p$= .003). Importantly, Context did not show significant main effect or significant interactions with other variables ($p$s> .10), so all the interaction terms were removed.

*Table 2. Descriptive data of participants' performance in Experiment 1 with mean reaction time (M), error rates (E%), standard errors (SE), and preparation effects*

| Age Group | | Homogeneous | Heterogeneous (Control) | Preparation Effect (ms) |
|---|---|---|---|---|
| **Grade 1** | M | 672 | 691 | 19* |
| | E% | 1.34 | 1.06 | |
| | SE | 3.36 | 3.54 | |
| **Grade 2** | M | 679 | 682 | 3 |
| | E% | .92 | .46 | |
| | SE | 3.48 | 3.58 | |
| **Grade 4** | M | 657 | 650 | -7 |
| | E% | 1.16 | .93 | |
| | SE | 3.65 | 3.43 | |
| **Adults** | M | 595 | 596 | 1 |
| | E% | .25 | .21 | |
| | SE | 2.40 | 2.43 | |

* $p$< .05

The four models for different Age Groups were run as planned. For all the four groups, the final reduced model was ACC~Block + Seq +Context + (1+Context|Participant) + (1+Context|Item). In other words, for each group, Context did now showed significant interaction with any other variables ($p$s> .10). For Grade 1 children, in the final model, there was no significant main effect of Sequence or Context ($p$s> .10). However, compared with Block 1 (ACC= 99.4%), participants showed significantly lower accuracy rate in Block 2 (98.6%; $Z$ = -2.005, $p$ = .045) and Block 3 (98.4%; $Z$ = -2.407, $p$ = .016). The above difference might be due to a fatigue effect. For Grade 2 children, none of the three variables showed significant main effect in the final model ($p$s> .10). For Grade 4 children, neither Context nor Block showed significant effect in the final model (*p*s> .10). A significant Seq effect was shown: compared with those who received the control condition first (ACC= 98.2%), participants who received the homogeneous condition first showed higher accuracy rate (ACC= 99.6%, $Z$= 2.868, $p$= .004). For Adults, none of the three variables showed significant main effect in the final model (*p*s> .10). In summary, the most important result was not Context did not show any effect in the analysis of accuracy rate.

***Response Time.*** Combining all the four age groups (See Table 3 for the full results), the critical result was a significant Age × Context interaction ($F$ (3, 67.6) = 3.2894, $p$ = .0258). Also, the main effect of Age was significant ($F$ (3, 68) = 4.4944, $p$ = .0062), since the RTs of younger age groups were longer than those of older age groups (Grade 1: 682ms; Grade 2: 681ms; Grade 4: 654ms; Adults: 596ms). There was also a Block main effect ($F$ (2, 15550.2) = 10.1296, $p$ < .001) and a significant Block × Age interaction ($F$ (6, 15550.1) = 12.8338, $p$ < .001). Separate analysis for each age group was conducted, and the Block effect would be discussed in the separate analysis. All other main effects and interactions failed to show significant results.

*Table 3. Results of the ANOVA approach to the linear mixed-effect model analysis for all the four age groups in Experiment 1*

| | Sum Sq | Mean Sq | NumDF | DenDF | F.value | Pr(>F) |
|---|---|---|---|---|---|---|
| Block | 0.53369 | 0.26685 | 2 | 15550.2 | 10.1296 | 4.02E-05*** |
| Seq | 0.0107 | 0.0107 | 1 | 68 | 0.0691 | 0.7935 |
| Age | 0.36924 | 0.12308 | 3 | 68 | 4.4944 | 0.0062** |
| Context | 0.01786 | 0.01786 | 1 | 12.9 | 0.5362 | 0.4771 |
| Block:Seq | 0.15308 | 0.07654 | 2 | 15550.1 | 2.5244 | 0.0801 |
| Block:Age | 2.35311 | 0.39219 | 6 | 15550.1 | 12.8338 | 1.62E-14*** |
| Seq:Age | 0.10799 | 0.036 | 3 | 68 | 1.0565 | 0.3734 |
| Block:Context | 0.07446 | 0.03723 | 2 | 15550.1 | 1.2137 | 0.2971 |
| Seq:Context | 0.09427 | 0.09427 | 1 | 67.6 | 3.1172 | 0.0820 |
| Age:Context | 0.30108 | 0.10036 | 3 | 67.6 | 3.2894 | 0.0258* |
| Block:Seq:Age | 0.23241 | 0.03873 | 6 | 15550.1 | 1.2693 | 0.2677 |
| Block:Seq:Context | 0.01586 | 0.00793 | 2 | 15550 | 0.2774 | 0.7577 |
| Block:Age:Context | 0.21573 | 0.03595 | 6 | 15550 | 1.1652 | 0.3217 |
| Seq:Age:Context | 0.04856 | 0.01619 | 3 | 67.6 | 0.5276 | 0.6648 |
| Block:Seq:Age:Context | 0.11111 | 0.01852 | 6 | 15550 | 0.6055 | 0.7262 |

*Note.*: $p < .05$; **: $p < .01$; ***: $p < .001$*

The four models for different Age Groups were run as planned. Grade 1 children (Table 4) a significant 19ms form preparation effect (i.e., faster response time in the homogeneous lists) ($F$ (1, 15.5) = 5.1363, $p$ = .0381). Context did not show any interactions with any of the other variables ($p$s> .10).

*Table 4. Results of the ANOVA approach to the linear mixed-effect model analysis in Grade 1 children in Experiment 1*

| | Sum Sq | Mean Sq | NumDF | DenDF | F.value | Pr(>F) |
|---|---|---|---|---|---|---|
| Block | 0.129369 | 0.064684 | 2 | 4021.7 | 1.7172 | 0.1797 |
| Seq | 0.000295 | 0.000295 | 1 | 18 | 0.0041 | 0.9496 |
| Context | 0.185794 | 0.185794 | 1 | 15.5 | 5.1363 | 0.0381* |
| Block:Seq | 0.151449 | 0.075725 | 2 | 4021.8 | 2.0531 | 0.1285 |
| Block:Context | 0.139069 | 0.069535 | 2 | 4021.6 | 1.8997 | 0.1497 |
| Seq:Context | 0.014113 | 0.014113 | 1 | 18 | 0.3925 | 0.5389 |
| Block:Seq:Context | 0.019688 | 0.009844 | 2 | 4021.7 | 0.2708 | 0.7628 |

*Note.*: $p < .05$*

Grade 2 children (Table 5) showed a significant Block effect (*F* (2, 3653) = 7.2101, *p* < .001). Their RTs were faster in later blocks (Block 1: 690ms; Block 2: 678ms; Block 3: 674ms), probably due to a practice effect. However, Context did not show a significant main effect or interaction with any of the other variables (*p*s> .10)

*Table 5. Results of the ANOVA approach to the linear mixed-effect model analysis in Grade 2 children in Experiment 1*

| | Sum Sq | Mean Sq | NumDF | DenDF | F.value | Pr(>F) |
|---|---|---|---|---|---|---|
| Block | 0.50318 | 0.251589 | 2 | 3653 | 7.2101 | 0.0007*** |
| Seq | 0.0541 | 0.054098 | 1 | 16 | 1.5388 | 0.2327 |
| Context | 0.0065 | 0.006504 | 1 | 10.7 | 0.1729 | 0.6858 |
| Block:Seq | 0.19397 | 0.096983 | 2 | 3652.7 | 2.8118 | 0.0602 |
| Block:Context | 0.0863 | 0.043149 | 2 | 3652.7 | 1.2276 | 0.2931 |
| Seq:Context | 0.00057 | 0.000575 | 1 | 15.9 | 0.0171 | 0.8977 |
| Block:Seq:Context | 0.05 | 0.025 | 2 | 3652.6 | 0.7127 | 0.4904 |

*Note.***: p< .001*

Grade 4 children (Table 6) showed a significant Block effect (*F* (2, 4063.3) = 4.5531, *p* = .0106). Unlike Grade 2 children, their RT was slower in later blocks (Block 1: 645ms; Block 2: 652ms; Block 3: 663ms), probably due to a fatigue effect. Critically, Context did not show significant main effect or interaction with any of the other variables (*p*s> .10).

*Table 6. Results of the ANOVA approach to the linear mixed-effect model analysis in Grade 4 children in Experiment 1*

| | Sum Sq | Mean Sq | NumDF | DenDF | F.value | Pr(>F) |
|---|---|---|---|---|---|---|
| Block | 0.278821 | 0.139411 | 2 | 4063.3 | 4.5531 | 0.0106* |
| Seq | 0.054844 | 0.054844 | 1 | 18 | 1.3042 | 0.2684 |
| Context | 0.008166 | 0.008166 | 1 | 13.9 | 0.2621 | 0.6168 |
| Block:Seq | 0.052808 | 0.026404 | 2 | 4063.2 | 0.8653 | 0.4210 |
| Block:Context | 0.052623 | 0.026312 | 2 | 4063.4 | 0.8422 | 0.4309 |
| Seq:Context | 0.0151 | 0.0151 | 1 | 18 | 0.4872 | 0.4941 |
| Block:Seq:Context | 0.034826 | 0.017413 | 2 | 4063.3 | 0.5653 | 0.5683 |

*Note.*: p< .05*

Adults (Table 7) showed a significant Block effect as well ($F$ (2, 3768.6) = 49.771, $p$ < .001). Their RT was faster in later blocks (Block 1: 614ms; Block 2: 584ms; Block 3: 588ms), probably due to a practice effect. Context did not show significant main effect ($F$ (1, 12.4) = .042, $p$ = .8417). The only significant results involving Context was a significant interaction between Sequence and Context ($F$ (1, 15.9) = 7.070, $p$ = .0172). Participants showed a 12ms interference effect when they received a heterogeneous list first, whereas they showed a 10ms facilitative effect when a homogeneous list was given first. Nevertheless, neither the interference effect nor the facilitative effect reached significance (for the interference effect, $\chi^2$= 3.5352, $p$= .1202; for the facilitative effect, $\chi^2$= 2.4639, $p$= .1202).

*Table 7. Results of the ANOVA approach to the linear mixed-effect model analysis in Adults in Experiment 1*

| | Sum Sq | Mean Sq | NumDF | DenDF | F.value | Pr(>F) |
|---|---|---|---|---|---|---|
| Block | 1.91473 | 0.95737 | 2 | 3768.6 | 49.771 | 2.00E-16*** |
| Seq | 0.00476 | 0.00476 | 1 | 16 | 0.034 | 0.8570 |
| Context | 0.00081 | 0.00081 | 1 | 12.4 | 0.042 | 0.8417 |
| Block:Seq | 0.00783 | 0.00391 | 2 | 3768.5 | 0.208 | 0.8119 |
| Block:Context | 0.02877 | 0.01438 | 2 | 3768.6 | 0.748 | 0.4733 |
| Seq:Context | 0.13587 | 0.13587 | 1 | 15.9 | 7.070 | 0.0172* |
| Block:Seq:Context | 0.01607 | 0.00803 | 2 | 3768.6 | 0.418 | 0.6584 |

*Note.*: p< .05;***: p< .001*

**Orthographic Experience**

Table 8 shows the descriptive statistics of the reading tasks and the exposure to different writing systems, English is the only other writing system that participants are exposed to in addition to Pinyin and Chinese characters. Therefore, there are only three writing systems involved in the table: Pinyin, Chinese characters and English.

*Table 8. Mean scores and standard deviation (in parentheses) for the two reading tasks and average language exposure information (hours/week) for the participants in Experiment 1*

| | | Grade 1 | Grade 2 | Grade 4 | Adults |
|---|---|---|---|---|---|
| Pinyin reading score | | 45.25 (2.34) | 44.22 (2.34) | 43.75 (3.06) | 45.39 (2.95) |
| Character reading score | | 78.20 (24.63) | 90.78 (18.78) | 122.70 (12.96) | 139.72 (3.86) |
| Language Exposure (reading) hours/week | Pinyin | 4.40 (2.61) | 0.77 (0.50) | 0.44 (0.54) | 0 (0) |
| | Chinese character | 9.27 (5.76) | 11.19 (4.27) | 20.27 (7.74) | 29.97 (18.29) |
| | English | 3.39 (2.16) | 3.97 (3.72) | 6.70 (3.60) | 12.17 (9.15) |
| Language Exposure (writing) hours/week | Pinyin | 1.51 (0.84) | 0.49 (0.44) | 0.43 (0.57) | 0 (0) |
| | Chinese character | 3.56 (1.72) | 10.78 (9.38) | 10.70 (8.77) | 5.64 (4.39) |
| | English | 0.63 (1.35) | 1.63 (2.66) | 4.30 (2.83) | 3.63 (4.44) |
| Language Exposure (typing) hours/week | Pinyin | 0.15 (0.67) | 0.02 (0.12) | 0.45 (0.84) | 11.69 (12.09) |
| | Chinese character | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| | English | 0 (0) | 0 (0) | 0.15 (0.67) | 3.86 (2.92) |

A one-way ANOVA was conducted for both the reading tasks and participants' Pinyin:Character exposure ratio in reading and writing. In terms of typing, the three child groups rarely type in any writing system while adults type Chinese in Pinyin frequently (11.69 hours per week), which made the comparison among the four groups obvious. For the pinyin reading task, analysis failed to show a significant difference across the four groups ($F$ (3,72) = 1.6762, $p$= .1797). For character reading, a significant Age main effect was shown ($F$ (3,72) = 52.094, $p$< .001). Post-hoc analysis suggested that Adults' score was significantly better than Grade 1 children ($p$< .001), Grade 2 children ($p$< .001), and Grade 4 children ($p$= .016). Grade 4 children's score was also significantly better than that of Grade 1 children ($p$< .001) and Grade 2 children ($p$< .001). The comparison between Grade 1 and 2 did not show any significant result.

In terms of the Pinyin:character exposure ratio in reading, a significant Age main effect was shown ($F$ (3,72) = 55.946, $p$< .001). Grade 1 children's relative Pinyin exposure was significantly longer than that of all the three groups ($p$s< .001). Finally, for the Pinyin:character exposure ratio in writing, again, a significant Age main effect was shown ($F$ (3,72) = 19.547, $p$< .001). Grade 1 children's relative Pinyin exposure was significantly longer than that of Grade 2 children ($p$< .001), Grade 4 children ($p$< .001), and Adults ($p$< .001). No other significant difference was shown in any pairwise comparison.

Since the four groups showed significant difference in character knowledge and relative Pinyin exposure in reading and writing, an additional linear mixed effect model for the RT data was conducted, in which character knowledge (Chk) and relative Pinyin exposure in reading (PR) and writing (PW) were included to investigate the relationship between orthographic experiences and the context effect for the four age groups. Given that the number of fixed effects was large, a reduced model instead of full model was reported here, in which the insignificant interaction items were removed until the model with the best goodness-of-fit using the Chi-square test was reached. The final reduced model was: LogRT~ Block + Seq + Age + Context + Chk + PR + PW + PR:Context +Block:Age + Block:Seq + Seq:Context + (1+Context|Subject) + (1+Context|Item). Importantly, the Age*Context interaction was replaced by PR* Context interaction ($F$ (1,73.8) = 7.5234, $p$= .00764). See Figure 1 for the PR*Context interaction and Table 9 for the full result. The analysis within each Age Group did not show clear relationship between orthographic experiences and Context effect, thus was not reported here.

*Table 9. Results of the ANOVA approach to the linear mixed-effect model analysis for all groups when orthographic experiences were included as fixed effects*

| | Sum Sq | Mean Sq | NumDF | DenDF | F.value | Pr(>F) |
|---|---|---|---|---|---|---|
| Block | 0.53365 | 0.26682 | 2 | 15572.1 | 10.0992 | 4.14E-05*** |
| Seq | 0.00901 | 0.00901 | 1 | 68 | 0.0509 | 0.82214 |
| Age | 0.35905 | 0.11968 | 3 | 68 | 1.3823 | 0.25563 |
| Context | 0.01793 | 0.01793 | 1 | 16.1 | 0.0528 | 0.82107 |
| PR | 0.00455 | 0.00455 | 1 | 68.5 | 0.2156 | 0.64387 |
| PW | 0.0002 | 0.0002 | 1 | 68 | 0.0017 | 0.96765 |
| Chk | 0.00735 | 0.00735 | 1 | 68 | 0.2372 | 0.62779 |
| Context:PR | 0.20873 | 0.20873 | 1 | 73.8 | 7.5234 | 0.00764** |
| Block:Age | 2.36005 | 0.39334 | 6 | 15572.1 | 12.8308 | 1.63E-14*** |
| Block:Seq | 0.14707 | 0.07353 | 2 | 15572.1 | 2.407 | 0.09012 |
| Seq:Context | 0.11593 | 0.11593 | 1 | 72.6 | 3.7909 | 0.0554 |

*Note.* **: $p < .01$; ***: $p < .001$

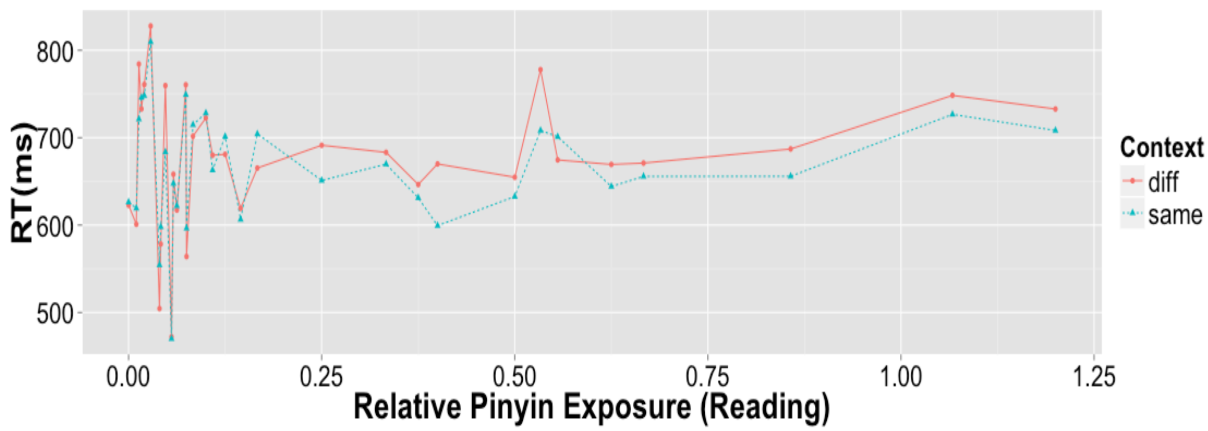



**Figure 1 The effects of Relative Pinyin Exposure (Reading) and Context on speakers' naming latency in Experiment 1.**

**Discussion**

Consistent with the prediction, only Grade 1 children showed significant onset facilitation in Experiment 1, suggesting that onset serves as the functional phonological unit in monosyllabic spoken word production in Grade 1 children. The reading tests and the results of the questionnaire were also consistent with the prediction, that the Pinyin: character exposure ratio in Grade 1 children is significantly larger than all the other groups.

**Onset as the Functional Phonological Unit**

Grade 1 children showed significant onset facilitation as the main effect of Context. More importantly, Context did not show an interaction with Sequence, suggesting that the sequence that the subject received the homogeneous and heterogeneous lists did not have an influence on the context effect. Also, Context did not show an interaction with Block, suggesting that the context effect is not a simple repetition effect—it was presented from the first block.

All the other groups failed to show any significant onset effect. For Grade 2 and Grade 4 children, Context did not show a significant interaction with any other variables. The absence of interaction between Context and Sequence in Grade 2 and Grade 4 children suggested that the children failed to benefit from the fore-knowledge of the onset whether or not they received the homogeneous lists first. The absence of an interaction between Context and Block suggested that even repetition or more practice did not make them benefit from the fore-knowledge of the onset. Adults' results were consistent with previous findings (O'Seaghdha, et al., 2010) that onset is not selected as the functional phonological unit in native Mandarin-speaking adults. Adults showed a significant interaction between Sequence and Context, and the post-hoc analysis suggested that this might be a result of a simple fatigue effect, since the RT of the context that was received later was always around 10ms longer than that of the context received first. In addition, the Context effect in neither Sequence reached significance, thus failing to provide evidence about onset facilitation or inhibition. The interaction between Sequence and Context suggested that the fatigue effect was present between lists; however, the Block effect suggests that a practice effect was present within each list. Overall, the comparison across the four age groups suggested that onset serves as the functional phonological unit in native Mandarin-speaking children at Grade 1, but that effect disappears in Grade 2 children and older literate speakers.

**The Influence of Orthographic Experience**

The analyses of participants' orthographic experience suggested that Grade 1 children's relative Pinyin exposure (i.e., Pinyin: Chinese character ratio) through each week was significantly higher than older children and adults. Compared to Pinyin knowledge and character knowledge, relative Pinyin exposure might be a more important factor that contributed to the selection of onset as the functional phonological unit in Grade 1 children. Since the four groups did not show significant difference in Pinyin knowledge but differed in character knowledge and orthographic exposure, we decided to include the character knowledge, relative Pinyin exposure in reading and writing in a new linear mixed effect model in which all the four groups were involved. Interestingly, the Age * Context effect was not significant any longer, but the interaction of relative Pinyin exposure in reading and Context reached significance. Figure 1 suggested that, when Pinyin:character ratio is large (e.g., >.25), participants consistently showed onset facilitation. In contrast, when the ratio is small (e.g., < .25) no clear trend was shown. According to the descriptive statistics, Grade 1 children were the group that had larger Pinyin: character ratio. To sum up, the different selection of functional phonological unit among the age groups was more likely to be a result of orthographic experiences rather than age/grade/maturation. An additional finding is that, since the relationship between orthographic experiences (including knowledge and exposure) and the Context effect was not clear in the new model, the selection of functional phonological unit may follow an all-or-none principle: once the orthographic experiences reach certain threshold, the size of the form preparation effect will not change according to orthographic experiences.

Two reasons may lead to Grade 1 children's more relative Pinyin exposure: firstly, Grade 1 children were required to read and write Pinyin every day as a part of their coursework, as Chinese teachers from the primary school suggested. Secondly, Grade 1 children also have limited character knowledge, as shown by the fact that their character reading score was significantly lower than Grade 4 children and adults, and was lower, although not significantly, than Grade 2 children. As a result, Grade 1 children need to rely on Pinyin in learning to read characters and need to read the corresponding Pinyin symbols of new characters to learn each character's pronunciation. As suggested earlier, Pinyin is an alphabetic writing system that encourages onset-rime division. Therefore, the relatively more extensive exposure to Pinyin and their reliance on Pinyin may encourage Grade 1 children to represent phonological information in an onset-rime format (following the orthographic feature of Pinyin) and also encode phonological information in an onset-rime format in spoken word production even though orthography is not required. From Grade 2, their Chinese literacy homework did not include Pinyin anymore, and they only read Pinyin when they came across new characters. As a result, their relative Pinyin exposure is significantly less than Grade 1 children. Grade 2 children's character and Pinyin reading scores were not significantly higher than Grade 1 children's, but the onset facilitation disappeared in Grade 2 and was not shown in older readers either. Therefore, consistent with the results based on the model when orthographic knowledge and relative Pinyin exposure were included as fixed effects, it is likely that orthographic exposure plays a more important role than orthographic knowledge in the selection of functional phonological unit.

Another fact that supports the above claim is that adults have better Pinyin knowledge (although not significant) than children but they still failed to show onset facilitation. The reaction time of the Pinyin reading task was not measured, because more than 90% of the Grade

1 children need to spell out each Pinyin syllable in the way of onset-rime-whole syllable (e.g., *m-ā-mā*). In contrast, all adults can pronounce the Pinyin symbols readily without spelling them out. With similar scores, adults completed the Pinyin reading task much more smoothly. Previous literature (e.g., Read et al., 1986) suggests that Chinese adults who have learned Pinyin were able to perform the phoneme segmentation task readily and accurately, suggesting a well-developed phonemic awareness. In other words, skilled readers were able to attend to and manipulate sounds at the phonemic level, and their rich character knowledge and exposure to Chinese characters did not make this ability disappear. Yet, when retrieving and encoding phonological information during spoken word production, skilled readers who have relatively higher exposure to Chinese characters may tend to select a larger unit (e.g., syllable segment) as an integral unit, according to previous literature (e.g., Chen & Chen, 2013).

In the present study, all the participants have been exposed to English that has an alphabetic writing system. The phoneme has been shown to be the functional phonological unit in native English speakers (O'Seaghdha, et al., 2010) and Chinese-English bilinguals (Verdonschot, et al., 2013). In addition, Verdonschot et al. has suggested that English experience may influence the functional phonological unit in Chinese among highly proficient Chinese-English speakers. In a masked primed visual word-naming task, Chinese ESLs (native **Chinese** speakers who speak **E**nglish as a **S**econd **L**anguage) with high English proficiency showed significant onset facilitation in English. Namely, when the visual prime (e.g., bark) shared the same phoneme onset with the visual target (e.g., BENCH), Chinese ESLs showed a significantly faster response when naming the visual word BENCH compared with a control condition (e.g., the prime is *dark* that does not share any phonological unit with the target word). Additionally, when the visual Chinese prime and visual Chinese target shared the same syllable structure (e.g., Consonant + Vowel) and share the same onset (e.g., 逼 /bi1/-八 /ba1/), the Chinese ESLs also showed significant onset facilitation in their native language Chinese. However, the results of the current Experiment 1 suggested that the experience of English learning did not influence the functional phonological unit in Chinese, since even the adult group that had at least 12 years experience of English learning and the highest English proficiency level (all of them had 100 out 120 in TOEFL test) failed to show onset facilitation. Note that all the three items in a homogeneous list also shared the same syllable structure (i.e., Consonant + Vowel) in the present study.

Finally, adults spent more than 10 hours on typing Pinyin each week whereas all other groups spent less than 1 hour per week. Although typing in Pinyin encourage adults to separate sub-syllabic units (i.e., onset, nucleus, and coda), this experience did not encourage them to attend to sub-syllabic units in spoken word production. Yet, if participants were required to type in a phonology-based input method, they were able to select sub-syllabic unit as the functional phonological units. For example, Chen and Li (2011) investigated native Mandarin speakers' (Taiwan) word form encoding in different output format. When the target visual character (e.g., 桃 /tao2/, peach) and the visual prime (e.g., 泰 /tai4/, Thai) shared the same onset, participants only showed the form preparation effect (i.e., facilitation) when being asked to type the visual target in Zhu-yin-fu-hao, a system of phonetic notation for the transcription of spoken Chinese that is similar to Pinyin and specifies sub-syllabic units (i.e., onset, rhyme) in its orthography (e.g., ㄊㄠ is the Zhuyin symbol of 桃 /tao2/, peach). However, the onset facilitation was not shown when participants were asked to name the target character. Similar findings have been shown in Chen and Chen (2012) when the form preparation paradigm was implemented and disyllabic words were served as the target stimuli.

Combining the results of Experiment 1 and previous studies, it might be true that typing in a phonology-based input method (e.g., Zhu-yin-fu-hao or Pinyin) encourages native Mandarin-speaking adults to encode monosyllabic Chinese words in sub-syllabic units (e.g., onset), but this encoding format may only apply to typing, this particular output format. It is possible that extensive exposure to a writing system in reading and writing at school age can reconstruct speakers' phonological representation in general (e.g., Grade 1 children represent phonology in sub-syllabic units) thus affecting phonological retrieval and encoding in spoken word production. However, extensive typing experience in adulthood can only influence the word form encoding in typing, since the phonological representation may have been formed in a stable status in adults.

In summary, within the same language, Chinese, more extensive exposure to Pinyin may encourage Grade 1 children to select onset as the functional phonological unit in producing monosyllabic words. However, the increasing exposure to Chinese characters may encourage native Mandarin speakers to attend to larger units as early as Grade 2. Note that extensive exposure to a particular writing system in typing in adulthood does not influence the selection of the functional phonological unit in spoken word production.

## Chapter 4 - Experiment 2: Onset as the Functional Phonological Unit in Disyllabic words

This experiment was designed to investigate the functional phonological unit in production of disyllabic words. Particularly, the functional phonological unit among Grade 1 children was examined. He and Li (1987) showed that among the 3,000 most common Chinese characters, 69.8% are disyllabic words whereas only 27.0% are monosyllables. In disyllabic words, there is a clear boundary between the two characters (i.e., the two syllables). Therefore, Experiment 2 was designed to investigate whether the onset is still selected as the functional phonological unit among Grade 1 children in disyllabic words, the most common type of words in Chinese. Another factor to be considered in Experiment 2 is whether or not it can demonstrate the reliability of the absence of onset effects in other age groups. Meyer (1991) suggested that word length should not influence the functional phonological unit used in planning spoken word production in Dutch. If this is also the case for Chinese, the results of Experiment 2 should be similar to those in Experiment 1, where only Grade 1 children show onset facilitation.

### Participants and Orthographic Experience Measures

Four age groups of participants from the same subject pool as Experiment 1 were recruited, including 1) 20 Grade 1 children at 7 years of age (10 males), 2) 18 Grade 2 children at 8 years of age (12 males), 3) 20 Grade 4 children at 10 years of age (7 males), and 4) 18 adult participants whose age ranged from 21 to 25 (4 males, Mean Age=22.33). None of the participants that participated in Experiment 1 participated in Experiment 2. The tests and questionnaire used to measure orthographic knowledge and exposure were same as those used in Experiment 1.

**Materials and Design**

The procedure to select the stimuli for the picture naming task was the same as the one used in Experiment 1. First, ten native Mandarin-speaking adults were asked to name 30 pictures using disyllabic words using the first three disyllabic words in their mind to name each picture. Only the pictures that were named consistently using the same noun were selected as stimuli for data collection (i.e., all the participants have the name in their list and at least seven of them use the same name as their first choice). Six children from Grade 1 and seven children from Grade 4 were recruited for the next step for selecting picture names in case children and adults may show different preferences in picture naming. Only pictures that were named consistently by the two groups of children were selected (i.e., for each age group, all of the children had the name in their list and at least three of them used the name as their first choice). In the end, nine pictures were selected as final stimuli to be used in data collection. Similar to Experiment 1, a simple picture naming task was conducted with the same design as the one used in Experiment 1. For the critical independent variable, **Context**, the items shared the onset of the first syllable in the homogenous condition and the items did not share anything systematically in common in the heterogeneous condition. The onset of the three sets of items were *h* ([x]), *sh* ([ʂ]), and *m* ([m]), respectively (each onset group has three items). Table 10 shows the sample stimuli of the set *sh* and the corresponding heterogeneous list (see Appendix F for all the stimuli in each list). Compared with Experiment 1, additional factors were controlled during the selection of stimuli for each list. First, within a list (for both homogeneous and heterogeneous lists), words were selected such that the second syllable of picture items would not be shared. Second, within a list, pictures were selected such that the second syllable of the corresponding word for one picture item should not share any phonological units with the first syllable of any other items.

*Table 10. Sample stimuli in Experiment 2*

| | | | |
|---|---|---|---|
| Homogenous Condition | 树叶(shù-yè, *leaf*)<br> | 狮子(shī-zi, *lion*)<br> | 手套(shŏu-tào, gloves)<br> |
| Heterogeneous Condition | 树叶(shù-yè, *leaf*)<br> | 核桃(hé-tao, *walnut*)<br> | 帽子(mào-zi, *hat*)<br> |

*Note*. The first symbol in the parentheses is the Pinyin symbol of the corresponding word.

**Procedure**

The procedure was exactly same as that in Experiment 1.

**Hypotheses**

In Experiment 1, only Grade 1 children showed significant onset facilitation. It was hypothesized that Grade 1 would also be the only group that shows an onset effect in Experiment 2. Similar to Experiment 1, an alternative hypothesis was that all groups would show onset facilitation since the influence of Pinyin may persist. If so, the effect size should be largest in Grade 1 children and smallest in adults. A third possibility was that all groups would fail to show onset facilitation. There is always space between two visual characters in Chinese. In addition, when Pinyin is printed without characters beside or below it, there is also space between two syllables (e.g., shù yè, *leaf*). Such a space may make it easy for readers to determine the boundaries between syllables for both Pinyin and characters. Therefore, it is possible that these clear boundaries induce children to attend to the syllable unit, and as a result, children select the syllable instead of the onset as the functional phonological unit when producing disyllabic words.

## Results

### The Picture Naming Task

***Accuracy Rate.*** The procedure of data cleaning and analyses were same as those used in Experiment 1. All four groups achieved very high accuracy rates: Grade 1= 98.89%, Grade 2= 98.51%, Grade 4= 98.98%, and Adults= 99.59%. As a result of cleaning, the data that were removed from the four age groups were: 5.25% for Grade 1, 5.35% for Grade 2, 3.54 % for Grade 4, and 1.77% for Adults. Table 11 shows the mean naming latency and the standard deviations of different groups. Again, for brevity, only the main effect of all fixed effects and the interactions between Context and other factors are reported. Similar to Experiment 1, when all groups are combined, the final reduced model was ACC~Age+Context+Block+Seq+ (1+Context|Subject) + (1+Context|Item), and all children groups showed significantly lower accuracy rate than the adults group (For Grade 1 and Adults: $Z = -2.686$, $p = .007$; For Grade 2 and Adults, $Z = -3.429$, $p < .001$; For Grade 4 and Adults: $Z = -2.189$, $p = .029$). Importantly, Context did not show significant main effect or significant interactions with other variables ($p$s$> .10$), so all the interaction terms were removed.

*Table 11. Descriptive data of participants' performance in Experiment 2 with mean reaction time (M), error rates (E%), standard errors (SE), and preparation effects*

| Age Group | | Homogeneous | Heterogeneous (Control) | Preparation Effect (ms) |
|---|---|---|---|---|
| **Grade 1** | M | 714 | 734 | 20* |
| | E% | 1.34 | .88 | |
| | SE | 4.00 | 4.16 | |
| **Grade 2** | M | 690 | 682 | -8 |
| | E% | 2.00 | .98 | |
| | SE | 3.91 | 3.85 | |
| **Grade 4** | M | 650 | 650 | 0 |
| | E% | 1.20 | .83 | |
| | SE | 3.11 | 2.96 | |
| **Adults** | M | 633 | 627 | -6 |
| | E% | .62 | .21 | |
| | SE | 2.96 | 2.92 | |

* $p < .05$

The four models for different Age Groups were run as planned. For Grade 1 children, the final reduced model was ACC~Block + Seq *Context + (1+Context|Subject) + (1+Context|Item). There was a significant interaction between Seq and Context ($Z = -2.202$, $p = .027$). For the children who received the homogeneous condition first, participants showed lower accuracy rate in the homogeneous condition (98.2%) than the control condition (99.3%); for the children who received the control condition first, they showed higher accuracy rate in the homogeneous condition (99.2%) than the control condition (98.9%). The above results suggested that children tended to show higher accuracy rate in the condition that they received later. Therefore, it might be related to a practice effect. Consistently, they also showed higher accuracy rates in later blocks (98.7% for Block 1, 98.9% for Block 2, 99.9% for Block 3), though not significant (for pairwise comparison between blocks, *p*s> .10).

For Grade 2 children, the final reduced model was ACC~Block + Seq +Context + (1+Context|Subject) + (1+Context|Item). In other words, Context did not show significant interaction with Block or Seq. In addition, none of the three variables showed significant main effect in the final model (*p*s> .10).

For Grade 4 children, the final reduced model was ACC~Block * Context +Seq + (1+Context|Subject) + (1+Context|Item). The most important result was that, when comparing Block 1 and Block 2, there was a significant interaction between Block and Context ($Z$= 2.299, $p$= .022). Participants showed onset inhibition in Block 1 (1.1% lower accuracy rate in the homogeneous condition; for the homogeneous condition, ACC= 98.6%; for heterogeneous condition, ACC= 99.7%) but facilitation in Block 2 (0.6% higher accuracy rate in the homogeneous condition, for the homogeneous condition, ACC= 99.2%; for heterogeneous condition, ACC= 98.6%). In Block 3, participants showed onset inhibition again, but the effect size was smaller than that in Block 1 (for the homogeneous condition, ACC= 98.6%; for heterogeneous condition, ACC= 99.2%). Another significant result was that, participants who received the homogeneous condition first showed 1.2% higher accuracy rate the those who received the control condition first ($Z$= 1.988, $p$= .047). In summary, the Context effect was not robust and did not show consistent trend in the three blocks. The inconsistency might be related to a mixed effect of practice and fatigue. More investigation in RT analysis is needed.

For Adults, the final reduced model was ACC~Block + Seq +Context + (1+Context|Subject) + (1+Context|Item). In other words, Context did not show significant interaction with Block or Seq. In addition, none of the three variables showed significant main effect in the final model (*p*s> .10).

In summary, Context did not show any significant effect among Grade 2 children and adults in the analysis of accuracy rate. Although it showed some interactions among Grade 1 and Grade 4 children, no consistent facilitative or inhibitory effect was shown. For example, the direction of the Context effect was opposite for different Sequence among Grade 1 children, and it was also opposite for Block 1 and Block 2 among Grade 4 children. Further investigation on RT is needed to reach a reliable conclusion.

***Response Time.*** The RTs were log-transformed and analyzed in the same way that we used in Experiment 1. Combining all the four age groups (See Table 12 for the full results), the critical result was a significant Age × Context interaction ($F$ (3, 66.7) = 6.346, $p$< .001). Age also showed a significant main effect ($F$ (3, 68) = 4.8159, $p$= .0042), since younger groups showed overall longer RTs than older groups (Grade 1: 724ms; Grade 2: 686ms; Grade 4: 650ms; Adults: 630ms). There was a significant Block main effect ($F$ (2, 15557.5) = 10.7213, $p$< .001). Block also showed significant interaction with Age ($F$ (6, 15557.4) = 8.7135, $p$< .001) and Context ($F$ (2, 15558.3) = 6.4416, $p$= .0016). Separate analysis for each age group was conducted, and the Block effects would be discussed in the separate analysis.

*Table 12. Results of the ANOVA approach to the linear mixed-effect model analysis for all the four age groups in Experiment 2*

| | Sum Sq | Mean Sq | NumDF | DenDF | F.value | Pr(>F) |
|---|---|---|---|---|---|---|
| Block | 0.71745 | 0.35872 | 2 | 15557.5 | 10.7213 | 2.22E-05*** |
| Seq | 0.00589 | 0.00589 | 1 | 68 | 0.2454 | 0.6219 |
| Age | 0.35452 | 0.11817 | 3 | 68 | 4.8159 | 0.0042** |
| Context | 0.00049 | 0.00049 | 1 | 8.5 | 0.0047 | 0.9467 |
| Block:Seq | 0.05166 | 0.02583 | 2 | 15557.4 | 0.6764 | 0.5084 |
| Block:Age | 1.79765 | 0.29961 | 6 | 15557.4 | 8.7135 | 1.70E-09*** |
| Seq:Age | 0.14739 | 0.04913 | 3 | 68 | 1.4456 | 0.2372 |
| Block:Context | 0.44664 | 0.22332 | 2 | 15558.3 | 6.4416 | 0.0016** |
| Seq:Context | 0.01911 | 0.01911 | 1 | 66.7 | 0.5191 | 0.4738 |
| Age:Context | 0.65061 | 0.21687 | 3 | 66.7 | 6.3460 | 0.0008*** |
| Block:Seq:Age | 0.51846 | 0.08641 | 6 | 15557.4 | 2.5348 | 0.0187* |
| Block:Seq:Context | 0.01042 | 0.00521 | 2 | 15558.2 | 0.1622 | 0.8503 |
| Block:Age:Context | 0.14576 | 0.02429 | 6 | 15558.1 | 0.7128 | 0.6393 |
| Seq:Age:Context | 0.04161 | 0.01387 | 3 | 66.7 | 0.4029 | 0.7514 |
| Block:Seq:Age:Context | 0.15359 | 0.0256 | 6 | 15558.1 | 0.7490 | 0.6101 |

*Note.*: p< .05; **: p< .01; ***: p< .001*

The four models for different Age Groups were run as planned. For Grade 1 children (Table 13), they showed a significant 20ms form preparation effect (i.e., faster response time in the homogeneous lists) ($F$ (1, 9) = 5.6576, $p$ = .0412). Context did not show interaction with any of the other variables ($p$s> .10).

*Table 13. Results of the ANOVA approach to the linear mixed-effect model analysis in Grade 1 children in Experiment 2*

| | Sum Sq | Mean Sq | NumDF | DenDF | F.value | Pr(>F) |
|---|---|---|---|---|---|---|
| Block | 0.044588 | 0.022294 | 2 | 4048.5 | 0.5236 | 0.5924 |
| Seq | 0.029127 | 0.029127 | 1 | 18 | 0.6777 | 0.4212 |
| Context | 0.239799 | 0.239799 | 1 | 9 | 5.6576 | 0.0412* |
| Block:Seq | 0.003427 | 0.001713 | 2 | 4048.6 | 0.0370 | 0.9637 |
| Block:Context | 0.182864 | 0.091432 | 2 | 4048.7 | 2.1802 | 0.1131 |
| Seq:Context | 0.001431 | 0.001431 | 1 | 53.1 | 0.0329 | 0.8568 |
| Block:Seq:Context | 0.103779 | 0.05189 | 2 | 4048.4 | 1.2239 | 0.2942 |

*Note.*: $p$< .05*

For Grade 2 children (Table 14), they showed a significant Block effect ($F$ (2, 3620.2) = 4.0849, $p$= .0169). Their RT was slower in the third block (Block 1: 682ms; Block 2: 680ms; Block 3: 697ms), probably due to a fatigue effect. However, Context did not show a significant main effect or interaction with any of the other variables ($p$s> .10).

*Table 14. Results of the ANOVA approach to the linear mixed-effect model analysis in Grade 2 children in Experiment 2*

| | Sum Sq | Mean Sq | NumDF | DenDF | F.value | Pr(>F) |
|---|---|---|---|---|---|---|
| Block | 0.33896 | 0.169479 | 2 | 3620.2 | 4.0849 | 0.0169* |
| Seq | 0.0275 | 0.0275 | 1 | 16 | 0.5419 | 0.4723 |
| Context | 0.05444 | 0.054441 | 1 | 10.2 | 1.3037 | 0.2796 |
| Block:Seq | 0.02419 | 0.012095 | 2 | 3620 | 0.2900 | 0.7483 |
| Block:Context | 0.05912 | 0.02956 | 2 | 3620.4 | 0.7136 | 0.4899 |
| Seq:Context | 0.00076 | 0.000756 | 1 | 15.6 | 0.0175 | 0.8964 |
| Block:Seq:Context | 0.0143 | 0.007151 | 2 | 3620.5 | 0.1726 | 0.8415 |

*Note.*: $p$< .05*

For Grade 4 children (Table 15), they showed a significant Block effect ($F$ (2, 4102.1) = 6.4133, $p$ = .0017). Unlike Grade 2 children, their RTs were faster in later blocks (Block 1: 657ms; Block 2: 648ms; Block 3: 645ms), probably due to a practice effect. Critically, Context did not show a significant main effect or interaction with any of the other variables ($p$s> .10).

*Table 15. Results of the ANOVA approach to the linear mixed-effect model analysis in Grade 4 children in Experiment 2*

| | Sum Sq | Mean Sq | NumDF | DenDF | F.value | Pr(>F) |
|---|---|---|---|---|---|---|
| Block | 0.38538 | 0.192692 | 2 | 4102.1 | 6.4133 | 0.0017** |
| Seq | 0.03551 | 0.035513 | 1 | 18 | 1.2579 | 0.2768 |
| Context | 0.00002 | 0.000017 | 1 | 9.7 | 0.0007 | 0.9799 |
| Block:Seq | 0.36735 | 0.183674 | 2 | 4102 | 6.1319 | 0.0022** |
| Block:Context | 0.14835 | 0.074173 | 2 | 4102.6 | 2.4668 | 0.0850 |
| Seq:Context | 0.05453 | 0.054528 | 1 | 17.8 | 1.7913 | 0.1976 |
| Block:Seq:Context | 0.0334 | 0.016702 | 2 | 4102.4 | 0.5524 | 0.5756 |

*Note. **: p< .01*

For Adults (Table 16), they showed a significant Block effect as well ($F$ (2, 3756.9) = 38.994, $p$< .001). Their RTs were faster in later blocks (Block 1: 648ms; Block 2: 623ms; Block 3: 618ms), probably due to a practice effect. Context did not show a significant main effect ($F$ (1, 8.5) = .437, $p$ = .5260). The only significant results involving Context was a significant interaction between Block and Context ($F$ (2, 3756.9) = 4.426, $p$ = .0120). Participants showed a 12ms interference effect in Block 1 ($\chi^2$= 1.59121, $p$= .6215) and Block 2 ($\chi^2$= 1.2041, $p$= .6215), whereas they showed a 7ms facilitative effect in Block 3 ($\chi^2$= .2771, $p$= .6215).

*Table 16. Results of the ANOVA approach to the linear mixed-effect model analysis in Adults in Experiment 2*

| | Sum Sq | Mean Sq | NumDF | DenDF | F.value | Pr(>F) |
|---|---|---|---|---|---|---|
| Block | 1.74302 | 0.87151 | 2 | 3756.9 | 38.994 | 2.00E-16*** |
| Seq | 0.04819 | 0.04819 | 1 | 16 | 2.099 | 0.1667 |
| Context | 0.00974 | 0.00974 | 1 | 8.5 | 0.437 | 0.5260 |
| Block:Seq | 0.17139 | 0.0857 | 2 | 3756.9 | 3.845 | 0.0215* |
| Block:Context | 0.19738 | 0.09869 | 2 | 3756.9 | 4.426 | 0.0120* |

| | | | | | | |
|---|---|---|---|---|---|---|
| Seq:Context | 0.0013 | 0.0013 | 1 | 15.8 | 0.058 | 0.8134 |
| Block:Seq:Context | 0.01183 | 0.00592 | 2 | 3756.9 | 0.265 | 0.7674 |

*Note.*: p< .05;***: p< .001*

**Orthographic Experience**

Table 17 shows the descriptive statistics of the reading tasks and the exposure to different writing systems in terms of reading, writing and typing (hourly/week). Similar to Experiment 1, since the results of the questionnaire suggested that English was the only other writing system that participants were exposed to in addition to Pinyin and Chinese characters, there were only three writing systems involved in the table: Pinyin, Chinese characters and English.

*Table 17. Mean scores and standard deviation (in parentheses) for the two reading tasks and average language exposure information (hours/week) for the participants in Experiment 2*

| | | Grade 1 | Grade 2 | Grade 4 | Adults |
|---|---|---|---|---|---|
| Pinyin reading score | | 43.80 (2.93) | 44.89 (2.11) | 43.45 (2.74) | 46.44 (1.45) |
| Character reading score | | 72.00 (27.10) | 79.44 (26.65) | 123.25 (12.30) | 139.78 (3.23) |
| Language Exposure (reading) hours/week | Pinyin | 3.58 (1.80) | 0.90 (0.71) | 0.40 (0.56) | 0 (0) |
| | Chinese character | 8.23 (4.12) | 13.08 (1.29) | 22.25 (6.88) | 26.03 (16.00) |
| | English | 2.90 (2.06) | 3.42 (1.02) | 6.75 (3.47) | 13.19 (9.45) |
| Language Exposure (writing) hours/week | Pinyin | 1.65 (0.93) | 0.97 (0.36) | 0.40 (0.57) | 0 (0) |
| | Chinese character | 2.97 (1.38) | 5.78 (1.36) | 10.65 (8.43) | 4.06 (4.17) |
| | English | 0.15 (0.50) | 0.22 (0.39) | 4.15 (2.54) | 3.50 (4.69) |
| Language Exposure (typing) hours/week | Pinyin | 0 (0) | 0 (0) | 0.35 (0.76) | 9.64 (7.82) |
| | Chinese character | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| | English | 0 (0) | 0 (0) | 0.15 (0.67) | 3.55 (2.93) |

A one-way ANOVA was conducted for both the reading tasks and participants' Pinyin:Character exposure ratio in reading and writing. Similar to Experiment 1, the three children groups rarely type in any writing system while adults type Chinese in Pinyin frequently (9.64 hours per week), which made the comparison among the four groups obvious. For the Pinyin reading task, there was a significant Age main effect ($F$ (3,72) = 5.8784, $p$= .0012). Post-hoc analysis suggested that Adults performed significantly better than Grade 1 children ($p$= .006) and Grade 4 children ($p$= .002), but the children groups did not show any significant difference. For character reading, a significant Age main effect was also shown ($F$ (3,72) = 50.956, $p$< .001). Adults' score was significantly better than Grade 1 children ($p$< .001) and Grade 2 children ($p$< .001). It was also better than Grade 4 children and the difference was only marginally significant ($p$= .064). Grade 4 children's score was significantly better than that of Grade 1 children ($p$< .001) and Grade 2 children ($p$< .001). There was no significant difference between Grade 1 and Grade 2 children. In terms of the Piniyin:character exposure ratio in reading, a significant Age main effect was shown ($F$ (3,72) = 82.242, $p$< .001). Grade 1 children's relative Pinyin exposure was significantly longer than that of the other three groups ($p$< .001). Finally, for the Piniyin:character exposure ratio in writing, again, a significant Age main effect was shown ($F$ (3,72) = 29.941, $p$< .001). Grade 1 children's relative Pinyin exposure was significantly longer than that of all the other three groups ($p$< .001). No other significant difference was shown in any pairwise comparison.

As Experiment 1, Pinyin knowledge, Character knowledge, and relative Pinyin exposure in reading and writing were entered as fixed effects in the full model for the RT data of the simple picture naming task, in which all the four groups' data were combined. Pinyin knowledge was included in Experiment 2 but not Experiment 1 because Age Group difference was only shown in Experiment 2. However, unlike Experiment 1, no matter how to remove insignificant interaction items, the inclusion did not explain significantly more variance of the Context effect. None of the fixed effects about orthographic experiences showed significant interaction with Context or Age. Therefore, the results of the full new model were not shown here for brevity. Nevertheless, according to Figure 2, similar to Experiment 1, when Pinyin:character ratio is large (e.g., > .25), participants consistently showed a trend for onset facilitation. In contrast, when the ratio is small (e.g., < .25), no clear trend was shown. The insignificant interaction between the orthographic experiences and Context in the linear mixed effects model with all the four groups might be due to the fact that 1) the relationship between orthographic experiences (e.g., relative Pinyin exposure in reading) and Context effect within each Age Group was rather unclear, and 2) the variance of orthographic knowledge and exposure was huge.

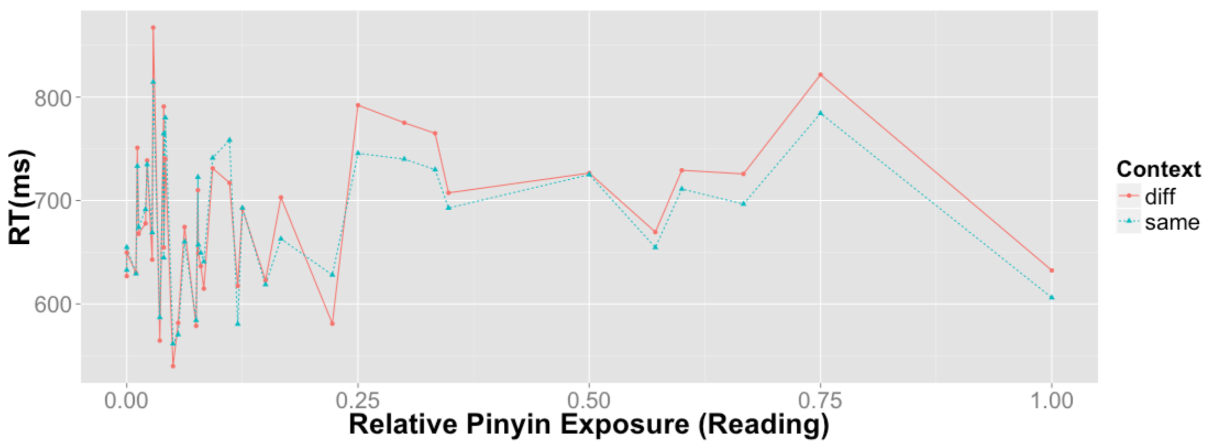



**Figure 2. The effects of Relative Pinyin Exposure (Reading) and Context on speakers' naming latency in Experiment 2.**

## Discussion

### Onset as the Functional Phonological Unit

Similar to Experiment 1, when producing disyllabic words, only Grade 1 children showed significant onset facilitation with similar effect size compared with Experiment 1 (20ms vs. 19ms), suggesting that onset serves as the functional phonological unit among Grade 1 children but not among older children or adults. Combining the results in Experiments 1 and 2, the findings were consistent with Meyer (1991), that the functional phonological unit does not change when speakers produce words of different lengths. For both monosyllables and disyllabic words, onset serves as the functional phonological unit among Grade 1 children in the current study. The absence of word length effect on the selection of functional phonological units might be universal given that it applies to different languages, at least for Dutch and Chinese. In addition, there is clear syllable boundary between both visual Pinyin symbols and visual characters that makes syllable a more salient unit. In spite of this fact, Grade 1 children still retrieve disyllabic words in smaller units (i.e., onset). It is possible that the Pinyin instruction also makes a contribution here since, as mentioned earlier, Grade 1 children are instructed to read Pinyin in as onset-rime-whole syllable (e.g., *m-ā-mā*). In addition, similar to Experiment 1, all the Grade 1 children need to spell the Pinyin in the above order during the Pinyin reading task. Therefore, the explicitly presented segmental information in Pinyin and the method instructors use to teach Pinyin may jointly contribute to Grade 1 children's selection of the functional phonological unit (i.e., onset). On the other hand, the absence of onset facilitation in Experiment 2 was also consistent with the findings in Experiment 1 on the other age groups. It seems that older children (Grade 2 and Grade 4 children) and adults do not encode onset separately when planning spoken word production. Although Adults showed significant interaction between Block and Context, the Context effect showed a trend of onset inhibition in the first two blocks and a trend of facilitation in Block 3. The interaction suggests that the facilitative effect in Block 3 might be a result of repetition. In addition, the Context effect in every block failed to reach significance. Therefore, the effects were overall not robust and failed to show the evidence of onset facilitation or inhibition.

**The Influence of Orthographic Experience**

Regarding the participants' orthographic experience, Experiment 2 did not show exactly the same results as those in Experiment 1. In Experiment 1, participants did not show significant differences in Pinyin reading, but they did in Experiment 2 since Grade 1 and Grade 4 children performed significantly worse than adults. This difference might be due to the individual differences among participants between Experiments 1 and 2. According to the reports from the teachers, there might be huge individual difference regarding students' Pinyin and character reading knowledge since parents made different efforts to teach their children to read at home. However, both experiments showed that Grade 1 children's relative Pinyin exposure was significantly longer than any other groups in both reading and writing. The effect of orthographic experiences provided further evidence that the functional phonological unit may be more related to orthographic exposure than orthographic knowledge. In both experiments, adults got the highest scores in Pinyin reading, but adults failed to show onset facilitation in either experiment. Although Grade 1 children did not show better Pinyin knowledge than adults, they were exposed to Pinyin more than adults and other children groups. As a result, they are more likely to encode word forms based on small units (e.g., onset and rime), which are consistent with the way Pinyin was taught to them. Likewise, Grade 1 and Grade 2 children did not show significant differences in Pinyin or character reading in both experiments, but only Grade 1 children benefitted from the fore-knowledge of onset when naming pictures. These results also indicted that orthographic knowledge may not be the primary or critical factor that affects the selection of the functional phonological unit, consistent with the results of Experiment 1. Nevertheless, the inclusion of orthographic knowledge and exposure as fixed effects did not explain significantly more variance of the Context effects in Experiment 2. As mentioned in Experiment 1, the selection of functional phonological units might follow the all-or-none principle, and there might be a threshold for the selection. Once the orthographic experiences pass the threshold and remain stable, the size of the form preparation effect, does not change as the orthographic experiences increase. Therefore, it might be more reasonable to treat orthographic experiences, exposure in particular, as a categorical variable that overlaps with Age Group/Grade Level instead of a continuous variable.

In summary, in both experiments, Grade 1 children showed longer relative Pinyin exposure than Grade 2 children as well as other groups in reading and writing. This difference may be the critical factor that led to the difference in the selection of functional phonological units. Experiments 1 and 2 showed different patterns regarding the Pinyin and character reading test, while participants showed the same pattern in the picture naming task. Importantly, Grade 1 children showed significantly larger Pinyin:character ratio exposure in both experiments, and they were the only group that showed consistent onset facilitation. Given the letter-sound mapping features of Pinyin and its instructional approach, the above results suggested that orthographic exposure might be the critical factor that leads to the age group difference in the selection of the functional phonological unit. In contrast, orthographic knowledge might only play a secondary role, if any.

A limitation of Experiments 1 and 2 is that it is not clear what the functional phonological unit is among the age groups who failed to show onset facilitation. Experiment 3 was designed to address this issue.

## Chapter 5 - Experiment 3: Syllable Segment as the Functional Phonological Unit in Disyllabic Words

Previous literature (Chen et al., 2002; Chen & Chen, 2013; O'Seaghdha, et al., 2010) has suggested that the functional phonological unit is the syllable segment (i.e., syllable without the tonal information or atonal syllable) in literate native Mandarin-speaking adults. The current experiment was designed to address whether the syllable segment is selected as the functional phonological unit among the three age groups who failed to show onset facilitation in the previous two experiments (i.e., Grade 2 children, Grade 4 children, and Adults). Meyer (1991) showed that the fore-knowledge of longer consecutive beginning segments (e.g., knowing the whole syllable rather than onset only in advance) is able to increase the effect size of form preparation. Therefore, the present experiment also examined if this is also the case for Chinese. For Grade 1 children, they should also show facilitation because a shared initial syllable means the onset is also shared. In addition, they are expected to show a larger effect size in Experiment 3 since the fore-knowledge of longer consecutive beginning segments is able to increase the effect size (Meyer, 1991).

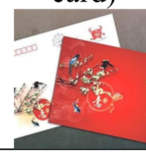
### Participants and Orthographic Experience Measures

Four age groups of participants were recruited, including 1) 18 Grade 1 children at 7 years of age (7 males), 2) 18 Grade 2 children at 8 years of age (12 males), 3) 20 Grade 4 children at 10 years of age (8 males), and 4) 18 adult participants whose ages ranged from 21 to 25 (3 males, Mean Age=22.18). The adults recruited for this experiment were from the same subject pool used in Experiments 1 and 2. All the children were recruited from a different primary school from than the one where recruitment took place in Experiments 1 and 2. Both schools are located in Tianjin, China and use the same textbooks. The Chinese literacy teaching method was also consistent across the two schools, as required by the government of the city. Among the participants selected for Experiment 3, none of the participants had been selected to participate in Experiments 1 or 2. The tests and questionnaire used to measure the orthographic knowledge and exposure were same as those used in Experiments 1 and 2.

**Materials and Design**

The procedure to select the stimuli for the picture naming task was same as the one used in Experiment 2. The same adults and children that were recruited in Experiment 2 to norm the names of the pictures were also asked to name a total of 25 candidate stimuli for Experiment 3 in disyllabic words, resulting in nine pictures being selected as final stimuli. Similar to Experiment 2, a simple picture naming task was conducted using the same design as the one used in Experiment 2. For the critical independent variable, **Context**, the items share the initial syllable segment in the homogenous condition and nothing systematically in common in the heterogeneous condition (See Table 18 for the sample stimuli for the initial syllable segment *shan* and Appendix G for the full stimuli for Experiment 3). The Pinyin symbol of the three initial syllable segments is *mao, shan,* and *he*, respectively with each syllable segment group consisting of three items.

*Table 18. Sample stimuli in Experiment 3*

| | | | |
|---|---|---|---|
| Homogenous Condition | 山羊(shān-yáng, goat)  | 扇子(shàn-zi, *fan*)  | 闪电(shǎn-diàn, lightning)  |
| Heterogeneous Condition | 山羊(shān-yáng, goat)  | 帽子(mào-zi, *hat*)  | 贺卡 (hè-kǎ, greeting card)  |

*Note*. The first symbol in the parentheses is the Pinyin symbol of the corresponding character.

**Procedure**

The procedure was exactly same as the procedure used in Experiments 1 and 2.

**Hypotheses**

It was expected that all the groups should show a facilitative effect in the homogenous condition. For Grade 4 children and adults, their functional phonological unit is likely to be the syllable segment due to their more extensive exposure to Chinese characters and better character knowledge compared to Grade 1 children, as shown in previous studies (e.g., Chen, et al., 2002; Chen & Chen, 2013; O'Seaghdha, et al., 2010). For Grade 1 children, they should also show facilitation since the shared initial syllable contains the onset. In addition, they are expected to show a larger effect size in Experiment 3 compared with Experiment 2 as the fore-knowledge of longer consecutive beginning segments is able to increase the effect size of the form preparation effect (Meyer, 1991). Grade 2 children were also expected to show a facilitative effect. Since Grade 2 children failed to show an onset effect in Experiment s1 or 2, it was expected that they have finished the transition from the onset to the syllable segment for their functional phonological units. For the comparison between Grade 4 children and adults, it is predicted that adults should show a larger effect size than Grade 4 children because of the joint contribution of their longer experience with Chinese characters and more advanced character knowledge. This character knowledge allows them to have a better representation of the syllable segment and to make more use of the repeated initial syllable segment to facilitate articulation. For the same reason, Grade 4 children were expected to show a larger effect size than Grade 2 children.

**Results**

The procedure of data cleaning and analyses were same as that of Experiments 1 and 2.

**The Picture Naming Task**

***Accuracy Rate.*** All four groups achieved very high accuracy rates in the picture naming task: Grade 1 = 99.43%, Grade 2 = 98.12%, Grade 4 = 99.00%, and Adults = 99.71%. As a result of cleaning, the total percentage of data that were removed from each of the four age groups were: 5.27% for Grade 1, 7.44% for Grade 2, 5.58 % for Grade 4, and 1.87% for Adults.

Table 19 shows the mean naming latency and the standard deviations of different groups. Again, for brevity, only the main effect of all fixed effects and the interactions between Context and other factors (e.g., Context and Block) are reported, considering that Context is the critical variable in the present study. The final model was ACC~Block + Seq + Age + Context + Seq:Age:Context + (1+Context|Participant) + (1+Context|Item). Since there was a complicated Seq × Age × Context interaction ($Z$= 1.990, $p$= .047) and the critical component was Age × Context interaction in this combined model, I focused on the four models for different age groups to examine the Context effect.

*Table 19. Descriptive data of participants' performance in Experiment 3 with mean reaction time (M), error rates (E%), standard errors (SE), and preparation effects*

| Age Group | | Homogeneous | Heterogeneous (Control) | Preparation Effect (ms) |
|---|---|---|---|---|
| **Grade 1** | M | 732 | 707 | -25* |
| | E% | .87 | .26 | |
| | SE | 4.14 | 3.75 | |
| **Grade 2** | M | 703 | 708 | 5 |
| | E% | 1.39 | .88 | |
| | SE | 3.85 | 3.96 | |
| **Grade 4** | M | 665 | 689 | 24* |
| | E% | 2.36 | 1.39 | |
| | SE | 3.29 | 3.38 | |
| **Adults** | M | 586 | 604 | 18* |
| | E% | .46 | .10 | |
| | SE | 2.39 | 2.33 | |

* $p < .05$

For Grade 1 children, the final model was ACC~Block + Seq*Context + (1+Context|Subject) + (1+Context|Item). The final model did not show any significant main effect or interaction (*p*s> .10). However, when the Seq × Context interaction term was removed, a significant Context main effect was shown. An ANOVA test suggested that dropping the interaction term led to a significantly poor fit ($\chi^2 = 5.3362$, *p*= 0.021). Therefore, the interaction term was kept, and Context did not show any significant effect (*p*s> .10).

For Grade 2 children, the final reduced model was ACC~Block + Seq +Context + (1+Context|Subject) + (1+Context|Item). The only significant effect in the final model is the main effect of Sequence (*Z*= 2.486, *p*= .013). Participants who received the homogeneous condition first (ACC= 98.6%) showed higher accuracy rate than those who received the control condition first (ACC= 97.6%). Neither Context nor Block showed significant effect (*p*s> .10).

For Grade 4 children and Adults, the final reduced model was ACC~Block + Seq +Context + (1+Context|Subject) + (1+Context|Item) as well. Context did not show significant interaction with Block or Seq. In addition, for both groups, none of the three variables showed significant main effect in the final model (*p*s> .10). In summary, Context did not show any significant effect (main effect or interaction) in any age group in the analysis of accuracy rate.

***Response Times***. The RTs were log-transformed. Combining all the four age groups (See Table 20 for the full results), the critical result was a significant Age × Context interaction ($F$ (3, 65.3) = 8.4749, $p$< .001) with Age also showing a significant main effect ($F$ (3, 66) = 10.1824, $p$< .001). Younger groups showed overall longer RTs than older groups (Grade 1: 719ms; Grade 2: 705ms; Grade 4: 677ms; Adults: 595ms). There was a significant Block main effect ($F$ (2, 14977) = 11.942, $p$< .001) as well as a significant interaction between Block and Age ($F$ (6, 14977) = 8.6076, $p$< .001) and Block and Context ($F$ (2, 14976.74) = 4.1289, $p$= .01612). Separate analyses for each age group were conducted with the Block effect discussed in a separate analysis. All other main effects and interactions failed to show significant results.

*Table 20. Results of the ANOVA approach to the linear mixed-effect model analysis for all the four age groups in Experiment 3*

| | Sum Sq | Mean Sq | NumDF | DenDF | F.value | Pr(>F) |
|---|---|---|---|---|---|---|
| Block | 0.80632 | 0.40316 | 2 | 14977 | 11.942 | 6.57E-06*** |
| Seq | 0.0011 | 0.0011 | 1 | 66 | 0.0048 | 0.9449 |
| Age | 0.88744 | 0.29581 | 3 | 66 | 10.1824 | 1.35E-05*** |
| Context | 0.0361 | 0.0361 | 1 | 11.8 | 0.9134 | 0.3583 |
| Block:Seq | 0.14039 | 0.07019 | 2 | 14977 | 1.9875 | 0.1371 |
| Block:Age | 1.77058 | 0.2951 | 6 | 14977 | 8.6076 | 2.28E-09*** |
| Seq:Age | 0.10473 | 0.03491 | 3 | 66 | 1.1231 | 0.3461 |
| Block:Context | 0.27698 | 0.13849 | 2 | 14976.7 | 4.1289 | 0.01612* |
| Seq:Context | 0.0023 | 0.0023 | 1 | 65.3 | 0.0890 | 0.7664 |
| Age:Context | 0.87039 | 0.29013 | 3 | 65.3 | 8.4749 | 7.78E-05*** |
| Block:Seq:Age | 0.06356 | 0.01059 | 6 | 14977 | 0.3092 | 0.9325 |
| Block:Seq:Context | 0.06989 | 0.03495 | 2 | 14976.7 | 1.0046 | 0.3662 |
| Block:Age:Context | 0.1517 | 0.02528 | 6 | 14976.7 | 0.7400 | 0.6173 |
| Seq:Age:Context | 0.01926 | 0.00642 | 3 | 65.3 | 0.1874 | 0.9046 |
| Block:Seq:Age:Context | 0.09636 | 0.01606 | 6 | 14976.7 | 0.4703 | 0.8309 |

*Note.*: $p$< .05; ***: $p$< .001*

The four models for different Age Groups were run as planned. For Grade 1 children (Table 21), they showed a significant 25ms interference effect (i.e., slower response time in the homogeneous lists) ($F$ (1, 13.6) = 4.9248, $p$ = .0440). Context did not show an interaction with any of the other variables ($p$s> .10).

*Table 21. Results of the ANOVA approach to the linear mixed-effect model analysis in Grade 1 children in Experiment 3*

| | Sum Sq | Mean Sq | NumDF | DenDF | F.value | Pr(>F) |
|---|---|---|---|---|---|---|
| Block | 0.033637 | 0.016818 | 2 | 3626 | 0.3501 | 0.7047 |
| Seq | 0.002117 | 0.002117 | 1 | 16 | 0.0273 | 0.8709 |
| Context | 0.236562 | 0.236562 | 1 | 13.6 | 4.9248 | 0.0440* |
| Block:Seq | 0.003621 | 0.00181 | 2 | 3626.2 | 0.0351 | 0.9655 |
| Block:Context | 0.036899 | 0.018449 | 2 | 3625.8 | 0.3933 | 0.6748 |
| Seq:Context | 0.000596 | 0.000596 | 1 | 16.1 | 0.0134 | 0.9094 |
| Block:Seq:Context | 0.071235 | 0.035618 | 2 | 3625.8 | 0.7400 | 0.4772 |

*Note.*: p< .05*

For Grade 2 children (Table 22), Context did not show a significant main effect or interaction with Sequence ($p$s> .10); however, there was a significant interaction between Context and Block ($F$ (2, 3538) = 3.3847, $p$ = .0340). In Block 1, a trend of inhibition (8ms) was shown for the homogeneous context; in Block 2, a trend of facilitation was shown (11ms); in Block 3, the difference between the contexts was only an 1ms facilitation. In addition, the post-hoc analysis showed that none of the above context effects reached significance ($p$s> .40).

*Table 22. Results of the ANOVA approach to the linear mixed-effect model analysis in Grade 2 children in Experiment 3*

| | Sum Sq | Mean Sq | NumDF | DenDF | F.value | Pr(>F) |
|---|---|---|---|---|---|---|
| Block | 0.080409 | 0.040205 | 2 | 3537.9 | 1.1137 | 0.3285 |
| Seq | 0.001373 | 0.001373 | 1 | 16 | 0.0091 | 0.9253 |
| Context | 0.004079 | 0.004079 | 1 | 14 | 0.1142 | 0.7404 |
| Block:Seq | 0.081789 | 0.040895 | 2 | 3537.8 | 1.1383 | 0.3205 |
| Block:Context | 0.245186 | 0.122593 | 2 | 3538 | 3.3847 | 0.0340* |
| Seq:Context | 0.00461 | 0.00461 | 1 | 15.6 | 0.1259 | 0.7274 |
| Block:Seq:Context | 0.03031 | 0.015155 | 2 | 3538 | 0.4170 | 0.6590 |

*Note.*: p< .05*

For Grade 4 children (Table 23), a significant Context main effect was shown ($F$ (1, 13.4) = 7.1925, $p$ = .0184). Grade 4 children showed significantly faster RTs in the homogeneous context. Context did not show any significant interactions with any other variables (*ps*> .10). There were no other main effects shown either.

*Table 23. Results of the ANOVA approach to the linear mixed-effect model analysis in Grade 4 children in Experiment 3*

| | Sum Sq | Mean Sq | NumDF | DenDF | F.value | Pr(>F) |
|---|---|---|---|---|---|---|
| Block | 0.202969 | 0.101484 | 2 | 4014.1 | 2.9427 | 0.0528 |
| Seq | 0.05348 | 0.05348 | 1 | 18 | 1.7825 | 0.1985 |
| Context | 0.251383 | 0.251383 | 1 | 13.4 | 7.1925 | 0.0184* |
| Block:Seq | 0.084812 | 0.042406 | 2 | 4014.2 | 1.1939 | 0.3031 |
| Block:Context | 0.113681 | 0.05684 | 2 | 4013.9 | 1.6154 | 0.1989 |
| Seq:Context | 0.008734 | 0.008734 | 1 | 17.7 | 0.2506 | 0.6228 |
| Block:Seq:Context | 0.053679 | 0.026839 | 2 | 4014 | 0.7704 | 0.4629 |

*Note.*: p< .05*

For Adults (Table 24), they showed a significant Block effect ($F$ (2, 3752.5) = 66.124, $p$ < .001). Their RTs were faster in later blocks (Block 1: 616ms; Block 2: 590ms; Block 3: 581ms), probably due to a practice effect. For the critical variable, Context, a significant facilitative effect was shown ($F$ (1, 18.6) = 5.825, $p$ = .0263). Context did not show significant interactions with any other variables (*p*s> .10).

*Table 24. Results of the ANOVA approach to the linear mixed -effect model analysis in Adults in Experiment 3*

| | Sum Sq | Mean Sq | NumDF | DenDF | F.value | Pr(>F) |
|---|---|---|---|---|---|---|
| Block | 2.25768 | 1.12884 | 2 | 3752.5 | 66.124 | <2E-16*** |
| Seq | 0.01866 | 0.01866 | 1 | 16 | 1.312 | 0.2689 |
| Context | 0.09946 | 0.09946 | 1 | 18.6 | 5.825 | 0.0263* |
| Block:Seq | 0.03044 | 0.01522 | 2 | 3752.4 | 0.888 | 0.4115 |
| Block:Context | 0.03034 | 0.01517 | 2 | 3752.4 | 0.881 | 0.4146 |
| Seq:Context | 0.00529 | 0.00529 | 1 | 16 | 0.309 | 0.5862 |
| Block:Seq:Context | 0.01592 | 0.00796 | 2 | 3752.4 | 0.467 | 0.6272 |

*Note.*: p< .05;***: p< .001*

**Orthographic Experience**

Table 25 shows the descriptive statistics of the reading tasks and the exposure to different writing systems in terms of reading, writing and typing (hourly/week). Similar to Experiments 1 and 2, since the results of the questionnaire suggested that English was the only other writing system that participants were exposed to in addition to Pinyin and Chinese characters, there were only three writing systems involved in the table: Pinyin, Chinese characters and English.

*Table 25. Mean scores and standard deviation (in parentheses) for the two reading tasks and average language exposure information (hours/week) for the participants in Experiment 3*

| | | Grade 1 | Grade 2 | Grade 4 | Adults |
|---|---|---|---|---|---|
| Pinyin reading score | | 44.33 (3.77) | 43.78 (3.17) | 42.15 (3.84) | 46.50 (1.34) |
| Character reading score | | 66.67 (25.61) | 90.78 (17.99) | 121.85 (12.20) | 139.44 (3.71) |
| Language Exposure (reading) hours/week | Pinyin | 3.72 (3.04) | 1.38 (1.34) | 0.57 (0.57) | 0 (0) |
| | Chinese character | 8.38 (3.14) | 12.74 (5.59) | 26.65 (11.11) | 34.47 (18.76) |
| | English | 3.36 (1.84) | 3.78 (3.79) | 9.57 (4.59) | 9.75 (8.10) |
| Language Exposure (writing) hours/week | Pinyin | 1.00 (0.59) | 0.95 (0.84) | 0.08 (0.28) | 0 (0) |
| | Chinese character | 3.27 (1.02) | 6.91 (7.12) | 18.35 (7.14) | 8.69 (8.67) |
| | English | 0.12 (0.26) | 1.37 (1.99) | 4.025 (1.87) | 5.05 (8.35) |
| Language Exposure (typing) hours/week | Pinyin | 0 (0) | 0.13 (0.36) | 0.94 (1.40) | 12.56 (13.78) |
| | Chinese character | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| | English | 0 (0) | 0 (0) | 0.17 (0.67) | 3.96 (3.09) |

A one-way ANOVA was conducted for both the reading tasks and participants' Pinyin:Character exposure ratio in reading and writing. Again, the three children groups rarely type in any writing system while adults type Chinese in Pinyin frequently (12.56 hours per week), which made the comparison among the four groups obvious. For the pinyin reading task, a significant Age main effect was shown ($F$ (3,70) = 5.8800, $p$= .0012). Post-hoc analysis suggested that Adults performed significantly better than Grade 4 children ($p$< .001), but the children groups did not show any significant differences. For character reading, a significant Age main effect was also shown ($F$ (3,70) = 67.6, $p< .001$). Adults' score was significantly better than all three children groups (for Grade 1 and Grade 2 children, *p*s< .001; for Grade 4 children, $p= .010$). Also, Grade 4 children's scores were significantly better than that of Grade 1 and Grade 2 children (*p*s< .001) while Grade 2 children performed significantly better than Grade 1 children. In terms of the Piniyin:character exposure ratio in reading, a significant Age main effect was shown ($F$ (3,70) = 56.12, $p< .001$). Grade 1 children's relative Pinyin exposure was significantly longer than that of all three other groups (*p*s< .001). No significant difference was shown for other pairwise comparisons. Finally, for the Piniyin:character exposure ratio in writing, again, a significant Age main effect was shown ($F$ (3,72) = 15.58, $p< .001$). Grade 1 children's relative Pinyin exposure was significantly longer than that of Grade 2 children ($p= .004$), Grade 4 children ($p< .001$), and Adults ($p< .001$). Grade 2 children's relative Pinyin exposure was also significantly longer than that of Grade 4 children ($p= .004$) and Adults ($p= .004$).

Considering that the only significant difference in Pinyin knowledge was between Grade 4 children and adults while these two groups did not show significant difference in the simple picture-naming task, only Character knowledge, relative Pinyin exposure in reading and writing were included in the new linear mixed effects model for the RT of the simple picture-naming task when all groups' data were combined. However, again, this inclusion did not significantly influence the results of the Context effects. The reason might be similar to that in Experiment 2.

## Discussion

### Syllable Segment as the Functional Phonological Unit

Native Mandarin-speaking adults showed a reliable form preparation effect in Experiment 3 with the benefit from the fore-knowledge of the initial syllable segment not showing any interaction with other variables. Consistent with previous studies (Chen, et al., 2002; Chen & Chen, 2013; O'Seaghdha, et al., 2010), the results of the current experiment supported the conclusion that the functional phonological unit in Chinese may be the syllable segment (i.e., atonal syllable) in native Mandarin-speaking adults. Grade 4 children also showed significant facilitation in the same initial syllable segment condition, suggesting that they also selected the syllable segment as the functional phonological unit. Although Grade 4 children performed significantly worse in both Pinyin and character reading than adults, the two groups did not differ significantly in relative Pinyin:Chinese character exposure. The comparatively more extensive exposure to Chinese characters compared to younger children may encourage Grade 4 children to perform like adults who select syllable segment when planning spoken word production.

However, inconsistent with the prediction, adults did not show a larger effect size than Grade 4 children. In fact, adults did not even show a trend of a larger effect size. Grade 4 children showed a larger effect size (6ms) than adults, but the difference was small (*Cohen'd*= .22). One interpretation is that the form preparation effect follows the all-or-none principle. Once speakers reach a threshold to rely on a phonological unit as the functional phonological unit, the strength or the size of the effect is not influenced by the speakers' knowledge or experience of the unit. Grade 4 children have finished the transition from onset to syllable segment for their functional phonological unit, so the size of their form preparation effect is similar to that of adults, although adults may have more experience with Chinese characters and better representations of the syllable segment. Another interpretation could be related to adults' orthographic experience: although adults spent 8 hours more per week on reading Chinese characters than Grade 4 children, they spent 10 fewer hours per week on writing Chinese characters since they did not have homework that required them to write in Chinese.

Instead, as college students, they typed on computers in Pinyin to finish their writing, which increased their exposure to Pinyin. As a result, their relative exposure to Chinese characters is not extensive enough to lead to a larger syllable segment facilitative effect compared with Grade 4 children. Although the typing experiences increased adults' exposure to Pinyin, it still failed to encourage them to select sub-syllabic units as functional phonological units, as discussed in Chapter 3.

Unexpectedly, Grade 1 children showed a significant interference effect. Recall that Grade 1 children benefit from the fore-knowledge of onset when producing disyllabic words in Experiment 2; however, when more information has been provided (i.e., shared syllable segment which means shared onset and shared rime), an interference effect was shown. This result is inconsistent with Meyer's (1991) finding that the fore-knowledge of longer consecutive beginning segments is able to increase the effect size of the form preparation effect. A possible reason is that tone is not shared among the items in the homogeneous list. Previous studies have suggested that the rime may interfere more than the onset in tone processing (Ho & Bryant, 1997; Lin, Wang, & Shu, 2013; Shu et al., 2008) among five-year-olds. This effect may persist for Grade 1 children and may explain the present results. If Grade 1 children encode rime segment and tone as an integral unit, a shared rime segment but unshared tone may lead to difficulty in articulation. In Pinyin instruction, children are taught to pronounce a syllable in the order of *onset segment– (rime segment+tone) - whole syllable* (e.g., spell *mā* by repeatedly spelling it as: *m-ā-mā*), so this instruction may also contribute to the way that children represent and encode the rime segment and tone, that they may represent rime segment and tone as an integral unit. Recall that previous literature suggested that lexical tone, as a metrical property, is processed later than functional phonological units (Chen, et al., 2002; O'Seaghdha, et al., 2010;

O'Seaghdha, 2015). However, Experiment 3 suggested that Grade 1 children might prepare rime segment and tone simultaneously. Unfortunately, the present study was not able to test whether the interference effect occurred at the stage of phonological retrieval or articulation. Future research that investigates the time course of the interference effect is needed (e.g., when ERP technique is employed). Nevertheless, the interference effect informed us that Grade 1 children's phonological encoding process in language production may be different from adults. For Grade 4 children and adults, extensive language experience has allowed them to encode rime segments and tones separately. Therefore, the stimuli with a shared rime segment with different tone did not lead to an interference effect among these more skilled readers.

For Grade 2 children, they did not show any clear effects, and as such, it is possible that they are in a transition period. At grade 2, the participants may be able to represent and encode rime segments and tones separately, but haven't started to treat syllable segment as the functional phonological unit. Because of this transition of selecting the functional phonological unit from onset to syllable segment, Grade 2 children may not have a fixed functional phonological unit when planning spoken word production. Another possibility is that they select a unit with more phonological information (e.g., tonal syllable - syllable with determinate tonal information) as the functional phonological unit. More extensive experience with Chinese characters could make them attend to larger units than onset and rime (i.e., syllable) and lead to the absence of onset facilitation; however, it is possible that they haven't been able to separate between syllable segments and tones during phonological retrieval. Unfortunately, the results of Experiment 3 are not able to examine these two possibilities. Experiment 4 sought to investigate whether tonal syllable is the functional phonological unit in Grade 2 children.

## The Influence of Orthographic Experience

Overall, the results of orthographic knowledge and exposure are similar to those of Experiments 1 and 2. For Pinyin knowledge, the only significant comparison was Grade 4 children and adult group. It is possible that adults' frequent use of Pinyin in typing and Grade 4 children's relative more emphasis on character reading in their curriculum contribute to the difference. For character knowledge, participants in older age groups always showed better scores than those in the younger age groups. Particularly, adults' character knowledge is better than Grade 4 children's, but they did not show significant difference in the effect size of the simple picture naming task. This result further suggested that orthographic knowledge might not be primary factor that affected the selection of functional phonological unit.

Grade 1 children showed significantly more exposure to Pinyin than all the other three groups, and they are the only group that showed syllable segment interference effect. As mentioned earlier, the extensive experience with Pinyin may encourage Grade 1 children to encode Pinyin in the format of *onset segment*- (*rime segment* + *tone*), which is consistent with the way they read and spell Pinyin. Grade 4 children and adults did not differ significantly in terms of their relative Pinyin exposure in reading or writing, and this might also be related to the fact that these two groups did not show significant difference between their effect sizes in the picture naming task. It remains unclear about Grade 2 children's functional phonological unit. The significant less exposure to Pinyin compared with Grade 1 children may make them less likely to select onset as the functional phonological unit. However, , they did not perform similarly as those Grade 4 and adult counterparts either. Although Grade 2 children and skilled readers (i.e., adults and Grade 4 children) did not show significant differences in terms of the relative Pinyin exposure in reading, Grade 2 children's relative Pinyin exposure in writing was significantly longer than skilled readers. Therefore, the orthographic exposure may still contribute to the differences between Grade 2 children and skilled readers.

Regarding the functional phonological unit in Grade 2 children, in addition to the two possibilities mentioned previously (i.e., they do not have a fixed functional phonological unit or their functional phonological unit carries more phonological information than syllable segment), a third possibility is that some of the children finished the transition from onset to syllable segment but some did not. Therefore, a correlation analysis was conducted to examine if the individual difference (i.e., the form preparation effect size) is related to their relative Pinyin exposure in reading and writing. The correlation coefficient is 0.04 between the effect size and children's relative Pinyin exposure in reading and is 0.14 between the effect size and children's relative Pinyin exposure in writing. For Grade 2 children who showed a trend of syllable segment facilitation, the average relative Pinyin exposure in reading was .098, and was .257 in writing; for Grade 2 children who showed a trend of syllable segment inhibition, their average relative Pinyin exposure in reading was .096, and was .280 in writing, both of which are similar to Grade 2 children who showed a trend of syllable segment facilitation. The above analysis suggested that the absence of syllable segment effect in Grade 2 children might be less likely due to individual differences. At least individual difference in orthographic experiences did not lead to different selection of functional phonological unit. Similarly, the correlation between the form preparation effect size and relative Pinyin exposure in all the age groups was very low ($r$s< .20). The low correlation also suggested that it is more likely that the similar effect size between Grade 4 children and adults is not because of their Pinyin: character exposure ratio. It is more likely that the form preparation effect follows the all-or-none principle, so Grade 2 children might have not passed the threshold to select syllable segment as the functional phonological unit.

# Chapter 6 - Experiment 4: Tonal Syllable as the Functional Phonological Unit in Disyllabic Words

Previous three experiments showed that the functional phonological unit is onset in Grade 1 children, and is syllable segment in Grade 4 children and adults. However, they failed to show the functional phonological unit in Grade 2 children. The current experiment was designed to address this question. Previous literature has shown that the form preparation effect size of tonal syllable was significantly larger than that of atonal syllable (Chen, et al., 2002) in native Mandarin speaking adults. Therefore, it is possible that adding tonal information can benefit Grade 2 children and facilitate their selection of syllable as their functional phonological unit. Experiment 4 examined whether tonal syllable (i.e., syllable including the tonal information) is the functional phonological unit in Grade 2 children

## Participants and Orthographic Experience Measures

Eighteen Grade 2 children at 8 years of age (9 males) were recruited from the primary school where recruitment took place in Experiment 3. None of the participants had been selected to participate in Experiments 1, 2, or 3. The reading tests and questionnaire used to measure the orthographic knowledge and exposure were same as those used in previous three experiments.

## Materials and Design

The procedure to select the stimuli for the picture naming task was similar to the one that was used in Experiment 3. Ten adults and ten Grade 2 children were asked to norm the names of the candidate stimuli for Experiment 4 in disyllabic words, resulting in nine pictures being selected as final stimuli. The ten children were not recruited to participate the real tests. Similar to Experiment 3, a simple picture naming task was conducted using the same design as the one used in Experiment 3. For the critical independent variable, **Context**, the items share the initial syllable (the tonal information is also shared) in the homogenous condition and nothing systematically in common in the heterogeneous condition (See Table 26 for the sample stimuli for the initial syllable segment *shù* and Appendix H for the full stimuli for Experiment 4). The Pinyin symbols of the three initial syllables are *xiàng, shù,* and *hé*, respectively with each syllable group consisting of three items.

*Table 26. Sample stimuli in Experiment 4*

| | | | |
|---|---|---|---|
| Homogenous Condition | 数字(shù-zì, number)<br> | 树叶(shù-yè, *leaf*)<br> | 竖琴(shù-qín, harp)<br> |
| Heterogeneous Condition | 象牙(xiàng-yá, ivory)<br> | 荷花(hé-huā, lotus)<br> | 竖琴(shù-qín, harp)<br> |

*Note*. The first symbol in the parentheses is the Pinyin symbol of the corresponding character.

**Procedure**

The procedure was exactly same as the procedure used in Experiments 1, 2, and 3.

**Hypotheses**

It was expected that Grade 2 children showed significant facilitation if tonal syllable is selected as their functional phonological unit. If they have not finished the transition from onset to syllable segment and do not have a fixed functional phonological unit, it was expected that they would not shown any significant form preparation effect in Experiment 4.

**Results**

The procedure of data cleaning and analyses were similar to that in the previous three experiments, except that there was no combined analyses with four groups in the model, since only one group was recruited in Experiment 4. Similar to the previous three experiments, for the picture naming task, only main effects and the interactions involve Context were reported.

**The Picture Naming Task**

***Accuracy Rate.*** The accuracy rate of Grade 2 children was 98.35%, and the total percentage of data loss due to data cleaning was 3.75%. Table 27 shows their mean naming latency and the standard deviations. The final model was ACC~Block + Seq + Context + (1+Context|Participant) + (1+Context|Item), and none of the three variables showed any significant effect (*p*s> .10).

*Table 27. Descriptive data of participants' performance in Experiment 4 with mean reaction time (M), error rates (E%), standard errors (SE), and preparation effects*

| **Age Group** | | **Homogeneous** | **Heterogeneous (Control)** | **Preparation Effect (ms)** |
|---|---|---|---|---|
| **Grade 2** | M | 728 | 757 | 29* |
| | E% | 1.34 | 1.95 | |
| | SE | 3.64 | 3.65 | |

*Note.*: p< .05*

***Response Times***. The RTs were log-transformed. Overall, Grade 2 children showed a 29ms form preparation effect (See Table 28 for the full results of the ANOVA approach to the linear mixed-effect model analysis). In addition to the significant Context main effect ($F$ (1, 14.7) = 7.9354, $p$= .0131), there was also a significant Block main effect ($F$ (2, 3262.6) = 5.1822, $p$= .0057). Participants showed faster RTs in later Blocks (Block 1: 750ms; Block 2: 737ms; Block 3: 741ms), probably due to a practice effect. There was also a significant Block × Context interaction ($F$ (2, 3262.6) = 8.858, $p$< .001). The post-hoc analysis showed that the syllable facilitation effect was not significant in Block 1 (3ms; $\chi^2$= .0598, $p$= .8067), but was significant in Block 2 (52ms; $\chi^2$= 18.9709, $p$< .001) and Block 3 (33ms; $\chi^2$= 8.5508, $p$= .007).

*Table 28. Results of the ANOVA approach to the linear mixed-effect model analysis in Grade 2 children in Experiment 4*

| | Sum Sq | Mean Sq | NumDF | DenDF | F.value | Pr(>F) |
|---|---|---|---|---|---|---|
| Block | 0.23988 | 0.119941 | 2 | 3262.6 | 5.1822 | 0.0057** |
| Seq | 0.00683 | 0.006828 | 1 | 14 | 0.1132 | 0.7416 |
| Context | 0.22979 | 0.229794 | 1 | 14.7 | 7.9354 | 0.0131* |
| Block:Seq | 0.23705 | 0.118524 | 2 | 3262.7 | 4.1838 | 0.0153* |
| Block:Context | 0.50788 | 0.253941 | 2 | 3262.6 | 8.858 | 0.0001*** |
| Seq:Context | 0.00341 | 0.003411 | 1 | 14 | 0.1211 | 0.7330 |
| Block:Seq:Context | 0.00016 | 0.000078 | 2 | 3262.7 | 0.0028 | 0.9972 |

*Note.*: p< .05; **: p< .01; ***: p< .001*

**Orthographic Experience**

Table 29 shows the descriptive statistics of the reading tasks and the exposure to different writing systems in terms of reading, writing and typing (hourly/week).

*Table 29. Mean scores and standard deviation (in parentheses) for the two reading tasks and average language exposure information (hours/week) for the participants in Experiment 4*

| | | Grade 2 |
|---|---|---|
| Pinyin reading score | | 42.83 (3.36) |
| Character reading score | | 97.78 (17.97) |
| Language Exposure (reading) hours/week | Pinyin | 1.09 (0.78) |
| | Chinese character | 11.17 (4.56) |
| | English | 2.62 (1.86) |
| Language Exposure (writing) hours/week | Pinyin | 0.51(0.95) |
| | Chinese character | 4.37 (2.58) |
| | English | 0.64 (1.27) |
| Language Exposure (typing) hours/week | Pinyin | 0.13 (0.36) |
| | Chinese character | 0 (0) |
| | English | 0 (0) |

Since only Grade 2 children were recruited in Experiment 4, it was impossible to conduct the ANOVA that has been done in Experiments 1, 2 and 3. However, it is easy to tell from Table 28 that Grade 2 children has low Pinyin: Character exposure ratio (0.097 in reading and 0.117 in writing). The children had very limited typing experiences. In terms of orthographic knowledge, Grade 2 children received 42.83 out of 48 in Pinyin reading, and 97.78 out of 150 in character reading.

**Discussion**

The significant Context main effect suggested that Grade 2 children did select the tonal syllable as the functional phonological unit. However, unlike previous experiments in which speakers showed significant form preparation effects even in the first block when their functional phonological units were shared (i.e., onset for Grade 1 children, syllable segment for Grade 4 children and adults), the form preparation effect did not reach significance until the second block in Experiment 4. It does not mean that the effect is a result of pure repetition, but that Grade 2 children are able to mentally orient to the tonal syllable. Recall that repetition cannot lead to onset facilitation for all the age groups except Grade 1 children in both Experiments 1 and 2. It is likely that their phonological representation is not stable considering that they are in the transition period. As a result, the form preparation was not significant in the beginning (i.e., Block 1). Nevertheless, the experience of only one block was enough to make Grade 2 children mentally orient to the tonal syllable and plan spoken word production in tonal syllable. It is likely that attention played a role in it, that the repetition made the tonal syllable unit more salient. Note that the three items in a homogeneous list only shared the same initial tonal syllable but not the same initial character and Grade 2 children are aware of this. In other words, Grade 2 children retrieved different lexical items when preparing the first character of the disyllabic words, but benefit from their same pronunciation. Therefore, the form preparation effect occurs at the lexeme level but not the lemma level.

Previous literature suggests that lexical tone, a metrical property, does not stand as an independent planning unit and does not serve as a part of functional phonological unit in native Mandarin speaking adults (Chen, et al., 2002; O'Seaghdha, et al., 2010; O'Seaghdha, 2015). However, the results of the current Experiments 3 and 4 jointly suggest that this might not be true for Grade 2 children. The fact that Grade 2 children did not even show a clear trend of syllable segment facilitation but showed significant tonal syllable facilitation suggests that tone may be involved in the stage of phonological retrieval and encoding. As a result, only when tonal information is involved do Grade 2 children benefit from the fore-knowledge of the initial syllable of the target word.

# Chapter 7 General Discussion

The current dissertation project examined the development of the functional phonological unit in native Mandarin speakers. In particular, it took into consideration the influence of speakers' orthographic experiences. Four experiments were conducted to explore the functional phonological unit in native Mandarin speakers from four age groups who have different orthographic experiences. Experiment 1 investigated whether a word's onset served as the functional phonological unit in production of monosyllabic words. The results suggested that only Grade 1 children select onset as the functional phonological unit. Both orthographic knowledge and orthographic experience were examined for each age group. For Grade 1 children, there were no significant differences from any other age groups regarding Pinyin knowledge. Although Grade 1 children's character knowledge was significantly worse than Grade 4 children and adults, they did not show a significant difference compared with Grade 2 children. On the other hand, Grade 1 children's relative Pinyin exposure was significantly higher than all other groups in terms of both reading and writing. As a result, their extensive Pinyin exposure may contribute to the selection of the onset as the functional phonological unit in Grade 1 children.

Experiment 2 examined whether the results of Experiment 1 could be applied to the production of disyllabic words, the most common word type in Mandarin Chinese. There is a clear syllable boundary when Pinyin symbols as well as characters are visually presented, so it is possible that this boundary makes the syllable unit more salient such that even Grade 1 children are encouraged to select the syllable as the functional phonological unit when producing disyllabic words. However, the results suggested that onset is still the functional phonological unit in Grade 1 children. Consistent with Experiment 1, the other three groups still failed to show onset facilitation, suggesting that the absence of onset facilitation among older children and adults applies to the most common type of words in Chinese.

Experiment 3 investigated whether the syllable segment was selected as the functional phonological unit if the onset was not selected. Adults and Grade 4 children showed syllable segment facilitation, suggesting that syllable segment is their functional phonological unit in spoken word production. The results are consistent with previous findings among adults (e.g., Chen & Chen, 2013). However, there was no significant difference in terms of the effect size between the two groups. It is possible that orthographic experiences can affect only which unit will be selected as the functional phonological unit, but not the degree that speakers benefit from the fore-knowledge of that unit. On the other hand, Grade 1 children did not show facilitation, which is in contrast with the prediction made at the outset of the experiment. This is unexpected since Grade 1 children showed significant facilitation even when only the onset was shared and a shared syllable segment represents a greater overlap than when just the onset is shared. Grade 1 children even showed a significant interference effect, possibly because the shared rime segment with different tones led to difficulty in articulation. Grade 2 children did not show any significant results, and three possibilities were put forward to explain the null result.

Experiment 4 investigated whether tonal syllable (i.e., syllable with its tonal information) served as the functional phonological unit. Since previous three experiments had shown clear results about the functional phonological unit in Grade 1 children, Grade 4 children and Adults while it remained unclear about Grade 2 children, only Grade 2 children were recruited in Experiment 4. Grade 2 children showed significant tonal syllable facilitation, suggesting that they selected tonal syllable as the functional phonological unit, although it might be tuned by other cognitive mechanisms such as attention.

### The Spoken Word Production Model Includes Functional Phonological Unit Principle

According to the WEAVER++ Model, two levels are involved in spoken word production after concepts are selected: the lemma level that involves semantic and syntactic information and the lexeme level that involves word form encoding, phonological retrieval and encoding in particular. Chen and Chen (2013) proposed a revised model in which the proximate unit (i.e., the functional phonological unit) principle was taken into consideration (See Figure 3).

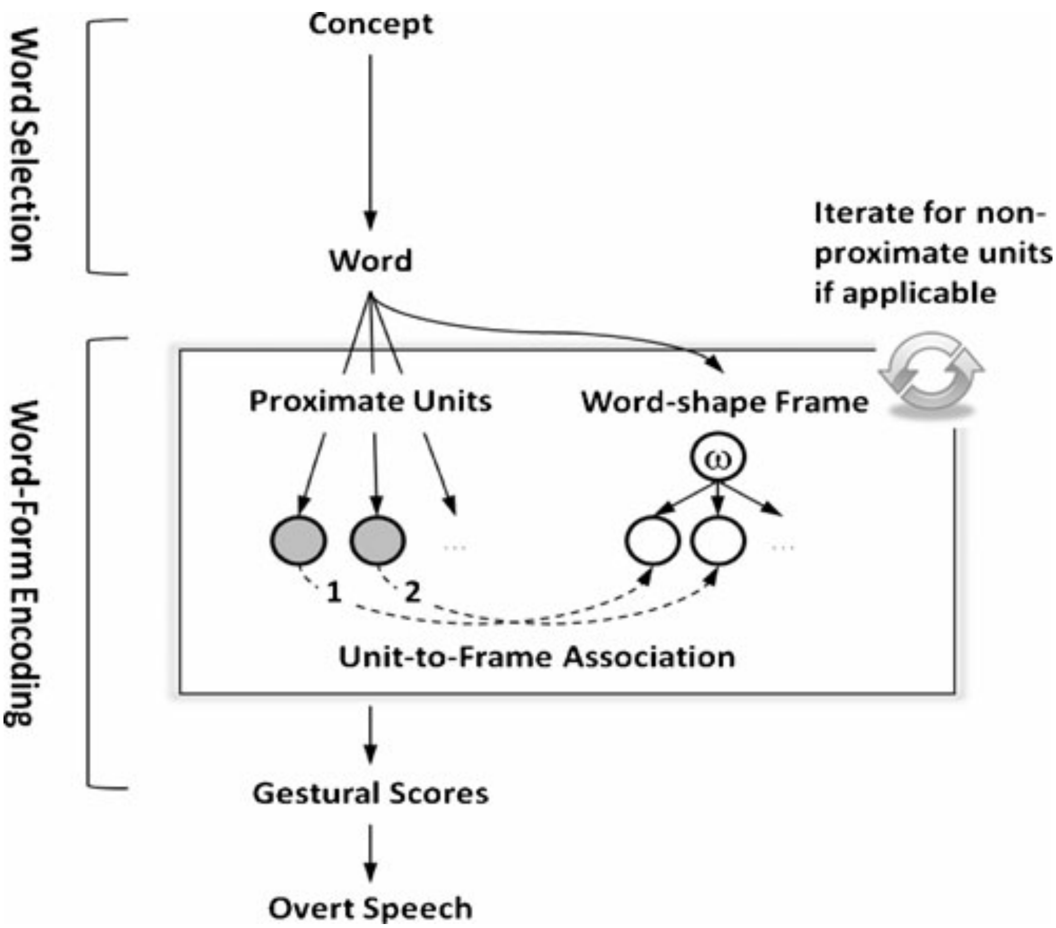



**Figure 3 The Modified Levelt-type model for word-form encoding that includes the language-general functional phonological unit principle proposed by Chen and Chen (2013).**

There are two important statements about the functional phonological unit and the Modified Levelt-type model (Chen & Chen, 2013; O'Seaghdha, et al., 2010; O'Seaghdha, 2015).

First, the functional phonological unit is the FIRST phonological unit that is selected for speakers to retrieve and encode phonological information. Meanwhile, other units (i.e., the non-proximate units in Figure 1) are also involved and selectable, and they are just not the ones selected first. For example, literate Chinese adults still have phoneme awareness but phonemes are not the first selectable unit in word form encoding. The word-form encoding process runs more than once and syllable segments are selected in the first place. In languages in which the proximate units are phoneme segments (e.g., English), non-proximate units do not apply, and the word-form encoding process runs only once.

Second, functional phonological units are abstract and symbolically addressable. For example, the syllable segment has been proven to be the functional phonological unit in native Mandarin-speaking adults. This unit is abstract relative to eventual articulation since it is uncommon to produce syllables without tonal information. Although the second syllable of some disyllabic words (e.g., 好的, *hǎo-de*, fine) may not carry tonal information (i.e., neutral tone), atonal syllable is not common and never occurs in the beginning of a word. Nevertheless, the syllable segment or atonal syllable is symbolically addressable and speakers are able to mentally orient to it to prepare for it. The supporting evidence of this statement is that previous literature and the current dissertation consistently showed that simple repetition was not able to encourage native Mandarin-speaking adults to prepare onset phoneme when producing spoken Chinese words. For example, in both O'Seaghdha et al. (2010) and current dissertation (Experiments 1 and 2), native Mandarin-speaking adults failed to show onset facilitation even in Block 3.

The Functional Phonological Unit Principle is consistent with early literature that investigated speech errors in various languages. For example, for Indo-European languages such as English, there are two major types of exchange errors: first, whole words or morphemes exchange, and second, phonemic segments exchange (Bock, 1991; Dell, 1995). For instance, a sentence like *The speakers of the minds of that community* might be produced in which the two words *minds* and *speakers* exchanged places; *b**r**ake f**l**uid* might be produced as *b**l**ake f**r**uid* due to a phoneme exchange error. However, both syllable and segment errors occur in Chinese (Chen, 1993), and both mora and phoneme errors occur in Japanese (Kubozono, 1989; Nakayama & Saito, 2014). For example, for Chinese,公(gōng)主(zhǔ)和(hé)王(wáng)子 (zǐ) (princess and prince) might be produced as 公(gōng)子(zǐ)和(hé)王(wáng)主(zhǔ) by mistake, because the syllables of princess and prince were exchanged. For Japanese, ku-ro-da-i (black porgy) might be mistakenly produced as ro-ku-da-i (sixth) due to the exchange of the first two morae. Importantly, syllables and morae exchange in Chinese and Japanese, respectively, but these errors rarely occur in Indo-European languages. It suggested that there was an additional step before phoneme selection in Chinese and Japanese spoken word production (i.e., the functional phonological unit retrieval step). However, phonemes are still processed and manipulated. Research has suggested phoneme still plays a fundamental and universal role in spoken word production even if it is not the functional phonological unit in a language (Qu, et al., 2012).

**The Cross-linguistic Difference**

Language-specific phonological characteristics are an important factor that leads to the cross-language difference in terms of the selection of functional phonological unit. This body of research demonstrates that English and Dutch are categorized as stress-timed (Cutler, Mehler, Norris, & Segui, 1986); Chinese speech is syllable-timed (Tseng, Huang, & Jeng, 1996); and Japanese speech is mora-timed (Otake, Hatano, Cutler, & Mehler, 1993). O'Seaghdha (2015) assumed that functional phonological units are acquired and become stable as early as when productive vocabulary reached certain amount in speakers' native languages.

Unlike the Chinese and Japanese, re-syllabification may occur in the stress-timed languages, so that lexical constraints may not apply to the process of syllabification. For example, for the word *post*, there is one syllable /poʊst/; however, when it is changed to the past tense *posted*, it is not syllabified as /poʊst-ɪd/. Instead, re-syllabification occurs, forming a second syllable such that the word is realized as /ˈpoʊs-tɪd/ where the coda of the present tense, /poʊst/, is shifted to become the onset of the second syllable in the past tense form. Because of this process, retrieving and encoding phonemes instead of syllables is easier for speakers to construct a spoken word in these languages. Accordlying, syllables of a word are best constructed online rather than stored and retrieved. By contrast, re-syllabification does not occur in Chinese or Japanese since the syllable and mora are salient in Chinese and Japanese, respectively, and thus it is natural for native Chinese and Japanese speakers to retrieve the syllable and mora first during spoken word production.

The cross-language differences do not only occur in terms of the grain size of the functional phonological unit, but also exist in terms of the way of its assembly. For languages in which the functional phonological unit is phoneme (e.g., English), the initial phoneme is the starting point and the ONLY starting point in the planning of a spoken word regardless of the word structure (i.e., for both compound and simplex words). In contrast, for Chinese in which the functional phonological unit is syllable segment, each syllable provides a new starting point in planning spoken word production. Jacobs and Dell (2014) showed that even for compound words such as *sawdust* or *hotdog*, native English speakers still plan them in a single sequence instead of two sequences that are in concert with the two morphemes (e.g., saw-dust, hot-dog). For example, an associate naming task was conducted on a set of compound words *eyeball, soybean, surfboard, fishbowl,* and *sandbox*. The first morpheme served as the prompt (i.e., *eye, soy, surf, fish,* and *sand*), and the second morpheme served as the response item (i.e., *ball, bean, board, bowl,* and *box*). In other words, participants memorized pairs of words like *eye-ball, soy-bean, and surf-board*. They were required to say "ball" when they saw the word "eye". Compared with the control condition in which the response items did not share anything systematically in common, native English speakers did not show the form preparation effect although the response items shared the same initial phoneme. In contrast, for the same response items, when the prompts and the response items are semantically related (e.g., *game-ball, meal-bean, wood-board, food-bowl,* and *crate-box*) or form noun phrases (e.g., *round-ball, red-bean, flat-board, hot-bowl,* and *large-box*), a significant form preparation effect was shown. For native Mandarin speaking adults who selected syllable segment as the functional phonological unit in spoken Chinese word production, shared initial phoneme failed to lead a form preparation effect regardless of the relationship between the prompts and the response items (See O'Seaghdha, et al., 2010, Experiments 1-4). However, Chen and Chen (2015) showed that, for both monomorphemic words (e.g., 珊瑚, *shān-hú, coral*, the two syllables stand for one morpheme) and bimorphemic words e.g., (连接, *lián-jiē, connect*, each syllable is a morpheme that can be used independently as *link or connect*), when the first syllable served as the prompt, a form preparation effect was shown when the response item was the second syllable of the disyllabic words and shared the same syllable segment in a list (e.g., 连**接**, *lián-**jiē**, connect*, 抢**劫**, *qiǎng-**jié**, robbery,* 拆**解**， *chāi-**jiě**, dismantling,* 租**借**,*zū-**jiè**, rent*).

In summary, the above research suggested English and Mandarin differ in 1) the grain size of functional phonological units, and 2) the way that functional phonological units are assembled. While English only has one starting point for a word—the initial phoneme, each syllable within a Chinese word provides a new starting point. Note that the second syllable segment is never shared in any list in the current Experiments 2 to 4. This manipulation avoided the influence of the second syllable segment on the form preparation effect. Also, the influence of orthographic experiences on the selection of functional phonological that was shown in the present study might also only apply to some languages. At least for languages that only has one orthography (e.g., English), the influence might not be applicable.

**The Flexibility of the Selection of Functional Phonological Units**

Returning to the grain size of functional phonological units, although functional phonological units differ across languages in general, it does not mean that they are fixed and absolutely stable within a language. Instead, the selection of functional phonological units is flexible and is influenced by various factors. The first factor, as mentioned in Chapter 3, is the output format in a production system (e.g., word typing vs. word naming), suggested by the Output Constraint Hypothesis (Chen & Chen, 2012; Chen & Li, 2011). Being asked to type words in Zhu-yin-fu-hao, participants' response time was speeded up if the target words always shared the same onset or if the target followed a prime that shared the same onset with it. This might be due to the fact that typing in Zhu-yin-fu-hao requires an onset-rime division. However, participants did not show the above onset effect in a word naming task. Both typing and naming tasks require accessing the phonological codes, but in word typing, participants use Pinyin/Zhu-yin-fu-hao to type character words and anticipate successive phonemes/sub-syllabic units from the segment-based finger movements, compared to naming where participants are not required to access the segmental information. This contrast promotes the encoding of the smaller unit, the onset, when producing Chinese words. Of course, if we restrict selection to SPOKEN word production requiring the output as auditory words, the output system will not affect the selection of the functional phonological unit or the way participants encode word form.

The second factor is the orthographic cues of the input, namely, the orthographic form of the materials used by speakers in production, as suggested by Li et al. (2015) and Kureta et al. (2015). When Chinese words were presented in Pinyin, the onset was selected as the functional phonological unit in an associate naming task; however, speakers failed to benefit from the fore-knowledge of the onset when the materials were presented in Chinese characters. Similarly, native Japanese speakers benefit from the fore-knowledge of the initial phoneme when words were presented in romaji but not when words were presented in an auditory format. According to the attentional theory of O'Séaghdha and Frazer (2014), speakers' attention was directed to the units that are smaller than the functional phonological units (e.g., phonemes) since they were explicitly provided/represented in the orthography. As a result, those small units become symbolically accessible, thus showing the form preparation effects.

The above two factors are based on the demands for specific tasks. In Chinese, the syllable segment may still be the functional phonological unit as an intrinsic property. It is the cues (e.g., Pinyin structure) that change it temporarily in a specific task, and without these explicit orthographic cues, it has been shown that the syllable segment is the preferred functional phonological unit when literate Chinese speakers need to construct a spoken word. The factor that was investigated in the present dissertation project is an intrinsic property of a population instead of factors that rely on specific tasks—orthographic experiences. The research conducted in this project shows that orthographic experiences may change the functional phonological units in spoken word production. Since no explicit orthographic cues were provided and the pictures were easy to name in the present research (i.e., the associate learning session is not involved), the different functional phonological units across the four age groups cannot be attributed to attention or other strategic factors. Therefore, the most plausible explanation is that orthographic experiences restructure speakers' phonological representation, thus forming different "first selectable units" in different age groups.

**Revisiting the Phonological Restructuring Hypothesis**

The Phonological Restructuring Hypothesis was originally put forward to explain the orthographic consistency effect. It claims that orthographic knowledge "contaminates" or restructures phonological representations in literate speakers. For an orthographically inconsistent word, in addition to the phonological representation that represents its original pronunciation, it also has an "orthographically influenced phonological representation" (OIP) (Taft, 2006; 2011). For example, for the auditory word /swɔp/, its OIP is /swæp/ because the spelling is swap. Its rime /ɔp/ can be spelt in different ways (e.g., *ap* or *op*), depending on the lexical information of the word (e.g., *swap* vs. *cap*). When literate listeners hear the orthographically inconsistent word /swɔp/, both phonological representations are activated and compete with each other, thus leading to a delay in the time it takes for listeners to respond (i.e., the orthographical consistency effect). For some other orthographically inconsistent words, such as *city* in which the onset /s/ can be spelt as c or s, the OIP and the original phonological representation are more similar compared with the *swap* case. In the word *city*, its onset, the soft c as a variant of c (i.e., /$c^s$/ in OIP), is transformed into /s/ (i.e., the original pronunciation that is represented in the phonological representation) at articulation.

This hypothesis applies to any language with a single alphabetic orthography. The connection between OIP and the other phonological representation led to the pseudohomograph priming effect (Taft, 2008). For example, hearing the pseudoword /swæp/ could facilitate native English speakers' response time when judging whether the auditory stimulus /swɔp/ was a real word. The prime /swæp/ pre-activated the lemma *swap* because this pseudoword could be spelt as swap, thus facilitating the recognition of lexeme level of the word *swap*, namely /swɔp/. The competition between the two phonological representations explained the orthographic consistency effect (Taft, 2011). Recall that words in a number of languages are orthographically inconsistent. For example, the phonological rimes of some words can be spelled in multiple ways (e.g., /-aɪt/ can be spelled as –ight/-ite/-yte). The orthographically inconsistent words (e.g., light) were found to take readers longer to identify compared with orthographically consistent words (e.g., duck in which the rime /-ʌk/ can only be spelled as –uck in English) in auditory lexical decision tasks or sematic categorization tasks (e.g., Peereman, Dufour, & Burt, 2009; Perre & Ziegler, 2008; Ventura, Morais, Pattamadilok, & Kolinsky, 2004; Ziegler & Ferrand, 1998). The different OIP might activate different lemma (e.g., /laɪt/ may activate *light* and *lyte*). Although one of them might be pseudoword (e.g., *lyte*) thus sending weaker feedback than the real word (e.g., *light*), it might still cost cognitive resources and slow down the recognition of the target lemma (i.e., *light*).

The present study suggests that orthographic experiences may also restructure phonological representations regarding grain size. This hypothesis at least applies to languages with multiple orthographies, such as Chinese and Japanese. There may be two types of phonological representations stored in literate Chinese speakers. One of them is influenced by orthographic experiences (i.e., the OIP) and represents the functional phonological unit that is related to the spoken word production model. The other type of representation (i.e., the Non-OIP) represents smaller units than functional phonological units. In the present study, Grade 1 children have had extensive exposure to Pinyin. On one hand, the onset segmental information is explicitly represented in Pinyin, on the other hand, children are instructed to spell each Pinyin symbol using an onset-rime-whole syllable phonological encoding technique. As a result, when reading and writing Pinyin symbols, Grade 1 children may be induced to encode the phonological information in an onset-rime format at the lexeme level within the first type of phonological representation. Within the rime unit, the rime segment and tone can still be represented and processed separately in the other type of phonological representation (i.e., the non-OIP representation), since Grade 1 children have acquired tone awareness (Shu et al., 2008) (See Figure 4). Grade 2 children are experiencing the transition period, and start to represent onset and rime segments as an integral unit in the OIP (See Figure 5). Skilled readers (e.g., Grade 4 children and adults) may utilize their extensive exposure to Chinese characters to represent phonological information using the syllable. Syllable segment is represented in the OIP, while sub-syllabic units still can be represented in the Non-OIP presentation (See Figure 6).

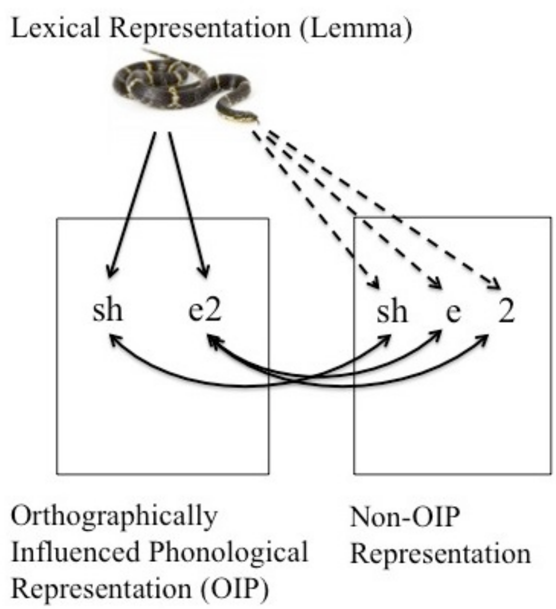



**Figure 4 The Phonological Representations of Grade 1 children. The phonological information is represented in Pinyin symbols, and tone is represented in numbers.**

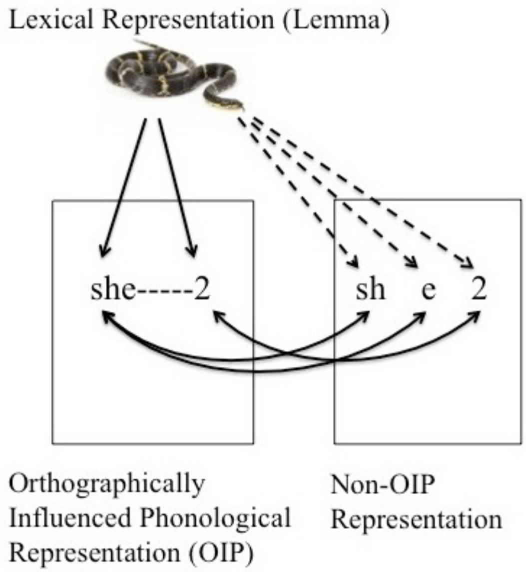



**Figure 5 The Phonological Representations of Grade 2 children. The phonological information is represented in Pinyin symbols, and tone is represented in numbers.**

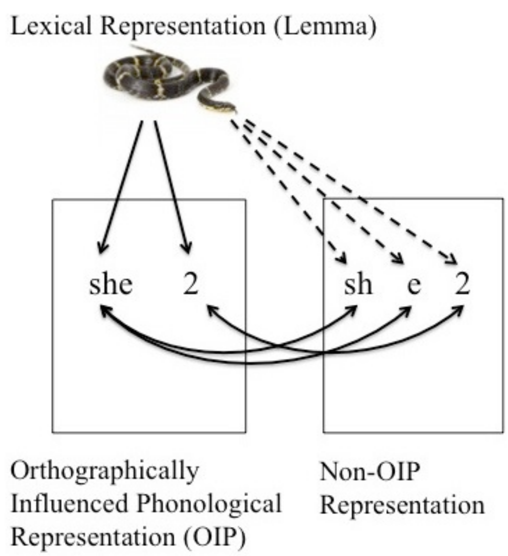



**Figure 6 The Phonological Representations of Skilled Readers (including Grade 4 children and adults). The phonological information is represented in Pinyin symbols, and tone is represented in numbers.**

Another difference among the three groups of readers is that, in OIP, the tonal information is associated with the rime segment in Grade 1 children, while it is represented independently in skilled readers. Again, Grade 2 children are in the transition period - they begin to process tonal information separately in OIP. But unlike skill readers, the tonal information is still not completely independently represented. Experiment 3 of the present dissertation research showed that significant interference effect among Grade 1 children when the response names shared the same syllable segment but different tones. Since shared onset has shown significant facilitation in Experiments 1 and 2, one more shared component (i.e., rime segment) in Experiment 3 should have led to stronger facilitation or at least facilitation of the same effect size, if rime segments are encoded as an independent unit. The interference effect could be evidence that the rime segment and tone are represented as an integral unit, and as such, the consistent same rime-different tone combination in this research's stimuli led to difficulty in articulation, leading to the observed interference effect.

On the other hand for skilled readers, the syllable segment and tonal information are represented separately in OIP. This assumption was also supported by an ERP study (Zhang & Damian, 2009), which further suggested that segmental information becomes available prior to tonal information in spoken word production. In a Go/noGo decision task, native Mandarin speakers were asked to covertly name a picture in monosyllables and to press a button either if its name began with a particular target onset (segment condition), or had a particular target tone (tone condition). The N200 component on noGo trials, namely a negative-going waveform that suggests more cognitive resources are used to withhold an action (e.g., to press a button), was measured. For the segment condition, the onset latencies of the N200 were observed in the 283-293 ms time window, whereas the onset latencies of the same component were observed in the 483–493 ms time window for the tone condition. The earlier N200 component suggested that segments are accessed earlier than tones in spoken word production in Mandarin Chinese. In summary, for skilled readers, segmental information and tonal information is represented separately in mental lexicon and syllable segment is the FIRST selectable phonological unit in planning spoken word production. For Grade 2 children, onsets and rimes are not represented independently at the first lexeme level, and they are still linked to the tone, though the link is not as strong as that in Grade 1 children. As a result, Grade 2 did not show inhibition as Grade 1 children did or facilitation as skilled readers did in Experiment 3. Correspondingly, they showed significant tonal syllable facilitation in Experiment 4.

In Figure 2 to 4, the phonological units in OIP stand for the functional phonological units in the Modified Levelt-type Model in Chen and Chen (2013), while those in the Non-OIP presentation stand for the non-proximate units. For skilled readers (e.g., Grade 4 children and adults), phonological information were presented in syllables in the OIP, and they selected syllable segment first after lexical retrieval during the planning of spoken words. Syllable segments were deployed sequentially in the context with metrical properties (tone in the case of Mandarin Chinese) while the phonological units in the Non-OIP presentation iterate. Note that although tone is represented in the OIP among skilled readers, it was not involved in the retrieval of the functional phonological units. It only provides a context of metrical property. The cases of Grade 1 and Grade 2 children were more complicated since tone was also involved in functional phonological units. Usually, suprasegmental information was accounted as metrical properties and was not involved in initial phonological retrieval and encoding that occurred in functional phonological units. However, developing children have not formed stable phonological representation that can represent segmental and suprasegmental information separately. For Grade 1 children, although future research is needed to investigate the role of rime segment and tone, it is possible that onset and (rime segment + tone) were retrieved and encoded at the beginning of phonological processing in spoken word production, while rime segment iterate as the non-proximate unit and tone still serve as a metrical property. For Grade 2 children, the tonal syllable served as the functional phonological unit at the beginning of phonological retrieval and encoding. Although tone had been included during syllable retrieval, it still served as a metrical property when multiple syllables needed to be assigned sequentially in speech production. Meanwhile, onset and rime segments iterate as non-proximate units.

The results from these four experiments improve our understanding of the development of phonological processing among literate speakers who are exposed to multiple orthographies. Particularly, the results shed light on the contribution of literacy experience to the development of phonological processing; hence helping educators develop better pedagogical approaches in class to improve language learners' phonological processing abilities.

**Limitations**

One limitation of the current dissertation is that the investigation of some age groups requires further examination. Particularly, without the involvement of preschool children who have not received formal orthographic instruction, it remains unclear what the functional phonological unit is before orthographic experiences start to "contaminate". Secondly, it remains unclear how Grade 1 children would perform in the tonal syllable condition (i.e., Experiment 4). Due to time constraints, Grade 1 children were not recruited in Experiment 4, given that Experiments 1 and 2 had clearly shown that Grade 1 children's functional phonological unit is onset. Also, the present research has shown that Grade 2 children are in the transition period while Grade 4 children perform similarly to adults, but it is still unclear when the transition is completed (e.g., whether it is finished by Grade 3 or Grade 4).

A second limitation is that it is difficult to differentiate the influence of age and orthographic experiences, although different orthographic experiences of the four age groups could provide reasonable interpretation about the difference of their selection of functional phonological units. A solution is to compare the children in the same age groups with different orthographic experience. For example, for two groups of children at Grade 1, one of them has learned Pinyin and has been exposed to Pinyin extensively while the other group has never learned Pinyin but has only been exposed to Chinese character. This manipulation could investigate the influence of orthographic experiences without involving age difference. Unfortunately, this is not feasible since all the primary schools in Mainland China require Grade 1 children to study Pinyin according to the policy of the government. It is also not feasible to compare Grade 1 children in Mainland China and in Hong Kong. Although children in Hong Kong do not study Pinyin, they speak both Mandarin and Cantonese, and it is possible that the experiences of Cantonese have influence on the selection of functional phonological units when speaking Mandarin.

A third limitation is that the different orthographic experiences of the four age groups are not clear-cut. For example, although Grade 1 children rely more on Pinyin during reading than Grade 2 and 4 children, they are also exposed to and learn to read Chinese characters during the same time period. The skilled readers who served as the baseline are also more exposed to English, an alphabetic language, which may influence their selection of the functional phonological unit (Verdonschot, et al., 2013). Verdonschot et al. found Chinese-English bilinguals' functional phonological units in their native language-Mandarin Chinese may be influenced by English if they are highly proficient in English, their second language. In other words, these bilinguals showed benefits from the fore-knowledge of the initial phoneme in spoken word production in Mandarin. As a result, an ideal way to obtain clear-cut orthographic experience is to have a group of Grade 1 children which have only been exposed to Pinyin so that their functional phonological units can be compared with 1) a group of Grade 4 children who are only exposed to Chinese characters but have previously learned Pinyin in grade 1, and 2) a group of skilled adult readers who are also only exposed to Chinese characters but have learned Pinyin in grade 1 as well. However, similar to the second limitation, this manipulation is not realistic since 1) all children in their grade 1 should learn to read Chinese characters at school, and it is not feasible to prevent parents from teaching children characters at home; 2) it is almost impossible to find adults who are skilled in reading Chinese but have not learned English.

Fourthly, although both orthographic knowledge and exposure were measured in the current dissertation, it is difficult to tease apart the influence from these two factors. In most cases, speakers will have advanced knowledge of a writing system if they are frequently exposed to it. If possible, it will be interesting to compare the functional phonological units among speakers who have advanced knowledge in but limited exposure to an orthography and those who have little knowledge in but extensive exposure to the same orthography. Considering that all groups had high scores in the Pinyin reading test (>42 out of 48), it might also be helpful to add tests to measure Pinyin awareness (e.g., onset/rime/tone substitution) to better differentiate Pinyin knowledge at the metalinguistic level among different groups in the future.

Fourthly, due to the nature of the syllable structure in Chinese, it is not feasible to investigate whether the onset facilitation in Mandarin speakers is a phoneme effect or an onset effect. Considering that Pinyin instruction emphasizes onset-rime division instead of phoneme division, we hypothesized that if Pinyin experiences lead to onset facilitation, it should be a result of the fore-knowledge of onset rather than that of phoneme. However, there is no empirical evidence to support this hypothesis. For languages which allow consonant clusters to serve as the onset, one method to differentiate the onset effect and the phoneme effect is to include a group of words of which the onsets are consonant clusters (e.g., *skirt, stain,* and *slash*), we can then compare speakers' response when the items in the homogeneous lists only share the same initial phoneme and when the items share the whole onset. If the overlapped initial phoneme only is not able to lead to a form preparation effect but a shared onset can, then this suggests that the functional phonological unit is the onset and not the phoneme. However, for languages (e.g., English) that allow consonant clusters to differentiate onset and phoneme, there is only one orthographic form. As a result, it is challenging to investigate these languages to answer this research question in English or Chinese.

Lastly, behavioral data might not be sufficient for us to examine how the fore-knowledge of certain phonological units affects the procedure of spoken word production. Qu, et al. (2012) suggested that the effects of this fore-knowledge may be two-fold. On one hand, it may facilitate articulation or spoken word planning because of the repetition of certain phonological units, as seen in the facilitation in the posterior ERP amplitude in the 200-300ms time window in their study. On the other hand, this repetition may lead to an extra cost of cognitive control because speakers need to put more effort on internal speech monitoring in order to avoid speech errors (e.g., to avoid repeating the previous utterance entirely). This cost can be seen in the anterior ERP effect in the 300-400ms time window in their study. These effects jointly led to the overall null effect in the behavioral data. Without more advanced techniques (e.g., ERP) to target the time course of the influence, it is difficult to determine the detailed process about the form preparation effect. Although the current research has shown significant onset facilitation in Grade 1 children, it is difficult to tease apart facilitation due to onset repetition and potential inhibition due to internal speech monitoring, if there is any. In a future study, it is necessary to include ERP data to have a better understanding of the influence of onset repetition across time.

## Direction for Future Research

Due to time constraints, the current dissertation project did not investigate the role of tonal syllable in a picture naming task among Grade 1, Grade 4 children and adults. This experiment can be conducted as part of a future research project, so that empirical evidence can be provided to illustrate an overall picture about the developmental trajectory of children's functional phonological unit. More importantly, all the four experiments could be conducted among native Mandarin-speaking children in preschool and Grade 3. The results of the current dissertation have shown that Grade 1 children select the onset as the functional phonological unit regardless of word length. However, as mentioned earlier, it remains unclear what the functional phonological unit is when no orthographic knowledge has not been formally introduced to children. Although it is difficult to find 100% preliterate children in the modern society nowadays, it would be interesting to investigate the functional phonological unit in preschool children who have not received any formal training in reading.

The hypotheses about preschool children are that 1) they would fail to show any effect in Experiments 1 and 2 (i.e., no onset facilitation) since Chinese is syllable-timed and they haven't received any training to separate onsets and rimes; 2) they would show a syllable segment interference effect in Experiment 3, considering that they may not able to process segmental and tonal information separately; 3) they would show significant tonal syllable facilitation in Experiment 4. The four experiments may be conducted among Grade 3 children as well. In a pilot study, preliminary results have shown findings that are consistent with the above hypotheses, the 5-year-old children failed to show onset facilitation in Experiments 1 and 2, suggesting that they failed to select onset the functional phonological unit. Similar to Grade 1 children, a clear trend of syllable segment interference effect was shown in Experiment 3 among

5-year-old children. However, the reason of the interference effect should be different from that for Grade 1 children, considering that 5 year olds seem not to process onsets and rimes separately. Instead, they may process tonal syllable as an integral unit so that the shared syllable segment with different tones led to difficulty of articulation. This hypothesis has been at least partially confirmed by the preliminary results of Experiment 4, in which 5-year-old children showed a clear trend of tonal syllable facilitative effect, suggesting that tonal syllable might be selected as their functional phonological unit.

Given that Grade 2 children are still in the transition period and Grade 4 children perform like adults, it is possible that the transition from the onset to the syllable segment has completed by Grade 3. If so, Grade 3 children should show the same results as Grade 4 children, that no effect was shown in Experiments 1 and 2, while significant facilitation was shown in Experiment 3. An alternative hypothesis is that Grade 3 children select the whole tonal syllable unit as the functional phonological unit; namely, the transition is not completed until Grade 4. In this case, Grade 3 children should show the same results as Grade 2 children, that no effect was shown in Experiments 1, 2, and 3, while significant facilitation was shown in Experiment 4.

Another direction for future research is to conduct a training study in which all the participants are from the same age group, so that the age difference/effect will not intertwine with the influence of orthographic experiences. For example, Group A studies Mandarin without any visual aids (i.e., only auditory stimuli are provided), Group B studies Mandarin with extensive exposure to Pinyin, and Group C studies Mandarin with extensive exposure to Chinese characters. At the end of the training study, picture naming tasks with the form preparation paradigm will be conducted. The prediction is that only Group B should select the smaller unit (i.e., onset) as the functional phonological unit, since the morphosyllabic feature of Chinese characters and the syllable-timed feature of Chinese speech would encourage speakers to attend more to the syllable.

Lastly, since the current dissertation research did not investigate the interaction between the influence of orthographic experiences and other factors such as attention and working memory, future research is needed to investigate the influence of orthographic experiences on different types of spoken word production. In natural speech planning, the articulation of a spoken word is not limited to simple tasks such as picture naming. For example, in real life, spoken word production may involve different demands, such as memorization and reasoning, so that different cognitive mechanisms are involved. Previous studies that examined the influence of orthographic consistency have considered different types of tasks, including simple picture naming, associate naming that required memorization, and reading that required phonological decoding (Bi, Wei, Janssen, & Han, 2009; Roelofs, 2006), and showed that the influence of orthographic consistency is modulated by task demands. Only in a reading task which is directly related to the spelling of a word, whether or not a set of response words always begins with the same initial letter (e.g., ***s**andaal, **c**ircuit,* and ***C**D* (lemon, circuit, CD) vs. ***c**itroen, **c**ircuit,* and ***C**D* (sandal, circuit, CD) in Dutch) influenced the form preparation effect such that inconsistent spelling reduced the effect size (Roelofs, 2006). For Mandarin Chinese, if the first character of a set of words only shared similar orthographic information but not phonological information (e.g., 汤勺 (/tang1shao2/, spoon), 杨柳 (/yang2liu3/), willow, 肠子 (/chang2zi/, gut)), it led to an inhibitory effect only in a reading task with the form preparation paradigm but not in associate naming or simple picture naming tasks (Bi, Wei, Janssen, & Han, 2009).

In summary, it is possible that orthographic related effects on spoken word production are modulated by task demands. However, this dissertation research did not compare the influence of orthographic experiences on the functional phonological unit in different tasks. Although it is expected that orthographic influence should be larger in tasks that are more relevant to orthographic processing, such as a written word association task, this issue needs to be addressed in future research. Particularly, in a task in which the orthographic information is explicitly represented, the orthographic form of the visual words may influence children's selection of the functional phonological unit while influence from the explicit orthographic form may interact with children's orthographic experiences. Therefore, it is particularly interesting to investigate what functional phonological unit children would select if the explicit orthographic form is different from the orthography they are exposed to. It is also possible that other cognitive mechanisms (e.g., working memory and attention) interact with orthographic experiences in a complicated production task. To sum up, it is interesting to compare the orthographic experiences' effect in tasks that have various cognitive demands (e.g., high vs. low working memory).

**Broader Impact**

This dissertation project improves our understanding about the development of phonological retrieval and encoding in spoken word production. Previous literature suggested that the functional phonological unit for speakers in a language might vary in different contexts, that is, the functional phonological unit is flexible. The present dissertation suggested that orthographic experiences in the process of acquiring literacy skills might contribute to this flexibility. For example, the extensive Pinyin experience may encourage Grade 1 children to select onset as the functional phonological unit in a simple picture-naming task, and may allow them to select onset in other contexts or tasks whenever necessary in the future.

The present dissertation will also benefit society by providing a number of important contributions to pedagogical practices. First, based on the findings of this project, teachers and educators will be able to develop more effective educational methodology to improve children's spoken language fluency by integrating speech practice with ample orthographic input. For example, the current dissertation project showed that the functional phonological unit is the small unit- the onset - in children at Grade 1 when Pinyin is introduced, but selection of this unit transitions toward the larger unit- the tonal syllable among Grade 2 children and then toward the syllable segment due to the extensive exposure to Chinese characters among skilled readers. The results suggest that readers' functional phonological unit is influenced by the orthography they are extensively exposed to. As a result, educators may guide language learners to attend to the proximate phonological unit consistent with the nature of the orthography (e.g., phoneme for languages with alphabetic orthographies; mora for Japanese; and syllable for Chinese) when learners are exposed to multiple orthographies. This consistency may help to improve language learners' speech proficiency and fluency.

Second, the findings of this dissertation research may be helpful to children with language difficulties, particularly to those with speech disfluency or other speech-related difficulties. Identifying the influence of orthographic information on speech production should be useful for overcoming difficulties in speech planning. For example, for children with speech disfluency who are learning languages with alphabetic writing systems, directing them to phonemes via written forms of the language may enhance their speech planning.

Third, this project may promote future research on related topics among children who have experience with multiple orthographies. As a result of rapid globalization, it is likely that more and more children will be exposed to multiple orthographies and languages. Training on the orthography of a language may not only facilitate children's reading ability in that language, but also improve their oral proficiency by helping them with phonological planning and preparation.

**Conclusion**

This dissertation project examined the development of the functional phonological unit in native Mandarin speakers and the influence of speakers' orthographic experiences on its selection. Participants consisted of four age groups, including Grade 1 children who have limited Chinese character knowledge and have extensive Pinyin exposure, Grade 2 and Grade 4 children who have better character knowledge and limited exposure to Pinyin, and adults who have the most advanced character knowledge and seldom read and write Pinyin in their daily lives. The onset is selected as the functional phonological unit in spoken word production in Grade 1 children, but the syllable segment is selected in skilled readers (Grade 4 children and adults), and tonal syllable is selected in Grade 2 children. The difference might be attributed to the speakers' orthographic experiences, orthographic exposure in particular. In addition, it is possible that Grade 1 children process the rime segment and tone as an integral unit, while Grade 4 children and adults prepare them separately in spoken word production. For Grade 2 children, the connection between rime segments and tones may be stronger than that in skill readers but weaker than that in Grade 1 children. This dissertation shed light on the development of children' phonological retrieval and encoding in the planning of spoken word production. It is among the first empirical studies that take into consideration the influence of speakers' orthographic experiences. The findings from this dissertation suggested that orthographic experiences might restructure children' phonological representation to be consistent with the features of the orthography that they are frequently exposed to in their life.

## Appendix A

Pinyin knowledge test

指导语：请从左到右依次阅读每一行拼音。如果你不认识，就说“我不知道”。

Instruction: Please read the following Pinyin one by one from left to right. If you do not know how to read it, please say “I don’t know”.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | qí | guāng | lèi | ǎi | biān | qiū | zhǒu | máo |
| 2 | yān | qiā | quàn | suǒ | róu | kuài | liáng | jiā |
| 3 | shuāi | hù | lóng | wǎng | lì | qióng | qīng | jú |
| 4 | huá | pěng | miáo | é | zhuō | cún | tā | ǒu |
| 5 | ā | níng | bó | zhèn | áng | fú | jué | shè |
| 6 | ào | ān | chí | xiē | duì | xiōng | zēng | diào |

**Appendix B**

Character knowledge test

指导语：请从左到右依次阅读每一行汉字，有些汉字你可能不认识因为你还没有学过。如果你不认识，就说“我不知道”。

Instruction: Please read the following characters one by one from left to right. Some of the characters may be new to you because you haven’t learned it. If you do not know how to read it, please say “I don’t know”.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 包 | bao1 | 灯 | deng1 | 害 | hai4 | 好 | hao3 | 黑 | hei1 | 秋 | qiu1 |
| 2 | 问 | wen4 | 雪 | xue3 | 达 | da2 | 思 | si1 | 梨 | li2 | 爽 | shuang3 |
| 3 | 杨 | yang2 | 具 | ju4 | 引 | yin3 | 选 | xuan3 | 猜 | cai1 | 证 | zheng4 |
| 4 | 环 | huan2 | 攻 | gong1 | 腰 | yao1 | 拜 | bai4 | 仙 | xian1 | 秒 | miao3 |
| 5 | 幻 | huan4 | 积 | ji1 | 碟 | die2 | 忽 | hu1 | 滑 | hua2 | 退 | tui4 |
| 6 | 筋 | jin1 | 辣 | la4 | 劳 | lao2 | 舒 | shu1 | 谈 | tan2 | 艳 | yan4 |
| 7 | 荒 | huang1 | 悦 | yue4 | 枪 | qiang1 | 浓 | nong2 | 膛 | tang2 | 澡 | zao3 |
| 8 | 潮 | chao2 | 规 | gui1 | 缘 | yuan2 | 堆 | dui1 | 疼 | teng2 | 嗓 | sang3 |
| 9 | 爆 | bao4 | 忍 | ren3 | 忧 | you1 | 驰 | chi2 | 烫 | tang4 | 浴 | yu4 |
| 10 | 敬 | jing4 | 革 | ge2 | 邻 | lin2 | 忠 | zhong1 | 堵 | du3 | 纲 | gang1 |
| 11 | 抛 | pao1 | 棺 | guan1 | 渐 | jian4 | 励 | li4 | 幽 | you1 | 挤 | ji3 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | 孤 | gu1 | 核 | he2 | 熄 | xi1 | 隐 | yin3 | 煤 | mei2 | 愣 | leng4 |
| 13 | 谎 | huang3 | 歹 | dai3 | 繁 | fan2 | 洼 | wa1 | 款 | kuan3 | 辱 | ru3 |
| 14 | 逢 | feng2 | 焰 | yan4 | 磷 | lin2 | 烽 | feng1 | 碑 | bei1 | 侦 | zhen1 |
| 15 | 衫 | shan1 | 燥 | zao4 | 茂 | mao4 | 奸 | jian1 | 锈 | xiu4 | 拆 | chai1 |
| 16 | 痕 | hen2 | 愚 | yu2 | 痴 | chi1 | 跪 | gui4 | 仅 | jin3 | 寨 | zhai4 |
| 17 | 潘 | pan1 | 屈 | qu1 | 宴 | yan4 | 郁 | yu4 | 哲 | zhe2 | 沸 | fei4 |
| 18 | 赐 | ci4 | 焊 | han4 | 篱 | li2 | 旷 | kuang4 | 拯 | zheng3 | 捷 | jie2 |
| 19 | 搔 | sao1 | 释 | shi4 | 颖 | ying3 | 洽 | qia4 | 烁 | shuo4 | 暇 | xia2 |
| 20 | 涉 | she4 | 絮 | xu4 | 彦 | yan4 | 糙 | cao1 | 寇 | kou4 | 衰 | shuai1 |
| 21 | 籁 | lai4 | 拣 | jian3 | 袅 | niao3 | 榛 | zhen1 | 瀚 | han4 | 黏 | nian2 |
| 22 | 髦 | mao2 | 译 | yi4 | 峭 | qiao4 | 漾 | yang4 | 钦 | qin1 | 墅 | shu4 |
| 23 | 懦 | nuo4 | 灶 | zao4 | 赫 | he4 | 瞻 | zhan1 | 翱 | ao2 | 哽 | geng3 |
| 24 | 遂 | sui4 | 跛 | bo3 | 讳 | hui4 | 嗜 | shi4 | 畀 | bi4 | 喀 | ka1 |
| 25 | 羁 | ji1 | 戍 | shu4 | 煜 | yu4 | 蠡 | li2 | 斡 | wo4 | 泶 | xue2 |

*Note. The Pinyin symbol was not printed in the version that was shown to participants.*

## Appendix C

关于书写经历的调查问卷。

*阅读部分:*

1. 您/您的孩子能够阅读多少种书写系统 (如：拼音，汉字，英文，西班牙文等，阿拉伯数字不算在其中)？都分别是哪些书写系统？

2. 对于如下四种阅读材料，请回答以下问题：

语文课本；其他科目课本；课外读物；网络文字

1) 一般情况下，您/您的孩子每周平均花多少时间在阅读这些读物上？

2) 这些读物分别都包含哪些书写系统 (如：拼音，汉字，英文，西班牙文等，阿拉伯数字不算在其中)？

3) 对于包含多种书写系统的读物，每周您/您的孩子是如何分配阅读时间在各种书写系统上的？ (如：语文课本包含汉字与拼音，您的回答可以是 4 小时拼音， 4 小时汉字)

| 问题编号 | 语文课本 | 其他科目课本 | 课外读物 | 网络文字 |
|---|---|---|---|---|
| 1) | | | | |
| 2) | | | | |
| 3) | | | | |

*书写部分:*

1. 您/您的孩子能够写多少种书写系统 (如：拼音，汉字，英文，西班牙文等，阿拉伯数字不算在其中)？都分别是哪些书写系统?

2. 您/您的孩子能够打 (即打字) 多少种书写系统 (如：拼音，汉字，英文，西班牙文等，阿拉伯数字不算在其中) ？都分别是哪些书写系统?

3. 对于每种书写系统，您/您的孩子平均每周花多少时间在用其书写上面？每周花多少时间在用其打字上面？

| 书写系统 | 写字时间 | 打字时间 |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

## Appendix D

Questionnaire about orthographic exposure

***Section I Reading:***

1. How many writing systems (e.g., Pinyin, Chinese, English, Spanish, etc., Arabic number does not count) can you/your child read? What are they?

2. For the following four types of readings, answer a series questions: Chinese textbook; other textbook; paper-based readings other than textbooks; Internet Media

1) How many hours do you/does your child spend on reading the following materials in a typical week?

2) What writing systems (e.g., Pinyin, Chinese, English, Spanish, etc. Arabic number does not count) are included in the readings?

3) For the readings involve multiple writing systems, how are the hours distributed to those writing systems? (e.g., Chinese textbook includes Pinyin and Chinese character; a possible answer could be 4 hours-Pinyin, 4 hours-Chinese character in a typical week)

| Question No. | Chinese textbook | Other textbook | Other than textbooks | Internet Media |
|---|---|---|---|---|
| 1) | | | | |
| 2) | | | | |
| 3) | | | | |

***Section II Writing&Typing:***

1. How many hours do you/does your child spend on writing in a typical week? What writing system(s) do you/does he (or she) use?

2. How many hours do you/does your child spend on typing in a typical week? What writing system(s) do you/does he (or she) use?

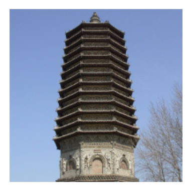
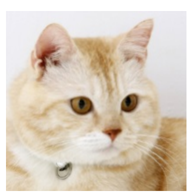
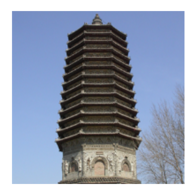
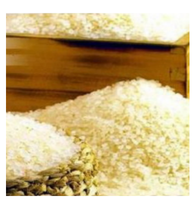
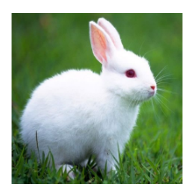
3. For each writing system, how many hours do you/does your child spend on writing it in a typical week? How many hours does your child spend on typing it in a typical week?

| Writing system | Time spent on writing | Time spent on typing |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

*Notes. Because adults and children's parents use the same questionnaire, the working "you/your child" in some questions are used to target different participants. For example, adults will answer "How many types of writing system can you read?" Parents will answer "How many types of writing system can your child read?"

**Appendix E**

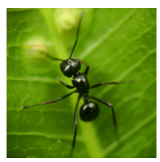
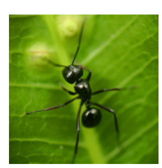
Stimuli for Experiment 1

| | | | | |
|---|---|---|---|---|
| Homogenous Condition | Set 1 | 马 (mǎ, *horse*)  | 猫(māo, *cat*)  | 米(mǐ, *rice*)  |
| | Set 2 | 蛇(shé, *snake*)  | 树(shù, *tree*)  | 勺(sháo, *spoon*)  |
| | Set 3 | 兔(tù, *rabbit*)  | 塔(tǎ, *tower*)  | 桃(táo, *peach*)  |
| Heterogeneous Condition | Set 1 | 猫(māo, *cat*)  | 蛇(shé, *snake*)  | 塔(tǎ, *tower*)  |
| | Set 2 | 米(mǐ, *rice*)  | 勺(sháo, *spoon*)  | 兔(tù, *rabbit*)  |
| | Set 3 | 桃(táo, *peach*)  | 马 (mǎ, *horse*)  | 树(shù, *tree*)  |

*Note*. The first symbol in the parentheses is the Pinyin symbol of the corresponding character.

**Appendix F**

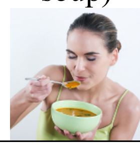
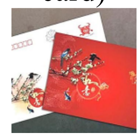
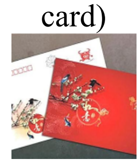
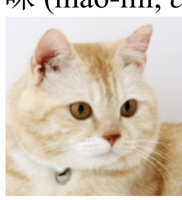
Stimuli for Experiment 2

| | | | | |
|---|---|---|---|---|
| Homogenous Condition | Set 1 | 海豚 (hǎi-tún, *dolphin*)<br> | 核桃(hé-tao, *walnut*)<br> | 葫芦(hú-lu, *calabash*)<br> |
| | Set 2 | 树叶(shù-yè, *leaf*)<br> | 狮子(shī-zi, *lion*)<br> | 手套(shǒu-tào, gloves)<br> |
| | Set 3 | 蚂蚁(mǎ-yǐ, *ant*)<br> | 玫瑰(méi-guī, *rose*)<br> | 帽子(mào-zi, *hat*)<br> |
| Heterogeneous Condition | Set 1 | 海豚 (hǎi-tún, *dolphin*)<br> | 狮子(shī-zi, *lion*)<br> | 玫瑰(méi-guī, *rose*)<br> |
| | Set 2 | 树叶(shù-yè, *leaf*)<br> | 核桃(hé-tao, *walnut*)<br> | 帽子(mào-zi, *hat*)<br> |
| | Set 3 | 葫芦(hú-lu, *calabash*)<br> | 蚂蚁(mǎ-yǐ, *ant*)<br> | 手套(shǒu-tào, gloves)<br> |

*Note*. The first symbol in the parentheses is the Pinyin symbol of the corresponding character.

# Appendix G

Stimuli for Experiment 3

| | | | | |
|---|---|---|---|---|
| Homogenous Condition | Set 1 | 喝汤(hē-tāng, drink soup)  | 盒子(hé-zi, *box*)  | 贺卡 (hè-kǎ, greeting card)  |
| | Set 2 | 山羊(shān-yáng, goat)  | 扇子(shàn-zi, *fan*)  | 闪电(shǎn-diàn, lightning)  |
| | Set 3 | 猫咪 (māo-mī, *cat*)  | 帽子(mào-zi, *hat*)  | 毛衣 (máo-yī, sweater)  |
| Heterogeneous Condition | Set 1 | 喝汤(hē-tāng, drink soup)  | 扇子(shàn-zi, *fan*)  | 毛衣 (máo-yī, sweater)  |
| | Set 2 | 山羊(shān-yáng, goat)  | 帽子(mào-zi, *hat*)  | 贺卡 (hè-kǎ, greeting card)  |
| | Set 3 | 猫咪 (māo-mī, *cat*)  | 盒子(hé-zi, *box*)  | 闪电(shǎn-diàn, lightning)  |

*Note*. The first symbol in the parentheses is the Pinyin symbol of the corresponding character.

## Appendix H

Stimuli for Experiment 4

| | | | | |
|---|---|---|---|---|
| Homogenous Condition | Set 1 | 项链 (xiàng-liàn, *necklace*)<br> | 象牙(xiàng-yá, *ivory*)<br> | 相机(xiàng-jī, *camera*)<br> |
| | Set 2 | 树叶(shù-yè, *leaf*)<br> | 数字(shù-zì, *number*)<br> | 竖琴(shù-qín, harp)<br> |
| | Set 3 | 荷花(hé-huā, *lotus*)<br> | 核桃(hé-tao, *walnut*)<br> | 盒子(hé-zi, *box*)<br> |
| Heterogeneous Condition | Set 1 | 项链 (xiàng-liàn, *necklace*)<br> | 数字(shù-zì, *number*)<br> | 核桃(hé-tao, *walnut*)<br> |
| | Set 2 | 象牙(xiàng-yá, *ivory*)<br> | 竖琴(shù-qín, harp)<br> | 荷花(hé-huā, *lotus*)<br> |
| | Set 3 | 相机(xiàng-jī, *camera*)<br> | 树叶(shù-yè, *leaf*)<br> | 盒子(hé-zi, *box*)<br> |

*Note*. The first symbol in the parentheses is the Pinyin symbol of the corresponding character.

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