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Implicit statistical learning of patterns in orthography to phonology mappings in Chinese EFL learners

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Abstract

The majority of research in investigating the learning of spelling and pronunciation rules focused predominantly on children's L1 development with an alphabetic language background. With the wide spread of the English language around the globe, the composition of English as foreign language (EFL) learners is becoming more and more diverse. Group differences such as language systems may cause learning differences to the learning of graphotactics. However, current understandings of how second or foreign language learners perform in learning those orthography-to-phonology mapping rules remain ill-defined.

This study attempted to provide deeper insight into how adult EFL learners with a fundamentally different language system, that is, Mandarin Chinese, learn the English orthography-to-phonology patterns under brief incidental exposure. This quantitative research used pre- and post-test design to test the learning of the real English spelling patterns, i.e., the spelling and pronunciation patterns of letter <c>, in the experimental and control conditions. With Mandarin Chinese as their native languages, it may be possible that Chinese EFL learners' L1 may affect their learning of English spelling and pronunciation patterns. Therefore, the researcher is also interested in examining whether learners with better Chinese and English phonemic awareness may perform and improve better in the mapping task. In this sense, the researcher explored the correlations between Chinese and English phonological systems and their performance in orthography-phonology mapping.

This project involved a quantitative research design with data collected in the following phases. First, all the participants were asked to finish a language background questionnaire. In the second phase, the researcher conducted an orthographic mapping experiment with pre- and post-test designs with 60 Chinese EFL learners. The 30 experimental participants were also involved in the intervention, providing a brief, incidental exposure to the words embedding the target patterns. In the third part, all participants were then asked to complete English

and Chinese phonemic awareness tests. Finally, they were asked to finish a general vocabulary test and another questionnaire concerning their awareness of the target spelling and pronunciation patterns.

The results were divided into four parts correspondingly to answer four research sub-questions. The first finding comparing the experimental and control group suggested that the experimental participants improved in the post-test after the training. Chinese EFL learners could pick up on the spelling and pronunciation patterns and benefit from the incidental exposure to graphotactic and phonological mapping patterns. Secondly, English and Chinese phonemic awareness were found to be significantly correlated with all participants' pre-test performance in the orthography-phonology mapping task. However, phonemic awareness was not correlated with the experimental participants' gain scores from pre- to post-test.

The current research findings demonstrated that adult Chinese EFL learners can pick up on the patterns and generalize the patterns to new words under incidental condition. It would be interesting for future studies to explore whether explicit teaching in phonics knowledge and phonemic awareness may help these L2 learners to be more robust in their learning of these graphotactic patterns. Also, it provided supporting evidence that not only phonemic awareness in the target L2 language (English, in the current study) is correlated with learning the L2 spelling and pronunciation patterns, but L1 phonemic awareness may also play a positive role in L2 spelling and pronunciation patterns learning. Future research in this area can extend from the current study with a larger sample size and explore more validated task designs in testing orthography-to-phonology mapping and phonemic awareness in adult L2 language learners.

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1. Overview

1.1 Introduction

English as the lingua franca nowadays is being strongly promoted in China. To satisfy the needs of national development and economic expansion, English is prioritized in the Chinese education system (Hu, 2002; Hu, 2005), resulting in a significantly increasing number of Chinese English as a foreign language (EFL) learners. In learning a second language (L2), it is essential to learn the relationships between written and spoken language. This can be challenging for Chinese EFL learners since the two languages are fundamentally different. English is an alphabetic language system, while Chinese is a logographic language system. It should be noted that there is still similarity between the two languages. The Pinyin system is invented as the phonological system of Mandarin Chinese, using alphabetic letters to help Chinese students learn the pronunciation of Chinese characters. It is similar to the English phonological system in that syllables are formed by letters following specific rules in Pinyin. Also, some of the sounds in Pinyin are similar to those in English.

The relationship between written and spoken language has been investigated in a considerable volume of literature in children's L1 literacy development, but less in L2, where individuals often learn the written and spoken language simultaneously. In addition, Existing research exploring the learning of spelling patterns mainly focuses on investigating orthographic or graphotactic patterns in Western contexts targeting children whose L1 is mainly alphabetic languages. Therefore, the current study aims to fill the research gap and provide insights into will examine how L2 learners acquire the relationship between written and spoken language by focusing on Chinese EFL learners' knowledge of the English spelling and pronunciation patterns of letter <c>.

1.2 Structure of the Dissertation

To achieve the above goals, the literature review (Chapter 2) opens with a detailed introduction of theories basis on orthographic mapping, following a review of previous studies on aspects of spelling knowledge and the nature of spelling development. Secondly, this chapter will discuss the learning of spelling and spelling development from a statistical and implicit perspective. The last part of the literature review is centered around learning spellings in an L2 context. This part discusses cross-language transfer in the writing system and learning spelling and pronunciation patterns in an L2 context. Further, this chapter focuses on literacy development in an L2 context, that is, Mandarin Chinese in the current study. An introduction to the Chinese phonological system, the Pinyin system, will be presented before discussing how L1 phonemic awareness may affect L2 reading learning at a suprasegmental level (grapheme-phoneme level). The research questions of the present study are outlined as well.

The third chapter explains the overall research method for the current study. First, this chapter describes the study sample and participant recruitment. Then the experiment design, stimuli, and procedure will be introduced. The experiment in this study consisted of two parts: (1) exploratory, quantitative data collection via experiment; (2) a general vocabulary test, a language background questionnaire, and a pattern knowledge awareness questionnaire.

Chapter 4 presents the quantitative findings from the experiment and questionnaires. The first section contains results from preliminary analyses concerning participant profiling and their general language background and proficiency for the two groups. Next, findings are presented addressing each of the four research questions of this project:

1. Can Chinese EFL learners improve their knowledge of the pronunciation of English written words embedding the 'c' orthography-phonology mapping pattern following brief exposure to those words?

2. Can Chinese EFL learners acquire generalized knowledge of the 'c' orthography-phonology mapping pattern implicitly, following brief incidental exposure to words embedding that pattern?
3. Does English/Chinese phonemic awareness correlate with participants' knowledge of the pronunciation of English written words embedding the 'c' orthography-phonology mapping pattern prior to exposure?
4. Does English/Chinese phonemic awareness correlate with participants' ability to learn the 'c' pattern from implicit incidental exposure to words embedding that pattern?

The first and second questions were addressed through the data gathered by the orthography-phonology mapping task. The third and fourth questions were investigated through Spearman's correlations analysis using the scores from mapping task and English and Chinese phonemic awareness tasks.

The final chapter first reviews and discusses the results of the studies in light of the earlier theories and research findings. The external validity of the findings is discussed in the context of the study. In addition, the chapter evaluates the potential contributions and limitations of this study. In the end, this chapter discusses future research directions and implications for teaching and learning this kind of graphotactic knowledge for L2 learners.

2. Literature Review

2.1 Orthographic mapping: from letters to sounds

According to Sampson (1985), we usually think of a writing system as a way to visually record and represent spoken utterances. Readers need to apprehend the distinctive mappings between printed visual symbols and sounds of the oral language (Sarris, 2020). This process is considered orthographic mapping (OM). OM is enabled by the ability to connect letters in the spellings to sounds in their pronunciations and distinguish those sounds in pronunciations of words (Ehri, 2014), that is, phonemic awareness and grapheme-phoneme knowledge. In alphabetic languages, graphemes (i.e., letters) are symbols used to represent phonemes (i.e., units of sound). This mapping can be more or less transparent. Some transparent languages have a one-to-one mapping (or near so), while other languages like English have deep orthography, and mappings may be many to one, with exceptions. When reading and spelling words, OM enables readers to read words by sight and spell words (Miles & Ehri, 2019). The definition of the term sight word in this research follows the definition by Ehri (1992, 1998, 2005) as what the mind does to store the forms of written words in memory and the retrieving of spellings, pronunciations, and meanings of these words from the mind as soon as the readers read upon the words.

In many languages, including English, there are spelling patterns and 'rules' about how graphemes can be used in different contexts, though there may be exceptions. Therefore, the knowledge of grapheme-phoneme mapping rules helps in successful orthographic mapping. This contribution has been studied by Ehri and colleagues (2009) in a classroom-based longitudinal study. They conducted two instructional programs with struggling readers in Grade 1, 2, and 3. The Key method taught students to read words by analogy to keywords (e.g., using the word ‘mountain’ to read ‘fountain’). Extending this, the Key-Plus method additionally taught students to retain the words' spelling by analyzing mapping relations between graphemes and phonemes. Students needed to count phonemes in the pronunciation, then mapped graphemes in the spellings to its phonemes and explained the regularities. Results showed that students in the Key-Plus instruction outperformed students in the Key instruction on word reading and spelling abilities. The vast literature focused almost exclusively on beginning readers learning their native language. However, a closer look at the literature reveals a gap between research on L1 and L2 readers. Therefore, the learning of such 'rules' or patterns by adult L2 learners is the topic of the current study, which leads to the next section where these types of patterns will be discussed.

2.2 Spelling and Graphotactics

The English writing system is comprised of two primary groups of patterns (Venezky, 1967, p.77). The first is the internal structure of the orthography, which consists of the classes of letters (graphemes) and the allowable sequences of these classes (graphotactics). For example, the vowel letter <y> occurs mainly in the final position and <i> in all positions, and double consonants can occur at the ends of words but not at the beginning in English. These patterns are determined simply by graphical considerations necessary for learning to read.

The second set of patterns is more complicated than the above, linking spelling to sound, which can be further subdivided into two types. The first type of pattern is founded upon the idiosyncrasies of the orthography. For example, initial <c> can have two different pronunciations: soft sound /s/ and hard sound /k/ as in 'center' and 'car', respectively (the target patterns in the current study). The choice between these two sounds is dependent upon the English orthography; /s/ when the letter <c> is followed by the vowel <e> or <i>, and /k/ is followed by <a>, <o>, or <u> (see Table 1).

Table 1. The spelling and pronunciation patterns of letter <c> in English

Phonemes	Following vowel letters	Example (Pronunciation)
/s/ (soft sound)	Letter <e> and <i>	• Cease (/siːs/) • City (/sɪti/)
/k/ (hard sound)	Letter <a>, <o>, and <u>	• Call (/kɔːl/) • Cold (/kəʊld/) • Cute (/kjuːt/)

The second types of spelling-to-sound patterns are those patterns that derive directly from English phonological habits. For instance, the medial <n> also has two different pronunciations as /n/ and /ŋ/. The choice is primarily phonological. When followed by a velar stop, it is pronounced as /ŋ/, while the rule for the pronunciation /n/ is that it usually does not occur before /g/ or /k/. According to Venezky (1967), native English speakers switch between those two pairs of sounds with no conscious effort. However, how L2 learners acquire those spelling-to-sound patterns and apply them in word reading is much less explored. Therefore, one main focus of this research is to fill this gap and explore L2 learners, that is, Chinese EFL learners in the current study, in their learning of English spelling-to-sound patterns, using the 'c' patterns mentioned above as the experiment target. The following part will introduce the basis for the above two groups of patterns, that is, patterns of graphotactics and patterns linking spelling to sound.

2.2.1 Spelling patterns: Graphotactic perspective

According to the above discussion, the first group of spelling patterns concerning garphotactics derives purely from the internal structure of the English written language, which is a highly patterned domain with regularities and constraints for the visually presented words. The sensitivity to graphotactics in children's spellings in alphabetic languages such as English and French is evident in a large volume of studies. Research shows that children have graphotactic awareness and knowledge at an early stage. Some preschool children around 4 and 5 years old already exhibit knowledge in letter arrangement that they are able to write down letter strings when they are encouraged to write words, even though those strings are not phonologically related to the words they are asked to write. For example, 4-year-olds spelled <en> for 'drop' which are not phonologically motivated that /drɒp/ is related to 'drop' (Read, 1986). These prephonological spellers may use multiple letters and letter groups that are more common in the language that they are exposed to. For example, Pollo et al. (2009) investigated the invented spellings of prephonological 4-year-old children in Brazil and the US. Those researchers suggest that in the spelling task, Brazilian children tended to use more vowel letters than US children at approximately the same proportion that their local language, Portuguese texts, use more vowels than English texts. These findings indicate that prephonological spellers also have some basic understanding of what the written words look like in their languages, which is basic graphotactic knowledge.

Furthermore, several recent studies explore the awareness and learning of graphotactic constraints in spelling. The extensive analyses of English orthography show that these conditional spelling patterns are more powerful cues in spelling development (Kessler & Treiman, 2001; Treiman & Boland, 2017; Treiman & Kessler, 2006; Venezky, 1970). For example, In Treiman's (1993) research, Grade 1 children were found using consonant doublets (e.g., bb) more frequently in the medial and final positions rather than the initial positions. Other than letter positions, it is also found that Children's graphotactic knowledge, such as their use of spelling combinations (e.g., their spellings of consonants and vowels), are considered to be influenced by the surrounding consonants and vowels. In French, for example, double consonants are legitimate after vowels but not after other consonants. Pacton and Fayol (2000) discovered that 8-year-old French children had started to develop such graphotactic knowledge that they could tell ‘issoge’ as a word, but ‘genssor’ could not. Hayes et al. (2006) also conducted research to explore the graphotactic cues which, in its nature, were independent from phonology. Nevertheless, they found it challenging to distinguish graphotactic influence from the phonological influence when examining 7-8-year-olds' use of vowel context to help spell consonants. Since short vowels are mostly one-letter spellings such as /æ/ in 'rabbit', while long vowels are more likely to be two-letter spellings such as /i:/ in 'seat'. For adults, however, they did not find such preferences for using one-letter spellings for short vowels. Extending this research, Treiman and Boland (2017) conducted study testing adults in their L1. They provided evidence that graphotactic context played an essential role in using single or double consonants in the middle of disyllabic items. Using a spelling production task, they found that adult participants tended not to double the consonants if they spelled the first vowel with more than one letter or before certain final spelling like 'ic' and 'it'. These findings bring out the other more complicated set of spelling patterns which relate spelling to sound, leading to the discussion in the next section.

2.2.2 Spelling patterns: Phonological perspective

Phonology is another essential element needed to be discussed in learning spelling, regarded by Treiman (2017a, p.87) as having an early and undeniably lasting role in spelling development. Learning the link between letters and sounds is an essential part of being proficient in using an alphabetic language system. An example of this set is the pattern of the grapheme 'c' linking to phonemes /s/ and /k/ in different contexts (see Table 1 above), which is the main focus of the current study. Note that there are exceptions to this pattern, though it will not be investigated in this research.

Previous studies in this area have almost exclusively focused on children's learning of phonology and spelling development. According to Treiman (2017a), using letters to symbolize sounds begins around 5-6-years old when US children start to move from prephonological spellings (e.g., bparo for fit) to spellings such as 'ft' for 'fit'. Before children can eventually build up the link between letters and phonetics correctly, they experience the stage of failing to represent some phonemes within words and making spelling errors such as including unexpected letters even though they can pronounce the words correctly. For example, in Treiman's research (1993), some children pronounced the word 'slide' correctly but wrote 'sid' for slide, symbolizing the first consonant with the correct letter <s> but failing to include the consonant letter <l> in the initial consonant cluster. The spelling errors concerning consonant clusters reflect that children have difficulties conceptualizing spoken words as sequences of phonemes (Treiman, Zukowski, & Richmond-Welty, 1995). In other cases of spelling errors, children begin to incorporate phonology into spelling, using letter names to aid spelling. In English, for example, children spell 'hom' for 'home' since they spell the sequence of phonemes with the corresponding letter (Varnhagen, McCallum, & Burstow, 1997). Similarly, Pollo, Treiman and Kessler (2008) also observed this phenomenon in Portuguese children. They reported that those young speakers of Portuguese use the letter <q> to spell the 'ke' sequence since the letter <q> is named 'ke' in Portuguese.

Learning to spell becomes more challenging when the mappings between phonemes and letters are dependent on the context. Similar to the graphotactic context, the choice of alternative spelling of a phoneme can depend on the phonological context, which is the surrounding phonemes that come before or after it. Some adult-based studies using spelling production tasks support the idea that they found out adults' spellings of phonemes are affected by the identity of preceding or following phonemes (Cassar & Treiman, 1997; Dich, 2010; Perry & Ziegler, 2004; Treiman, Kessler, & Bick, 2002). For instance, in Cassar and Treiman's (1997) forced-choice task, participants were presented with two nonwords and instructed to choose the one that matched the spoken nonword. University students preferred single consonants after long vowels, such as 'janim' as a spelling of /ˈd͡ʒenɨm/, and double consonants after short vowels, such as 'jannim' as a spelling of /ˈd͡ʒænɨm/. Similar findings have also been seen with the 11-12-year-olds in the same study choosing items embedding the correct long and short vowels.

To recap, both developing and skilled readers are sensitive to a wide variety of spelling patterns in their L1, which helps them make the right option when faced with ambiguous spelling circumstances. Readers are usually not taught explicitly about these conditional spelling patterns within graphotactic and phonological contexts but may acquire these patterns implicitly via statistical learning. This ability improves gradually with age (Treiman, 2017a). In other words, the development of spelling proficiency is a continuous process reflecting gradual changes in readers' exposure and use of phonological and orthographic information (Ehri, 1992; Notenboom & Reitsma, 2003). The following section will start by focusing on children's spelling development in their L1 and looking for evidence of how readers learn and acquire these patterns.

2.3 Spelling development in child's L1

2.3.1 Dual-route theories

The dual-route theory (Barry, 1994; Tainturier & Rapp, 2001) is the dominant theoretical framework concerning the mental processes involved in the learning of spelling. This framework proposes that spelling development is not in a sequence of progressive processes but goes through two routes. The first route is called the lexical route, through which learners look up the previously stored memory of sight words in their mental dictionary. This theory suggests that a learner could learn no general rules, in principle, but only memorize the word as a single unit (Dehaene, 2009; Ehri, 2014) when they learn to spell. Ehri and Wilce (1983) examined Grade 2 and 4 readers' ability to read familiar object words (i.e., apple), consonant-vowel-consonant nonwords (i.e., baf), and single digits (i.e., 1,2, and 3). Results of their response latencies revealed that children read the familiar object words more quickly than nonwords. Meanwhile, they read the familiar object words as quickly as naming single digits. These findings demonstrated that those familiar object words were treated as a whole single unit, just like digits, rather than processing letter sequences when reading. However, readers may come across words that are not familiar and not stored as sight words in their minds, so processing words as single whole units may not always be a helpful strategy. Therefore, the other method of spelling a word is called the nonlexical route, which facilitates word learning by providing a systematic link between single phonemes and graphemes and mapping the graphemes to the corresponding phonemes before blending the sequence to pronounce the sound units in unfamiliar words or nonwords for the purpose of an experiment (Treiman, 2017b). In this sense, the spellings are glued to the pronunciations to boost sight word reading via this connection-forming process.

Therefore, phonemic awareness, the ability to segment words into sounds and identify letter names, is crucial in a successful orthographic mapping (Boyer & Ehri, 2011; Ehri & Wilce, 1987). Castiglioni-Spalten and Ehri's (2003) study on kindergartners provided evidence of this. They assigned those beginning readers into treatment and no treatment groups. In the treatment group, students were taught to identify images of articulatory gestures that matched the sequence of sounds and to represent the sequence of sounds with blocks. They outperformed the control group in phoneme segmentation tasks and were able to spell the sounds in target words better. A similar situation was observed in Boyer and Ehri's follow-up study (2011). They trained preschoolers in the experimental group to segment words into phonemes using mouth pictures and letters. They also taught the experimental students relationships between 15 graphemes and phonemes and the associations to segment spellings. On their sight word learning task following the training, the experimental group performed better in phoneme segmentation, spelling, word reading, and nonword repetition posttests. Moreover, this advantage could still be seen in the delayed posttest. These findings reveal that the interventions increased phonemic awareness and showed the facilitative effect of phonemic awareness in sight word reading for beginning readers.

The dependence on two routes also relies on the type of orthographic system used in the language they are learning (Marinelli et al., 2015). For example, English is a language system with deep and complex orthography, considered 'chaotic and unprincipled' (Dewey, 1971, p. 4). English learners may depend more on the lexical route since the letter-sound link required by the nonlexical route is not sufficient in the spelling system for English. For example, phoneme /k/ may be spelled as <c> in panic or <k> in kind. Therefore, when the links between sound and letter are not one-to-one, it is more difficult for English learners to rely heavily on the nonlexical route. On the other hand, several researchers who have applied the dual-route framework also suggest that developing spellers rely largely on the nonlexical route (e.g., Sprenger-Charolles, Siegel, & Bonnet, 1998) before they build up a store of memorized spellings.

Dual-route theories have inspired a great deal of study, highlighting disparities in the pace of spelling development in learners of diverse alphabetic language systems (Marinelli et al., 2015). This framework is challenged because it considers that the only accessible systematic patterns for spellers within a writing system are simple context-free associations between phonemes and graphemes. Even though words follow those rules at the level of phonemes and graphemes, it is not the case that those words are equally easy for every speller to learn (Treiman, 2017b). Furthermore, this framework fails to acknowledge the significance of probabilistic and those patterns that are dependent on the context.

2.3.2 Integration of Multiple Patterns

The theories and framework presented above have been increasingly challenged by later evidence. There is accumulating research emphasizing the significant role of orthographic and morphological input in learning and processing spellings (e.g., Cunningham, Perry, & Stanovich, 2001; Deacon & Kirby, 2004). Among them, Treiman and Kessler (2014) put forward the Integration of Multiple Patterns (IMP) framework. They postulate that children learn spelling information from two categories. The first class of patterns is writing's outer form. For example, 'cat' is a possible word according to the sequences of symbols occurring in written English but 'ckAt' is not. This kind of pattern aids children in reducing the possibilities they need to consider in learning to spell. When a child is unsure of the middle letter of 'dad,' they will not consider the spelling as 'ddd' if they are aware that sequences of three identical letters will not occur in English. The second class of patterns is the inner form of writing which relates to the connections between graphic forms and language. This involves phonology, morphology, and other linguistic features and thus grants this framework a larger role than the previous theories.

Based on this explanation of IMP, children use multiple sources of information such as phonological and graphotactic patterns when they need to choose different spelling options. People tend to learn a spelling more easily when those patterns converge upon the correct spelling or more difficult when patterns conflict with the correct spelling. The spelling of flaps was tested in Treiman, Cassar, and Zukowski's study (1994) with kindergartens, first grade, and second grade US children. Children saw the spelling of two-syllable real words with a blank for the critical letters and were told to listen to each word. It contained five /t/ flaps, five /d/ flaps, and medial unflapped /t/ and /d/ as control. They were asked to circle <t> or <d> to fill the blank as responses. Their results showed that children had a bias to spell flaps as <d>, but they did better in spelling unflapped /t/ and /d/. The confusions of letter <t> and <d> was more common in the former context than the latter. This suggested that children's choices of letters were influenced by the letters' sounds.

It is noteworthy that IMP also argues that the learning of those probabilistic patterns is enabled by statistical learning, which entails the discovery of patterns in the input (Romberg & Saffran, 2010). According to Treiman (2017b), statistical learning mechanisms herein is often implicit. Unlike dual-route theories, which consider mapping phonemes to spellings paramount, IMP emphasizes learning about the visual form first. Learners pick up tacit knowledge and properties of printed words when they learn to read and spell (Pollo, Treiman, & Kessler, 2008). Pollo, Kessler, and Kessler (2009) researched Brazil and US children. The target words were said, used in a sentence, and were repeated again. Children were asked to say and spell these words and identify each letter that was used. In order to test whether children's spellings were influenced by the writing they had been exposed to, the researchers analysed words from books and the written forms of children's names as another salient type of text. They saw correspondences between spellings (e.g., the distribution of spelling lengths and the use of geminates) in real words and nonwords and the writing systems children were exposed to. Children picked up recurring patterns of texts from the exposure and generalized the knowledge of rules to the words they had not seen before without knowing what those patterns meant in terms of letter-sound correspondence (Pollo, Treiman & Kessler, 2009, p.424). This idea is not new that children can learn the subtle statistical regularities from print exposure, which leads to the next section further discussing how these patterns and rules are learned.

2.4 The learning of spelling patterns: statistical learning perspective

According to IMP, children may acquire contextual spelling patterns via statistical and implicit learning (Treiman, 2017a). This concerns another fundamental and debated question in cognitive science, that is, whether children can learn structure simply from the information provided to them in their environment. Over a century, research has investigated human's ability to detect and learn recurring patterns (Arnon, 2019; Esper, 1925; Perruchet, 2019). This investigation has led to two distinct research areas: implicit learning and statistical learning.

The term 'implicit learning' was first introduced by Reber (1967) to characterize participants' learning of abstract rules that guided the construction of letter strings. The term was later adopted for broader use, referring to the learning of recurring patterns that happens without instruction or awareness (Arnon, 2019). Comparably, the field of statistical learning is relatively newer. It can be traced back to the work of Saffran, Newport, and Aslin (Saffran, Aslin, & Newport, 1996; Aslin, Saffran, & Newpoty, 1998). Researchers report that learners may pick up on those spelling patterns through the same type of implicit statistical learning operated in spoken language. In their seminal study, Saffran, Aslin, and Newport (1996) investigated whether 8-month-old infants can use statistical information to discover the word boundaries in running speech. Infants were exposed to a continuous speech stream containing four three-syllable nonsense words (e.g., tupiro, padori). These nonsense words were repeated in random order, generating a continuous auditory sequence (e.g., bidakupadotigolabu…) with no pauses, stress difference, or any acoustic cues. They found that 8-month-olds could use the transitional probabilities between syllables and successfully discriminate word boundaries. This finding suggested that infants are sensitive to statistical information in a complex learning task and can pick up those patterns from the language environment without knowing it.

Extending this to written language, some research more specifically focuses on the statistical learning of spelling patterns using experiments (Chetail, 2017; Nigro et al., 2016; Samara & Carvaolos, 2014, Samara et al., 2019; Singh et al., 2021). Samara and Carvaolos (2014) were the first to demonstrate graphotactic learning in incidental experimental conditions. They recruited 7-year-olds and adults in the research whereby they saw CVC nonwords and were told that they were going to play games with words. In different experiments, there were different constraints for the consonants, but these constraints were unbeknown to the participants. For example, the letter <l> was restricted to onset position in one experiment, while in another experiment, the consonants' positions were constrained by the middle vowels. Participants were asked to do legality judgments for the testing of generalization, deciding whether those stimuli (converge upon or conflict with the trained patterns) could be in the alien language they exposed to in the experiment. Since some of the novel words did not occur in the training sets, participants' ability to generalize the trained patterns was tested after the exposure. Both children and adults could discriminate between those 'legal' and 'illegal' nonwords in both constraint types in the incidental conditions.

Another similar study that tests students' ability to generalize graphotactic patterns is done by Pacton et al. (2014). They presented words embedding doubling patterns that did not violate the French graphotactics in the reading texts. In their experiment, participants were not taught explicitly. They were asked to first read one story aloud. Then the experimenter pronounced six nonwords contained less common but legal doublets in French and the participants were asked to spell the words as written in the stories. It was found that participants better recalled the correct spelling when the words contained no rare doublets even though the occurring frequency of those common and rare doubling patterns were similar in the stories. This study provides evidence of generalization from a more naturalistic condition such as reading in illustrating that existing graphotactic knowledge can be generalized and affect learning of novel spellings.

More recently, Singh et al. (2021) extended Samara and Carvaolos's (2014) work looking at learning graphotactic patterns under incidental conditions. One difference was that they remove the influence of phonological constraints and test pure graphotactic effect. They used homophone stimuli spelled with single and double letters, such as 'dd' and 'd' which map to the same sound /d/. Similarly, they tested generalization after exposure in the artificial lexicon experiments, indicating that both children and adults incidentally generalized over those context-based constraints that varied in complexity in incidental conditions. These findings revealed that children and adults are able to pick up on the spelling patterns from incidental exposure without any explicit teaching.

Nevertheless, even though children and adults can learn incidentally, some research revealed that explicit teaching might lead to more robust learning of spelling patterns (Singh et al., 2021; Sobaco et al., 2015). For example, Sobaco et al.'s (2015) study compared French adults' learning of graphotactic patterns in implicit and explicit conditions and found that participants with explicit instruction in which they were asked to memorize the spellings of the nonwords recalled spellings better than their implicit counterparts. Phonics instruction is one of the explicit instruction that most early literacy curriculum in alphabetic languages concentrates on, which explicitly teaches learners rules that each letter can be mapped into a corresponding sound (Li & Woore, 2021; Woore, 2022). Research shows that such explicit teaching on the mapping rules is helpful in L1 spelling development. For example, de Graaff et al. (2009) provided explicit phonics instruction on Dutch grapheme-phoneme correspondences to kindergarten children. They found that those who received explicit phonics instruction progressed more in isolating the sounds of consonant-vowel-consonant (CVC) words and constructing the spelling of orally presented CVC words than the control group who received no training. They therefore indicated that explicit phonics instruction helped improve learning spelling. It should be noted, though, that most of the alphabetic system has multiple spellings for the same phoneme. Therefore, those rules may be probabilistic and include exceptions that may not be mastered entirely via explicit instruction.

There are much fewer studies looking at teaching these contextual spelling patterns. One example is Singh et al.'s (2021) study which investigated the explicit teaching of contextual graphotactic patterns. As discussed above, they replicated the equivalent implicit learning experiments in their research but provided additional explicit instructions. They taught children the rules (e.g., letter <e> is always followed by a single letter as in 'rel' and 'det') for the written words in an artificial language and found that this explicit instruction benefited participants in later pattern generalization. They further examined participants' awareness of the graphotactic patterns using a questionnaire, indicating that those adults who demonstrated explicit awareness of the patterns showed markedly better performance in the task. These together support the practice of teaching spelling patterns explicitly. A closer look at the literature reveals that research in this area focuses mainly on L1 literacy development. There is still insufficient research investigating the link between statistical learning and L2 spelling development. This leads to the current research aiming to investigate the learning of spelling patterns in an L2 context.

2.5 Learning to spell in an L2

2.5.1 Cross-language transfer in writing systems

Cross-linguistic transfer happens when language learners use linguistic knowledge of one language in the acquisition of another language (Winke, 2013). This concept is central in bilingual reading development since language educators seek the circumstances that enable learning in one language to enhance learning in the other language. Lado (1957, 1964) believed that L2 learners capitalize on their L1. He put forward the contrastive-typological framework arguing that cross-language differences in L2 acquisition are predictable based on the comparison of specific features of the L1 and L2 and the degree of difficulty in terms of certain L2 elements for learners of different L1 backgrounds (Connor, 1996; Ellis, 1994; Odlin, 1989). In this sense, the contrastive framework suggests that transfer can be either positive or negative. Positive transfer mainly happens when two languages share certain elements that the learners may use the knowledge in their L1 to aid their acquisition of similar L2 elements. For example, some alphabetic languages (e.g., French and English) share many similarities in their writing system where the positive transfer is found (Hipfner-Boucher, Pasquarella, Chen, & Deacon, 2014). In Commissaire et al.'s (2011) research, word-specific knowledge (e.g., rain - rane) in two writing systems was tested using an orthographic choice task for Grade 6 to 8 French children in learning English. Their correlation analysis showed that L1 and L2 word-specific orthographic skills were significantly correlated and revealed a direct and positive cross-language transfer ($r = 0.554$, $p<.001$). On the other hand, when the language structures are very different, L1 may interfere with the acquisition of another language, and negative transfer occurs. For example, Wydell and Butterworth (1999) studied a Japanese boy who showed difficulties reading English texts but performed as well as his Japanese peers on logographic Japanese Kanji reading. In the following section, I will specifically focus on learning the writing system at a more suprasegmental level, that is, the letter and sound correspondences in an L2.

2.5.2 Learning letter and sound correspondences in an L2 context

Compared with L1 literature, there is relatively less work looking at how L2 language learners learn the relationships between letters and phonemes as well as the phonics teaching, which is the explicit instruction in the grapheme-phoneme mappings in an L2 context. Literature has documented the prominent role of phonics instruction in literacy learning, such as learning to spell in L1 (Torgerson et al., 2006). It is argued that phonics instruction helps develop children's phonological decoding proficiency (Li & Woore, 2021, p.2) and contributes to high-quality lexical representations. Phonological decoding refers to the ability to sound out the words a language learner sees in print for the first time. For instance, on seeing the word 'cat', readers can sound out the individual letters they have been taught <c>, <a>, and <t>, blend the sounds together, and recognize the resulting phonological form as a kind of animal. Regarding the learning of this basic mapping knowledge, Samara et al. (2019) suggest that adults can learn spelling patterns implicitly, just as children do (see section 2.4). It is interesting to see whether this will occur in a real L2 context. One thing that those studies haven't looked at is the learning of patterns of how orthography maps to phonology in different contexts, as in the pattern about the two pronunciations of letter <c> mentioned above (see Table 1 in 2.2 section). This would be an interesting question in an L2 situation since L2 learners often encounter new words via their written forms first, and thus they are more familiar with the written forms than the spoken forms. For instance, they may have read the word 'circus' but never heard it pronounced. In this case, they might read the word as starting with a phoneme /k/. In other words, learning the mapping patterns in an L2 is potentially very useful.

Recent qualitative research by Adeline (2020) examined the mastery of soft and hard sounds of English letter <g> in Indonesian EFL learners. Similar to the pronunciation pattern of the letter <c>, the choice of soft and hard 'g' sound depends on the following vowels (see Table 2), with exceptions.

Table 2. The spelling and pronunciation patterns of letter <g> in English

Phonemes	Following vowel letters	Example (Pronunciation)
/j/ (soft sound)	Letter <e>, <i> and <y>	• Gentle • Giraffe • Gym
/g/ (hard sound)	Any other letters	• Glass • Goal • Gather

Participants were asked to do a pronunciation test, in which they were required to read the 40 sentences consisting of various /g/ sound words. Adeline reported that the soft and hard 'g' sound in English were mispronounced as the 'g' sound in their mother tongue Indonesian and therefore suggested that students' native language may affect their learning of L2 pronunciation. However, this study only presented the students' mastery of two sounds but did not investigate whether these L2 learners can further learn the correct spelling and pronunciation patterns. Therefore, the current study aims to examine how L2 learners, that is, Chinese EFL learners, learn English spelling and pronunciation patterns. One research relevant to this is Li and Woore's (2021) quasi-experimental study on the effects of phonics instruction on L2 phonological decoding in Chinese EFL learners. They gave two classes of English major students twelve weeks of English phonics instruction (e.g., systematic instruction in 101 English symbol-sound correspondences). In contrast, the comparison class received only instruction in English pronunciation without mapping knowledge. Then they used pre- and post-tests to measure participants' phonological decoding ability and vocabulary memorization. Their results revealed that the phonics group significantly outperformed the comparison group in the post-tests. In like manner, the following section aims to investigate how Chinese as L1 may influence the learning of letter and sound mapping in L2 English, with the introduction of some language features in Chinese phonology.

2.6 Literacy development in Chinese learners of English

2.6.1 Pinyin: The Chinese Phonetic System

There is a rapid increase in the population in China learning English as a foreign language. The linguistic dynamics between Chinese and English have prompted researchers to explore the language transfer in various linguistic domains between these two languages (Tong & McBride-Chang, 2010; Wang et al., 2009; Zhang et al., 2012; Yeung & Ganotice, 2014). Chinese is a logographic orthography language in which each letter corresponds to a syllable, and therefore, it does not directly involve phoneme-level processing like alphabet languages. Pinyin or Hanyu Pinyin, an alphabet coding system, is invented as the phonetic transcription system for Mandarin (the official language of China). To make China more globally linked, Chinese linguist Zhou Youguang developed this system in the 1950s in response to a program of language reform initiated by the government of the People's Republic of China (Wang & Andrews, 2021). Zhou employed and adjusted the 26 Roman alphabet letters, combining them with lexical tone transcriptions to constitute Pinyin. After 1958, Pinyin was widely used in schools for literacy teaching across Chinese society. Children started to learn Pinyin in primary schools from the beginning of first grade (Lin et al., 2010; Soik & Fletcher, 2001; Zhou, 1980). Instead of replacing Chinese characters and writing system, Pinyin is utilized to annotate Chinese characters in textbooks and help students learn the standard pronunciation of Mandarin.

The Pinyin system represents the phonological structure of the standard Chinese language, with the basic phonetic unit as the syllable (Wang & Andrews, 2021). One syllable reflects the pronunciation of one Chinese character.

Table 3. Initials/Onsets of Pinyin

b	p	m	f	d	t	n	l
g	k	h	j	q	x	y	w
zh	ch	sh	r	z	c	s	

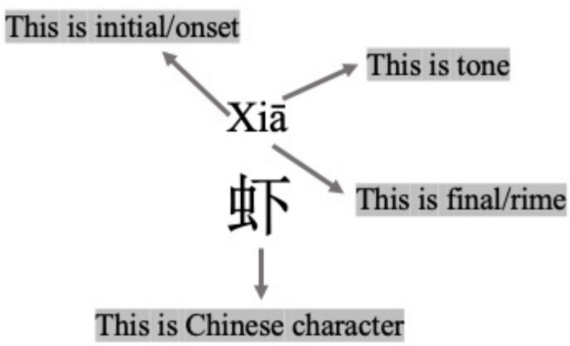
Most pinyin syllables begin with an initial, followed by a final and a tone mark. Initials (see Table 3 above), or onsets in Pinyin, are the beginning consonants in a Pinyin syllable. Finals (see Table 4 below), or rimes in Pinyin, could be simple or compound vowels with an optional final nasal consonant (Li & Thompson, 1981).

Table 4. Finals/rimes in Pinyin

Single letter	a	o	e	i	u	ü	
Double letter	ai	ei	ui	ao	ou	iu	ie
	üe	er	an	en	in	un	ün
Triple letter	ang	eng	ing	ong			

Pinyin consists of 23 onsets and 24 rimes. The letters in the Pinyin alphabet virtually all correspond to letters in the English alphabet. However, there is no letter <v> in Chinese Pinyin but an additional <ü>. An example of a Pinyin syllable 'Xiā' is given below (figure 1). It is formed by onset <x>, rime <ia>, and the flat tone (i.e., the first tone).

Figure 1. Chinese character 虾(xia) Pinyin Scheme



In Mandarin Chinese, there are only 400 syllables (Wang & Andrews, 2021). As a tonal language, however, the lexical tones (see table 5 below) in the Chinese language differentiate those syllables and expand them to approximately 1200 syllables. Tone is a suprasegmental feature that changes the pitch of the syllables. Notably, there is no apparent equivalent element in those often-studied Indo-European alphabetic languages such as English (Lin et al., 2010). In standard Chinese, there are four lexical tones (five if the neutral tone is included) in total and are represented in the writing of Pinyin but not in Chinese characters. In the speech, the four tones, high level, rising, falling-rising, and falling, are used to distinguish identical Chinese syllables. In conclusion, initial (onset), final (rime), and tone constitute the phonological system in the Chinese language. It should be noted that Pinyin is a fully transparent phonographic system in that each phoneme maps to one pinyin letter.

Table 5. Tones in Pinyin

First tone	Second tone	Third tone	Fourth tone	Neutral tone
八 bā	拔 bá	靶 bǎ	爸 bà	吧 ba
Eight	Pull	Target	Father	Question word
Flat →	Going up ↗	Down and up ↘↗	Going down ↘	light

Pinyin was created primarily to annotate the sounds of Chinese characters; hence, studying Pinyin is considered a linguistic and metalinguistic training experience for native Chinese to improve their phonological and phonemic awareness (Lü, 2017). The former refers to their knowledge and sensitivity to the underlying sound structure of spoken words. The latter, phonemic awareness, refers to the understanding of the individual sounds in spoken words. Since the Pinyin system has been built up to aid learning Chinese phonology, researchers have started to explicitly explore the degree to which pinyin education may improve phonological and phonemic awareness. Empirical studies on Chinese children have consistently shown that Pinyin facilitates phonemic awareness (e.g., McBride-Chang & Ho, 2000; Shu et al., 2008; Xu & Ren, 2004). For instance, Xu and Ren (2004) examined the relationship between Pinyin skills and phonemic awareness of children in Grade 1, 3, and 5 in Beijing, China, using oddity tasks (identify the different onset, rime, or tone in an aurally presented syllable) and a phoneme deletion task (repeat an aurally presented syllable with one phoneme removed). The Pinyin dictation task further measured Pinyin skills. Results showed that children with higher Pinyin skills scored higher than those with lower Pinyin skills on all phonological tasks, regardless of grade level. In addition, Pinyin scores explained 46% of the variance in Chinese phonemic awareness in their regression analyses. Another study by McBride-Chang et al. (2004) compared children at the same age with Pinyin learning experience and without, stating that the former group outperformed the latter group in syllable and phoneme awareness. Furthermore, there exists a considerable body of correlational and training studies in literacy acquisition and development, agreeing that phonemic awareness is a good predictor of word reading in alphabetic languages (e.g., Stanovich, 1992; Wagner, Torgesen, & Rashotte, 1994). In the past three decades, a growing number of studies have explored the relationship between Chinese phonemic awareness and word reading in Chinese. These studies indicated that Chinese phonemic awareness is predictive in both Pinyin and character reading among young learners (e.g., Cheung, Chan, & Chong, 2007; McBride-Chang & Ho, 2000; McBride-Chang & Kail, 2002) and adult readers (Perfetti & Zhang, 1995).

From the previous section, it can be seen that phonemic awareness in children was predictive of their literacy development in L1. The interesting question is that whether this phonemic awareness would transfer from L1 Mandarin Chinese to help with L2 English learning. Studies have shown that a cross-linguistic transfer concerning phonology from Chinese to English occurs predominantly at the syllable and phoneme levels (e.g., Cheung et al., 2010; Chien et al., 2008; Chow, 2014; Chow et al., 2005; Chung et al., 2013; Luo et al., 2014; Wang et al., 2005; Wang et al., 2009). Wang, Perfetti, and Liu (2005) investigated cross-language phonological transfer among a group of Grade 2 and 3 Mandarin-speaking children. This study used onset and rime matching tasks testing both Chinese and English. For Chinese, they additionally tested Pinyin naming, while for English, they used an additional phoneme deletion task. Comparable experiments generated critical findings that Chinese onset matching skill was significantly correlated with English onset and rime matching skills. Consistent with this, Wang, Yang and Cheng's (2009) study on grade 1 Chinese-English bilingual children revealed that Chinese tone and onset awareness measured by oddity tasks explained a significant amount of variance in English real-word reading. These findings provided evidence that cross-language phonological transfer occurred even when the two languages were distantly related.

2.7 The current study

This study aims to see if adult Chinese EFL learners can pick up on the 'c' spelling pattern from incidental exposure without explicit teaching. The current study is going to use an incidental exposure paradigm similar to that used by Samara and colleagues (2019) but using stimuli from a real language – English; and with current learners of the language, i.e., Chinese EFL learners. Because they are current language learners who already have language knowledge before starting this experiment, I will use a pre-/post- design to see if the experimental participants improve from baseline following exposure to the stimuli. Then a control group who do not get the exposure will be compared against with. Finally, to see what factors predict the ability to pick up on these patterns, I am going to administer tests of phonemic awareness in both English and Chinese to see how these relate to baseline performance and gains from the exposure in the experimental group. This design allows the researcher to answer the following questions:

1. Can Chinese EFL learners improve their knowledge of the pronunciation of English written words embedding the 'c' orthography-phonology mapping pattern following brief exposure to those words?
2. Can Chinese EFL learners acquire generalized knowledge of the 'c' orthography-phonology mapping pattern implicitly, following brief incidental exposure to words embedding that pattern?
3. Does English/Chinese phonological awareness correlate with participants'

knowledge of the pronunciation of English written words embedding the 'c' orthography-phonology mapping pattern prior to exposure?

4. Does English/Chinese phonological awareness correlate with participants' ability to learn the 'c' pattern from implicit incidental exposure to words embedding that pattern?

3. Methodology

3.1 Participants and recruitment

All the participants were recruited from the researcher's personal networks using social media. The participants were told that they had the opportunity to be entered into a prize draw and won a token of £50. Then, the researcher added the participants through WeChat (a Chinese social media app) and used the 'chat only' function for the purposes of privacy. The researcher answered any questions they had about the study and highlighted that their participation is completely voluntary, and they can withdraw at any stage. The study was conducted online, and the information about the research as well as the participant information sheet (see Appendix B and C) were shown at the beginning of the experiment. Participants provided informed consent before the experiment started. The experiment would only proceed if the participants gave their consent. They were then given a questionnaire to enter their age and gender before the experiment (see Appendix H). No names or identifying data were collected during the process of the experiment.

The G*Power software (Faul et al., 2007) was used to determine the sample necessary for 80% power (with alpha .05) for an interaction between session (pre-test versus post-test) and condition (control versus experimental) in a mixed ANOVA. In the absence of a sufficiently similar previous study on which to base effect size, an estimate based on the assumption of a medium effect size (Cohen's f = 0.25) was used. Correlation among repeated measures was set to the software default of 0.5. This suggested that a sample of N=54 was needed. In this study, a group of 60 Chinese adults (15 male and 45 female, average age = 22.8, SD = 2.85) was recruited eventually. All the participants were native Mandarin Chinese speakers learning English as a second language. Participants completed a language background questionnaire (see Appendix I), which included questions about the frequency of use in English and self-ratings of English proficiency (e.g., level of speaking, reading, listening, and writing abilities). All participants were randomly assigned to the experimental (n = 8 male and 22 female, average age = 22.93, SD = 3.25, age range: 18-32) and the control group (n = 7 male and 23 female, average age = 22.73, SD = 2.43, age range: 19-32). More specific demographic information will be shown in the result chapter. None of the participants had any language or hearing impairments.

3.2 Design

This research has two sets of tasks: (1) the orthography-phonology mapping experiment, which includes the pre-test, the intervention, and the post-test; (2) English and Chinese phonemic awareness tasks and the Pinyin knowledge task. This research adopted a between-subjects design in order to compare groups and measure change resulting from experimental treatment (Dimitrov & Rumrill, 2003). The experimental and control groups were first asked to take the pre-tests. The pre- and post-tests were the same for the experimental and the control group. In order to test generalization, half of the words used in the tests were included in the exposure set for the experimental group and half were not. The set that both used in the test and exposure were called 'trained' words, and the other half that was only used in the test but not exposure was called 'untrained' words. Note that the words used in the pre-test are also called 'trained' and 'untrained' even though they are not 'trained' yet. Similarly, for the control group, none of the words are really 'trained' both in pre-test and post-test. The researcher used mean scores based on the same sets of words for the purpose of making a fair comparison, so these names of word sets were continued to be used for the control group. After the pre-test, the intervention was introduced to the experimental group only to investigate whether participants could implicitly pick up the spelling patterns of letter <c> from incidental exposure.

The two groups were then instructed to do the post-tests after the intervention. Finally, in order to investigate the third and fourth research questions as to whether phonemic awareness would predict EFL learners' gain in learning the spelling patterns, participants were asked to complete English phonemic awareness tasks and Chinese phonological awareness tasks (Pinyin tasks). After all the tasks were done, participants were asked to complete a follow-up questionnaire, which included questions about whether they could explicitly articulate the rule at the end of the exposure and, if so, whether they knew the rule before the experiment or picked it up during the experiment (see Appendix J).

For the phonemic awareness task, sound difference detection, i.e., oddity tasks, was used to examine English and Chinese phonological awareness. The oddity task was devised by Bradley and Bryant (1983) to measure the development of onset and rime awareness. It is adapted and successfully used in a large volume of phonological studies in languages such as English (Bowey, 1994; Bowey & Francis, 1991), Greek (Papadopoulos, 2001), Chinese languages (Lü, 2017; Tong et al., 2017; Wang et al., 2009); and in different age groups such as on children (Wang et al., 2009) and adult (Bai, 2014; Hu, 2018; Xu & Zhang, 2015). For Chinese phonemic awareness, the current research did not rely exclusively on phonological oddity tasks but included the invented Pinyin task. Invented spelling is described by Read (1971) as children's spontaneous or self-directed efforts to represent words in print. According to Bear and Templeton (1998), invented spelling could measure children's abilities to develop phonological acuity, knowledge of sound-letter correspondence, and the understanding of the conventional association between sounds and print. Numerous empirical studies have demonstrated the association between invented spelling and phonological awareness (Hecht & Close, 2002; Ouellette & Sénéchal, 2008). Other than Chinese invented Pinyin task, a similar English invented spelling tool was used in McBride-Chang and Ho's (2005) study of Hong Kong Chinese children and these tests helped well investigate the cross-language transfer in word reading between Chinese and English. In like manner, Lin et al. (2010) also adopted invented Pinyin spelling to measure children's

Chinese phonological awareness and found it a strong predictor of Chinese character reading.

In order to measure the general English proficiency and ensure the experimental and control groups were well matched, English LexTALE was used in the study. It is a quick and feasible test of vocabulary knowledge for medium proficient learners of English as a second language in an experimental setting. This test has been designed to provide researchers with a practical and objective measure of English vocabulary knowledge. It is a lexical decision task that does not actually test whether the participants know the meaning of the target words. Instead, it tests whether participants could recognize the words. Although it is not a standard test of vocabulary knowledge, its validity as an indicator of general English proficiency has been tested in a large-scale study by Lemhöfer and Broersma (2012). This test well fitted the participants' English proficiency levels in the current study. It, therefore, was chosen to test general English levels to make sure that the two groups were well matched in their general English proficiency. The experiment was approved by CUREC (approval letter in Appendix A).

3.3 Stimuli

3.3.1 Orthography-phonology mapping experiment

The stimuli for the orthography-phonology mapping experiment (including pre- and post-test and the intervention) consisted of 40 English words beginning with the letter <c> (see Appendix D). Twenty of these words were followed by the letter <a>, <o>, and <u>, which made the letter <c> in these words pronounced as a hard 'c' sound /k/. The other 20 words were followed by the letter <e>, making the letter <c> in these words pronounced as a soft 'c' sound /s/. Among these words, 16 words (8 in each category) were chosen with word frequency from the Sketch Engine corpus ranking 312/1000, and 24 words (12 in each category) were with mean word frequency ranking 846/1000 in order to decrease the possibility that participants already learned the correct pronunciations. The 40 words were divided into three sets (see Table 6 below). Set 1 consisted of ten words with hard 'c' sounds words and ten words with soft 'c' sounds. Specifically, among the ten words with hard 'c' sounds, four were from the more frequent word group, and the other six were from the less frequent word group (same for the words with soft 'c' sounds). Set 2 and 3 both consisted of five words with hard 'c' sounds (two from the more frequent word group and three from the less frequent word group) and five words with soft 'c' sounds (two from the more frequent word group and three from the less frequent word group).

Table 6. The number and word frequency of target words in each set

	Hard c sound words		**Soft c sound words**	
	The more frequent word group	The less frequent word group	The more frequent word group	The less frequent word group
Set 1	4	6	4	6
Set 2	2	3	2	3
Set 3	2	3	2	3

Counterbalance was used in this experiment (see Table 7 below). The participants were randomly assigned into four groups: two experimental groups and two control groups. Set 1 words were used only in exposure for all participants in the experimental group but not in pre- and post-tests for all participants. Set 2 and Set 3 were used in pre- and post-tests for all the participants. However, half of the participants in the experimental group got Set 3 in their exposure set, and the other half got Set 2 in the exposure set (the assigned word sets are also shown in table 7 below). The set used in the exposure was called ‘trained’ words, and the other set not included in the exposure was called ‘untrained’ words.

This counterbalance design ensured that pre- and post-tests were exactly the same for both groups. In this case, if experimental groups increase more in the post-tests, it is not because that they get different words than the control groups. Second, the 'trained' and 'untrained' words in the test were counterbalanced; therefore, if there were improvements with trained words, the reason cannot be that they were easier words. In this design, participants take the same test with the same items in pre- and post-test, which means that the improvements in post-test could be due to practice effects. However, this is also true for the control group, so I am interested in seeing if the experimental group improves more than the control group, which will be assumed to be due to the intervention.

Table 7. The counterbalance of word sets used in the pre- and post-test for each group

	Two word sets used in intervention (20 words)	word set used in pre- and post-test (at post-test these are trained)	word set used in pre- and post-test (at post-test these are untrained- and so test generalization
experimental group, version 1	set1+set2	Set 2	Set 3
control group, version 1	/		
experimental group, version 2	set1+set3	Set 3	Set 2
control group, version 2	/		

A male American native English speaker recorded both the correct and an incorrect version of the words (e.g., 'ceiling' pronounced correctly with an initial /s/ and incorrectly with an initial /k/) using a normal intonation in a sound-attenuated room. The reason is that the correct versions of stimuli were used in training, while both correct and incorrect versions were needed in the tests. Pilot testing demonstrated that a native English speaker (not involved in the study prior to pilot testing) successfully identified all 80 words from the recordings.

3.3.2 English Phonemic Awareness task (EPA)

The Odd Man Out Test was used to test participants' rhyme and alliteration ability. The tests assessed the ability to recognize rhyme and alliteration in spoken words. Stimulus in this task were one-syllable English words adapted from both Bryant and Bradley's oddity test (1985) and Huang and Hanley's odd man out test (1995). Ninety-nine one-syllable English words (see Appendix E) were included in this task and were assigned to three subtasks equally, with each trial including three one-syllable English words as choices. The words were recorded by the same American male speaker in the orthography-phonology mapping task.

3.3.3 Chinese Phonemic Awareness tasks (CPA)

3.3.3.1 Onset, rime, and tone oddity

Since Chinese syllables are formed by onset, rime, and tone, these three elements will be tested separately in this task. In the present study, materials were chosen and modified from Wang et al. (2005) for the Chinese onset, rime, and tone task. In total, 108 one-syllable Chinese words (see Appendix F) were chosen as the stimulus in this task, recorded by a female Chinese native speaker. Pilot testing demonstrated that a native Chinese speaker (not involved in the study prior to pilot testing) successfully identified all 108 words from the recordings.

3.3.3.2 Invented Pinyin Spelling

This task was adapted from Lin et al.'s (2010) research to investigate participants' Pinyin skills. Lin et al.'s version aimed to test children's pinyin skills and therefore was unsuitable for the target people in this research. Therefore, this study added items to the test in order to make it more appropriate for the adult participants. Invented pinyin spelling was measured using six one-syllable Chinese words: 虾 xiā, 字 zì, 龙 lóng, 车 chē, 底 dǐ, 豆 dòu, 回 huí, 沙 shā, 鲁 lǔ, and 嫩 nèn (Each word illustrated here is followed by its pinyin spelling. Note that the tone for each syllable is indicated here above the vowel, as is the convention.). Stimuli were recorded by the same female Chinese speaker in the Chinese oddity task.

3.3.4 Vocabulary test

This study used a speeded version of English LexTALE. It comprises 60 items (40 words and 20 nonwords, see Appendix G) between 4 and 12 letters long (M = 7.3) (Lemhöfer & Broersma, 2012). The mean frequency of the 40 words is between 1 and 26 occurrences per million according to the CELEX database (Baayen, Piepenbrock, & Gulikers, 1995). The constitution of these words is displayed in Table 8 below.

Table 8. The word constitution in English LexTALE test

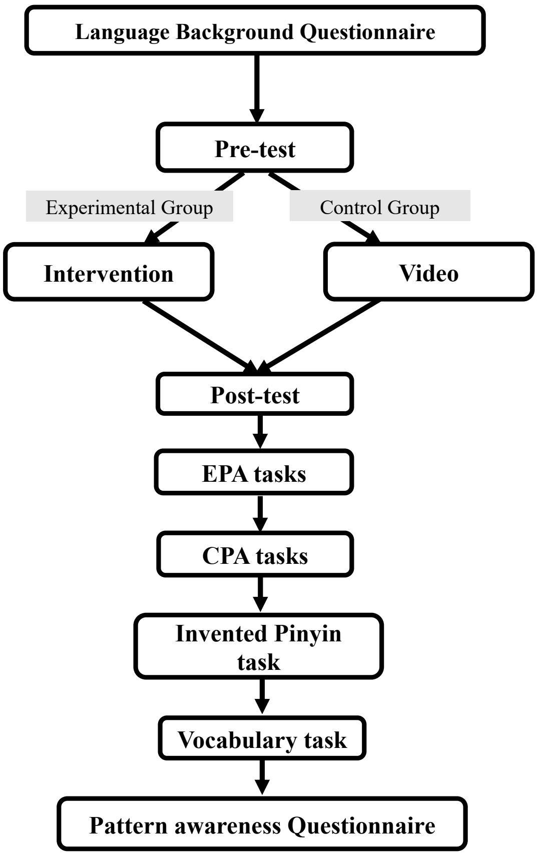
Part of speech	number
Noun	15
Verb	1
Verb participle	2
Adjective	12
Adverb	2
Both a verb and a noun	8

The other 20 nonwords are created by changing the existing words or recombining morphemes, which are all orthographically legal and pronounceable letter strings.

3.4 Procedure

Adult testing was carried out online using a link distributed via Gorilla.sc platform (AnwylIrvine et al., 2019). The adult experiment was designed on the Gorilla.sc platform and was run on participants' own devices at home. Participants were instructed to use headphones instead of the built-in microphone on the computer for better audio quality. Before the tests started, participants were asked to wear the headphones and do a short headphone test, checking that participants could hear the recordings properly. Next, the procedure of each task will be introduced in detail, and the whole procedure is displayed in figure 2 below.

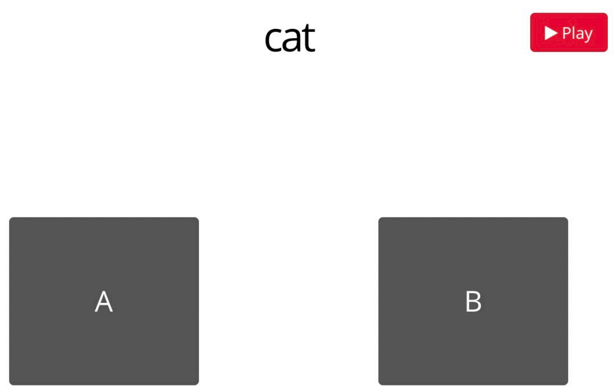
Figure 2. The procedure of the experiment



3.4.1 Orthography-phonology mapping experiment

Participants were asked to finish the pre-test, intervention, and post-test (without breaks). This experiment lasted approximately 15 minutes. The pre-test and post-test used a two-alternative forced choice task design, where in each trial, participants viewed the target word that appeared on the computer screen (Figure 3 shows an example trial). Participants were asked to click on the play button, and the first and second sounds of the target words were played at 1s interval. Among the two sounds, one sound was always correct, and the other was identical but with the 'c' mispronounced (e.g., /s/ replaced by /k/ or vice versa). After listening to the two sounds, participants were asked to choose the correct one by clicking on one of the choice bubbles. For example, 'cable' was shown on the computer screen, and they heard /keibl/ and /seibl/ before choosing the correct one. Within each block, the trial began with a 500 ms black fixation cross followed by the stimulus, which appeared at the center of the screen and remained there until the participants responded (the same for all other tasks). The correct pronunciations in all trials were randomized and played in the first or second position. The presentation order of the stimuli in each trial was randomized for each participant. Feedback was not provided during the whole task.

Figure 3. An example trial of the orthography-phonology mapping task



After the pre-test, the experimental groups were asked to do the training session, while the control groups were asked to watch an English vocabulary video teaching the word 'unequivocal' with approximately the same length as the training session. The experimental group was told to listen to the list of words (word sets used in training for each group are introduced in the 3.3.1 section). In training, target words appeared on the screen, and 500ms later participants heard their correct pronunciation for the first time. Then participants were asked to press the 'replay' button to listen to the correct pronunciation for the second time. Each trial ended after the recordings were played twice, then the next trial proceeded automatically. The presentation order of the stimuli in each trial was randomized for each participant. After the training and video ended, all the participants proceeded to the post-test. The procedure of the post-test was identical to the pre-test introduced above.

3.4.2 English phonemic awareness task

This task comprised the first sound difference trials, middle sound difference trials, and last sound difference trials. Each contained one practice trial and 10 experimental trials. In a first sound difference trial, for example, the participant heard three one-syllable English words (e.g., bed, hair, and bell) and had to indicate which was the odd word out in terms of its first sound. Participants were asked to click the 'play' button at the center of the screen and choose the correct answer. The ordering of the target word (the odd word) and the two foils was randomized across trials. Each word was pronounced with equal emphasis at a 1s interval. For example, they would click and hear the recordings of 'rot', 'rod', and 'box' only once, and then they were required to choose which one was different in its first sound (in this case, "box"). In the middle sound difference, the decision concerned the middle sound. In the end sound difference, the decision concerned the final sound. Feedback was not provided for any of the trials in this task.

3.4.3 Chinese phonemic awareness tasks

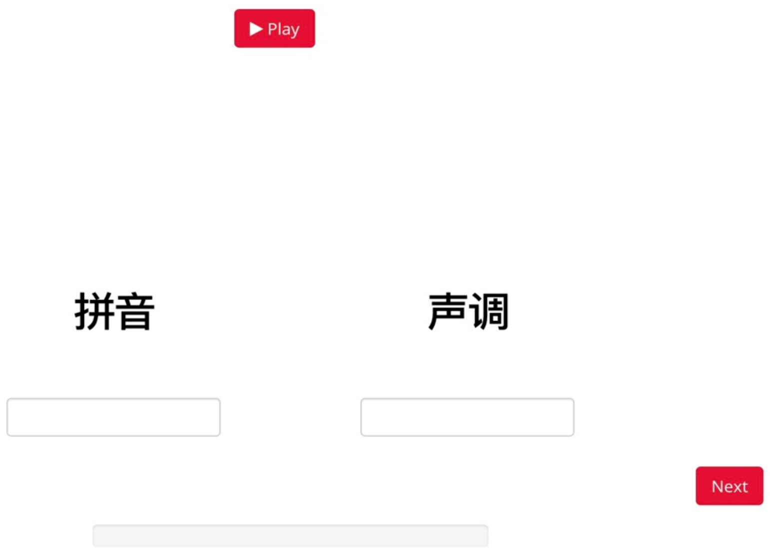
3.4.3.1 Onset, rime, and tone oddity

This task comprised three parts: onset difference trials, rime difference trials, and tone difference trials. Each contained two practice trials and 10 experimental trials. Participants were instructed to click and listen to the recordings of three one-syllable Chinese words pronounced with equal emphasis at 1s intervals and choose which one of the three syllables did not share either the onset, rime, or tone with the other two syllables. For example, recordings of /shang/, /chang/, and /sha/ would be played for the rime test. Subjects were expected to choose the one with different rime (in this case, /sha/). Feedback was not provided for any of the trials in this task.

3.4.3.2 Invented Pinyin Spelling

In this task, participants were instructed to click the audio button and listen to the recording of the target word twice with a 1s interval between them. Then they

Figure 4. An example trial of the invented Pinyin task



were asked to type down the Pinyin syllables in the Pinyin box and tone in the Tone box. There are four lexical tones in Chinese phonological systems. As mentioned in the previous chapter (see 2.6.1 section), Chinese students are taught to use ordinal numbers to represent these four tones in schools, that is, the first, the second, the third, and the fourth tone. Therefore, participants were instructed to use numbers 1, 2, 3, and 4 in this task to represent the lexical tones for each target Pinyin syllable. After typing the answers, participants needed to click on the 'next' button to proceed to the next one (Figure 4 shows an example trial).

There are a few unique features of Pinyin invented spelling. Although a one-syllable sound has multiple meanings across different Chinese words, this task focused on phonological representations but not meaning. Second, this task measured Chinese phoneme awareness since participants' knowledge of onsets, rimes, and the order of onsets and rimes in Pinyin were tested. Third, this task measured tone awareness by asking participants to identify and type down the lexical tone of the words.

3.4.4 Vocabulary test

In each trial, the target word was displayed on the computer screen, and participants were asked to decide whether the string of letters was an existing

English word or not. When participants thought it was an existing English word, they were asked to press J on their keyboard; if they thought it was not an existing English word or were unsure if it was an existing word, they were asked to press K on their keyboard. The task lasted approximately 2 minutes with a 2000 ms time limit for responding. The participants were asked to try to respond as quickly and accurately as possible. There was no practice block and break during the test.

3.5 Data analysis

After the data collection was completed, scores from the orthography-phonology mapping experiment (including pre-test and post-test), phonological tasks, and vocabulary tasks, together with the language background questionnaire and rule knowledge questionnaire responses, were entered into SPSS statistics for data transformations and statistical analyses. The orthography-phonology mapping experiment, English oddity tasks, and Chinese oddity tasks yielded accuracy scores as performance measures. A simple binary coding scheme, i.e., correct and incorrect for all the above tasks, was adopted, which provided consistency across the measures (Ben-Yehudah et al., 2019). Then the researcher computed participants' mean accuracy at pre- and post-test.

Separately, the coding and scoring scheme for the invented Pinyin task was different from the above tasks, followed and modified that used in Lin et al.'s (2010) study. Each Pinyin invented spelling item was given a score ranging from 0 to 10. The coding system included onsets, rimes, tones, and order of the target words. Onset and rime were coded and given scores separately with a 5-point scale (0-4). No point was awarded for typing nothing. One point was given for typing a random letter or letters, and 2 points were awarded for typing a combination of a closely related letter or letters together with unrelated letters. Finally, 3 points were awarded for typing only a closely related letter or letters without any unrelated letters, and 4 points were given for typing the exact letter or letters. Order of onset and rime was rated as either incorrect (0 points) or correct (1 point). Tone was scored on a 2-point scale, with 0 representing no tone and wrong tone and 1 representing correct tone.

The accuracy scores from all these tasks were then converted to mean accuracy in the analyses.

4. Results

Descriptive statistics for participants profiling, pre-test, post-test, English and Chinese phonemic tests, invented Pinyin task, and vocabulary task will be presented first. Second, the results of the examination of the intervention effect between the experimental and the control group will be presented. Finally, the results examining the relationship between English and Chinese phonological tasks, the invented Pinyin task and the vocabulary test with each of (a) pre-test performance; (b) pre-test to post-test gains will be presented.

4.1 Descriptive statistics for participants profiling and test scores

Demographic statistics, the vocabulary task, self-report English proficiency, and frequency of use for the study participants are shown in Table 9. The means and standard deviations revealed that there are no apparent discrepancies between the two groups on these items.

Table 9. Demographics, Means and standard deviation of Vocabulary task, and English self-report proficiency and use

	Experimental mean (sd)	Control mean (sd)
Age	22.933 (3.247)	22.733 (2.434)
Vocabulary	.565(.097)	.556 (.091)
Frequency of English use (%)	11.800 (8.841)	11.043 (5.004)
Self-report Speaking proficiency	4.269 (1.888)	4.130 (1.391)
Self-report Reading proficiency	5.461 (2.102)	5.478 (1.855)
Self-report Listening proficiency	4.615 (1.919)	4.217 (1.677)
Self-report Writing proficiency	4.500 (1.749)	4.652 (1.849)

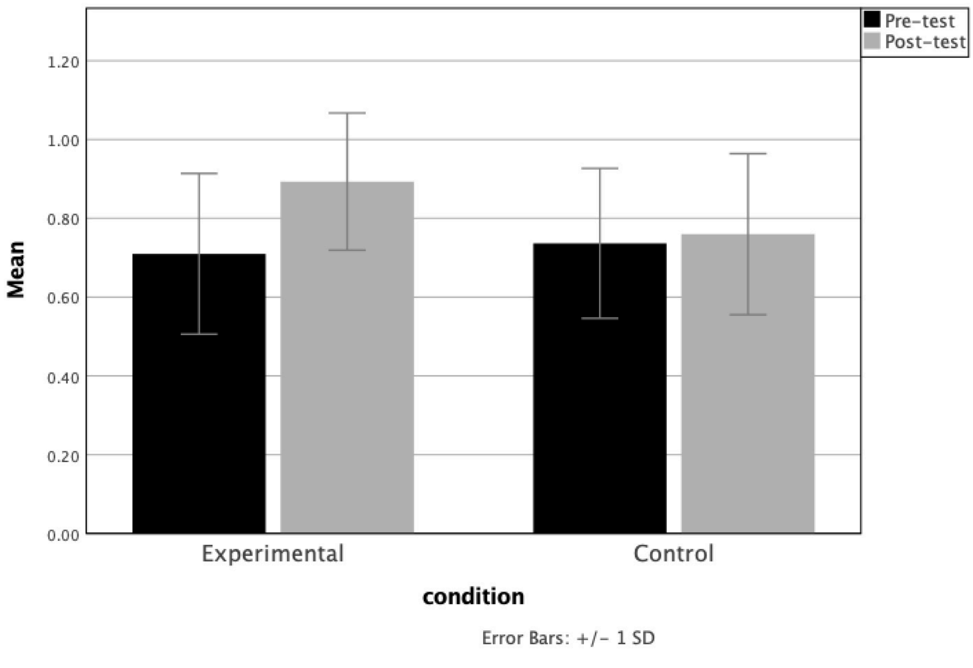
4.2 Learning of the orthography-phonology patterns

4.2.1 Performance on the mapping task

This section will focus on discussing participants' performance on the orthography-phonology mapping task. Following the research questions, this section will separately discuss the results for trained words and untrained words in the task. Note that the words used in the pre-test are also called 'trained' and 'untrained' even though they are not 'trained' yet (see 3.2 section).

The first part of this section will present the analysis in order to answer the first research question: whether Chinese EFL learners can improve their knowledge of the pronunciation of 'trained' English written words embedding the 'c' orthography-phonology mapping rule following brief exposure. The mean scores of 'trained' pre-test and 'trained' post-test for each group with standard deviation as the error bars are shown in Figure 5 below.

Figure 5. Performance with trained nouns at pre- and post-test

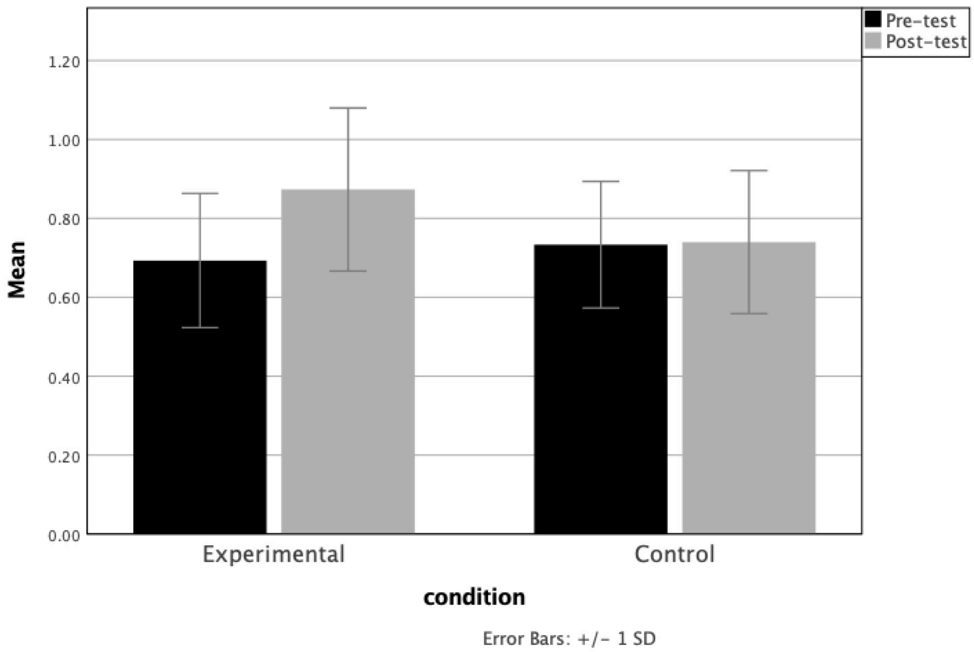


Initially, the researcher intended to do a mixed ANOVA with test-type (pre- and post-test) as the within-participants variable and conditions (the experimental and control condition) as the between-participants variable. If the data had met the normality assumptions, the researcher would have chosen to do this ANOVA with each of the 'trained' and 'untrained' items in the pre- and post-test and looked for an interaction between test-type and conditions. The score data in the whole post-test, however, were not normally distributed as indicated by the K-S test ($p < .001$); therefore, non-parametric tests were used for the whole orthographic mapping task.

First, gain scores of the trained words, i.e., the difference between trained pre-test and trained post-test performance, were used as the dependent variable in order to compare the extent of increase from pre-test to post-test for the trained words for the two groups. A Mann-Whitney U test revealed that the gain scores from trained words were significantly higher in the experimental group (Mean gains = 0.183) compared to the control group (Mean gains = 0.017), $U = 196.5$, $z = 3.948$, $p < 0.001$. Follow-up Wilcoxon signed rank tests were conducted to further compare the trained pre-test and post-test performance of the experimental and the control groups separately. The first Wilcoxon signed rank test revealed that the trained post-test scores of the experimental group ($M = 0.893$, $SD = 0.032$) were significantly higher than the pre-test ($M = 0.710$, $SD = 0.037$) after the intervention ($z = 4.085$, $p < .001$). For the control group, the Wilcoxon signed rank test showed that there was no significant difference between the trained pre-test ($M = 0.743$, $SD = 0.036$) and post-test scores ($M = 0.760$, $SD = 0.037$), $z = 1.098$, $p = .272$. In sum, the results showed that the intervention led to improved performance on the trained words in the orthography-phonology mapping task for the experimental group compared to the control group.

The second part of the analysis was done to answer the second research question: whether Chinese EFL learners can acquire generalized knowledge of the 'c' orthography-phonology mapping rule implicitly, following brief incidental exposure to 'untrained' words embedding the rules. Similarly, the mean scores of 'untrained' pre-test and 'untrained' post-test for each group with standard deviation as the error bars were shown in Figure 6 below. Gain scores from the untrained pre-test and untrained post-test were used as the dependent variable in order to compare the extent of increase from pre-test to post-test for the untrained words for the two groups. The Mann-Whitney U test here revealed that the gain scores from untrained words were significantly higher in the experimental group (Mean gains = 0.18) compared to the control group (Mean gains = 0.00), $U = 134.5$, $z = 4.834$, $p < 0.001$.

Figure 6. Performance with untrained nouns at pre- and post-test



Follow-up Wilcoxon signed rank tests were conducted to compare the untrained pre-test and post-test performance of the experimental and the control groups separately. The Wilcoxon signed rank test of the experimental group revealed that the untrained post-test scores (M = 0.873, SD = 0.038) were significantly higher than the pre-test (M = 0.693, SD= 0.031) after the intervention ($z = 3.871$, $p < .001$). For the control group, the Wilcoxon signed rank test showed that there was no significant difference between the untrained pre- (M = 0.740, SD = 0.031) and post-test scores (M = 0.740, SD = 0.033), $z = 0.187$, $p = .852$.

The above analysis shows that the experimental group improved significantly both in trained and untrained words. A follow-up non-parametric paired test was done to compare the gains in trained words and gains in untrained words for the experimental group. The result showed that although the mean gains for trained (M

= 0.183, SD = 0.031) were numerically larger than those for untrained (M = 0.180, SD = 0.029), the difference was not statistically significant (Z = 0.365, p = .715).

4.2.2 Awareness Questionnaire

Having answered the first two research questions and established that learning occurred in the experimental group, it is interesting to consider how this relates to their ability to explicitly describe the rules. Participants were asked to finish a questionnaire in which they were asked to type down the rules and specify when they knew the rules (i.e., before or during the experiment or do not know the rules). In total, 24 participants in the experimental condition and 20 in the control condition completed the questionnaire. For the experimental group, 12/24 (50%) of the participants in the experimental condition could report the pattern correctly (e.g., */s/ when letter <c> is followed by letter <e> and <i>, and /k/ when <c> is followed by letter <a>, <o> and <u>*), among which 10/12 said they learned the pattern in the experiment. For the control group, 16/20 (80%) participants in the control condition could not report the pattern. Among the other 4/20 control participants, 2/4 said they learned the pattern in the experiment. Of the remaining participants who were able to explain the pattern correctly, two in the experimental group and three in the control group either said they already knew it or did not say when they learned the spelling pattern.

The researcher was interested in seeing if, for the participants who were unable to report the patterns at the end, nevertheless showed evidence of improving from pre- to post-test as this would provide evidence that learning was implicit. Therefore, a Wilcoxon signed rank test was conducted to compare the pre- and post-test scores of the experimental participants who reported they did not know the spelling pattern. The test revealed a significant difference between the pre- and post-test scores for these participants (z = 2.373, p = .018). In order to specifically probe learning of the generalization, another Wilcoxon signed rank test was conducted to further test the performance of those unaware participants on untrained words. The test showed that the untrained pre-test scores (M = 0.62) were significantly lower (Z = 2.024, p

= .043) than the untrained post-test scores (M = 0.78).

4.3 Correlations between phonemic awareness and orthography-phonology mapping task

This section presents results and analyses in order to answer the third and fourth questions concerning the correlations between phonemic awareness and the performance of orthography-phonology mapping. First, the mean scores and standard deviation of all English and Chinese phonological tasks are presented in the Table 10 below.

Table 10. The Means and standard deviation of English and Chinese phonological tasks

	Experimental mean (sd)	Control mean (sd)
English Phonological tasks		
1. First	.782 (.176)	.760 (.146)
2. Middle	.774 (.174)	.711 (.211)
3. Last	.833 (.149)	.804 (.174)
4. Overall EPA	2.400(.431)	2.300 (.496)
Chinese Phonological tasks		
1. Onset	.789(.242)	.737 (.196)
2. Rime	.856(.178)	.762 (.188)
3. Tone	.882(.202)	.839 (.190)
4. Overall CPA	2.526(.452)	2.342 (.495)
5. Invented Pinyin	9.208(1.766)	8.862 (1.830)

4.3.1 Phonemic awareness and mapping performance in pre-test

This section is going to answer the third research question, that is, does English/Chinese phonemic awareness correlate with participants' knowledge of the pronunciation of English written words embedding the 'c' orthography-phonology mapping pattern prior to exposure. The researcher looked for correlations between accuracy scores in the pre-test and all phonological tasks. Note that data of all phonological tasks were tested not normally distributed (which will be discussed in the next chapter); therefore, bivariate Spearman's correlations were used herein. The results of the correlations are shown in Table 11, Column 1.

Starting with English phonological tests, there were significant positive correlations for all of the English tasks with medium (>.4) to strong (>.5) effect sizes, according to Cohen (1988). Among the three oddity tasks, the score of the English first sound detection task correlated the most significantly to the pre-test, $r = 0.55$, $p < 0.001$. For the Chinese tasks, there were significant correlations for Rime detection and CPA, with medium effect sizes (>.3). For onset detection and Invented Pinyin task, the positive correlations were also significant, with strong effect sizes (>.4 and >.5, respectively). The only task with insignificant correlation was the tone detection among Chinese phonological tasks.

Table 11. Correlations among phonological tasks and pre-test/gains

		Pre-test (All participants, N = 60)	Gains (Experimental group only, N = 30)
English tasks			
1.	First sound detection	.551**	-.097
2.	Middle sound detection	.531**	.175
3.	Last sound detection	.470**	.048
4.	EPA	.593**	-.002
Chinese tasks			
5.	Onset detection	.450**	.104
6.	Rime detection	.306*	.354
7.	Tone detection	.225	.206
8.	CPA	.342*	.368
9.	Invented Pinyin	.551**	-.192

Note: *P<0.05, **P<0.01

4.3.2 Phonemic awareness and gains in mapping task

Bivariate Spearman correlations were again conducted to further investigate the fourth research question: Does English and Chinese phonemic awareness correlate with participants' ability to learn the 'c' pattern from implicit incidental exposure to words embedding that pattern? Therefore, only data from the experimental group were used in these correlation analyses. Results are shown in Table 11, Column 2. There were no significant correlations between any of the measures of phonemic awareness and gains from training.

5. Discussion

The results from the present study support that adult language learners in the experimental group could pick up the contextual constraint patterns (Treiman, 2017a) and benefit from the incidental exposure of graphotactic and phonological mapping skills from a statistical learning perspective. Regarding the correlations between phonemic awareness and mapping tasks, English and Chinese phonemic awareness (except for Chinese tone awareness) were found strongly correlated with the orthography-phonology mapping performance in the pre-test. However, none of the phonemic awareness tasks were found significantly correlated to the gains from pre- to post-test. In this chapter, the researcher will go through these findings in turn and provide potential implications for language teaching and learning at the end.

5.1 Evidence of the Learning of spelling and pronunciation patterns from an implicit statistical learning perspective

In the orthography-phonology mapping task, the researcher investigated Chinese adult English learners' learning of the spelling and pronunciation patterns of letter <c>. In this section, results of pre- and post-test from the two groups will be compared to discuss whether Chinese EFL learners can improve and generalize their knowledge of the pronunciation of English written words embedding the 'c' orthography-phonology mapping pattern following brief exposure to those words.

As seen for the trained part, there was a significant improvement between trained pre- and post-test scores in the experimental group, which was above that in the control group. There was no evidence that the control group performed better in the post-test than in the pre-test. Together these findings indicate that improvement in the experimental condition is not simply due to repeating the same test twice in the pre- and post-test. The evident comparison between the two groups suggests that experimental participants improve their knowledge of the patterns from the exposure to pattern-embedded stimuli, indicating that the intervention is successful to some extent in improving participants' orthography-phonology mapping skills, as confirmed by the difference between the two groups. For the untrained part, the difference in the gain scores from pre-test to post-test between the experimental and control groups was also significant. There was a clear and significant improvement from untrained pre-test to post-test in the experimental group, while there was not in the control group. This corroborates that participants are able to improve with the words even though they did not see them in training, which provides evidence that participants are able to generalize the spelling and pronunciation patterns to the unseen new words. The above findings may imply that despite not being explicitly taught the patterns, some participants are still able to pick up on the patterns from incidental exposure, and then this knowledge becomes explicit. This experiment builds on Samara and Caravolas's (2014) and Singh et al.'s (2021) works. Note that the stimuli in this task were all pronounceable real English words which was different than Singh and colleagues who tested knowledge without phonological counterparts. Although the stimuli are different, the result from the current study also corroborates that adult language learners are sensitive to statistical information in a complex language learning task, which is consistent with previous research stating that graphotactic learning happens under brief incidental experimental conditions (Samara & Caravolas, 2014; Samara et al., 2019; Singh et al., 2021), and supplements Saffran, Aslin, and Newport's (1996) study on children.

Furthermore, it is interesting to see if there are some participants who learn the patterns but cannot report them explicitly. If there are, this would provide evidence that their learning is implicit rather than explicit. In this sense, additional analysis was done on participants who could not report the patterns at the test correctly. It was reported from the awareness questionnaire data that 12 out of 24 experimental participants did not recognize the spelling and pronunciation patterns, including four who tried to report the patterns but failed. The investigation of these 12 participants confirmed that these participants had nevertheless improved, both on average and on generalization items in isolation. In other words, participants who could not articulate the patterns after the training actually improved in their performance. Consistent with Singh et al. (2021), who found that unaware participants improved in their knowledge of graphotactic patterns, this result indicates that these participants pick up on the patterns unconsciously and are able to generalize the patterns in training to other items in the post-test even though they were not able to report the patterns.

The findings in this section are consistent with previous research that adults can generalize over those context-based constraints, which vary in complexity in incidental conditions (Samara & Caravolas, 2014; Singh et al., 2021). In line with those studies, this finding provides further evidence supporting implicit learning, at least in the sense of not being able to articulate what they have learned and the assumption that statistical learning involves implicit learning mechanisms. Given that this analysis here is specifically with just 12 unaware participants, future studies would need to replicate this with a larger sample of unaware learners in order to confirm this result. Additionally, the results from the awareness questionnaire showed that 12 out of 24 experimental participants correctly reported the spelling and pronunciation patterns at the test, and they reached close-to-ceiling performance (M = 0.96) in the post-test, showing some explicit knowledge of the test. The possible reasons for this result could be that they did the learning very explicitly, looking for the patterns directly and hypothesis testing. It could also be that they learned implicitly, but then that knowledge became explicit. Nevertheless, we are unable to answer this from the data which we have.

Compared to other statistical learning literature, which mostly uses artificial language in the experiment (Samara & Caravolas, 2014; Singh et al., 2021), the target words in this study are all existing English words with different levels of frequency. This study establishes that the type of learning previously shown with artificial items can also be seen with a real language with learners of that language. The real L2 pattern learning and performance in this study are informative and scale up directly to other real orthographic patterns, which establishes the relevance for literacy development in second language learning. However, there are potential limitations to this task. Though we look at real spelling and pronunciation patterns, we ignore some of the complexity of that pattern. In particular, we only look at words with the letter <c> at the beginning of the words, and we do not consider exceptions. For example, the letter <c> in 'soccer' is followed by the letter <e> but in the middle of the word. The correct pronunciation for this word is /sɑːkər/ rather than /sɑːsər/. Similarly, 'celt' is a word beginning with the letter <c> followed by the vowel <e>. According to the spelling and pronunciation patterns of letter <c>, it should be pronounced as /selt/, but the correct pronunciation is /kelt/. Future research may take this into consideration and change the stimuli to see if participants still learn those patterns when <c> is in different positions and those exceptions. Another potential difficulty in using a language that participants already know is that they might base their responses on previous knowledge and not that in the experiment, particularly for those untrained words which are real English words in the test (whereas with an artificial language, this cannot be the case). Nevertheless, the fact that we used a pre-post design with a control condition establishes that previous learning cannot explain the findings. That is to say, the findings that experimental participants are better following the intervention for both 'trained' and 'untrained' words must be due to their exposure to that intervention. As a potential solution, future experiments may explore the use of fully artificial languages. In sum, the findings of this task are consistent with the previous research that adult language learners can pick up the contextual constraint patterns (Treiman, 2017a) and benefit from the incidental exposure of graphotactic and phonological mapping patterns from a statistical learning perspective (Samara & Caravolas, 2014; Samara et al., 2019; Singh et al., 2021).

5.2 The role of phonemic awareness in the learning of spelling patterns

5.2.1 Correlations between phonemic awareness and orthography-phonology mapping

The second goal of this study was to investigate the role of the phonological system specifically in learning English spelling and pronunciation. Results showed that both English and Chinese phonemic awareness (except Chinese tone awareness) correlated to participants' performance prior to exposure significantly, implying phonemic awareness in both L1 and L2 play positive roles in learning spelling patterns. Previous research has focused mainly on a more general level of cross-language transfer between Chinese and English, such as bilingual reading acquisition and the role of phonology, orthography, and morphology (e.g., Wang et al., 2005; Wang et al., 2006). Scholars anticipate that the cognitive process of reading two fundamentally different language systems will be different in terms of the different orthographic forms and the strategies to obtain phonological code. As the literature discussed in the previous chapter suggests, phonemic awareness and letter knowledge are key skills in English orthographic mapping. The current study did not include the investigation of the Chinese writing system, which is a logographic orthographic system that does not involve phonemic awareness and letter knowledge. Hence, the current study concentrated solely on investigating how English and Chinese phonemic awareness, as well as Pinyin knowledge, may affect Chinese EFL learners' learning of English spelling and pronunciation patterns.

Testing both English and Chinese phonemic awareness is useful in the sense that participants' performance here is related to phoneme awareness in Chinese as well as English. If only English phonemic awareness is tested, the correlation could be just because participants who know more English perform better at knowing the spelling and pronunciation links of the words at pre-test and are better at phonological tasks because of their experience with English. The fact that their performance is correlated with Chinese phonemic awareness is more substantial evidence that phonemic awareness has actually helped them learn the spelling of these words.

The Pinyin system is the Chinese phonological system and was examined in the experiment to indicate participants' Chinese phonemic awareness. Given the fact that the Chinese Pinyin system shares many similarities with the English alphabet system in terms of some pronunciations and syllable constitution (e.g., the onset and rime C-VC structure), we hypothesized that there would be relations between the Chinese Pinyin system and the learning of English spelling and pronunciation patterns.

In this section, the relation between English and the performance of orthographic mapping will be discussed first. As the results suggest, there were strong correlations between all the English phonological tasks and the pre-test performance. This finding indicates that phonemic awareness indeed plays a role in English orthographic mapping. It is interesting to find that the strongest correlation was with English first sound detection (though further statistical analysis may needed as to confirm the strongest correlation), which may be reasonable given the nature of the orthographic task in this study. The possible explanation could be that the spelling and pronunciation patterns in this study concern the soft and hard 'c' sound as the first sound of letter <c> at the beginning of English words. Thus, it is reasonable to find a strong and significant correlation between English first sound detection and the performance in the pre-test. These findings support previous research (Boyer & Ehri, 2011; Ehri & Wilce, 1987) that the ability to segment words into sounds and identify them is essential for successful orthographic mapping. The above studies, however, only looked at phonemic awareness and L1 learning and did not provide supporting evidence that phonemic awareness is also crucial in learning L2 spelling and pronunciations patterns. Therefore, one potential contribution of the results in the present study may be that it provides and supplements the picture of how phonemic awareness plays a crucial role in adult L2 learning of orthography-phonology mapping.

In addition to English phonemic awareness, Chinese phonemic awareness was also found to be strongly correlated to the pre-test scores. It is important to note that the Pinyin system has been explicitly taught since primary school in China, so the participants in the present study all received explicit Pinyin instruction in schools. The alphabetic nature of the Pinyin system (see 2.6.1 section) may indicate that the Pinyin learning experience is likely to facilitate the transfer of Chinese phonemic awareness to English (Wang et al., 2009). It is speculated that such phonological transfer may be reduced for those Chinese students with less Pinyin learning experience. Previous research has provided evidence when comparing Hong Kong students who did not learn Pinyin and students with Pinyin experience from mainland China (Giovannetti, 1997), suggesting that Hong Kong students performed worse on English word and nonword reading than students from mainland China. Therefore, it is suggested that there are correlations between Pinyin knowledge and English word reading. This may be an interesting direction for future research to compare students with these different backgrounds. In the present study, all the Chinese phonological tasks except the tone detection task were correlated significantly to pre-test scores. These results are consistent with Wang et al. (2009), indicating that there is a strong cross-language phonological transfer from the Chinese phonological system to English. Significant correlations between Chinese onset, Chinese rime, and English orthography-phonology mapping performance suggest that there may be a shared phonological skill being indicated in these tasks. As discussed earlier, the orthography-phonology mapping task in the experiment required the ability to match different beginning 'c' sounds constrained by following vowel letters. Similar to the English phonological tasks, the Chinese onset detection task requires attention to initials within Pinyin syllables, which may be the most related skill aiding the beginning sound detection in the pre-test. For instance, the /s/ sound and /k/ sound, although represented by different onset letters <s> and <k> respectively in Pinyin, are pronounced the same as the soft and hard 'c' sound in English. Even though the onset is considered a relatively easy phoneme to perceive (Wang et al., 2005; Wang et al., 2009) in both Chinese and English, the Chinese onset awareness could still facilitate English word reading. These shared sounds in both the Chinese and English systems may aid the participants in the mapping task, which may explain Chinese onset detection being a significantly correlated variable to English orthographic mapping. Nevertheless, this significant contribution of Chinese onset awareness to English reading was not shown in Wang et al. (2005). This difference could be due to the different task designs and demands. Consistent with Wang et al. (2009), Chinese onset awareness was examined using oddity tasks in this study in which the participants were presented with three auditory stimuli and were asked to select the different onset from three choices. In comparison, Wang et al. (2005) used a relatively easier task in which the participants were asked to select one between two choices and match it with the target stimuli. This may more possibly lead to ceiling effects in that measure, preventing Wand and colleagues from seeing the correlation.

In terms of tone processing, this study found no evidence of a correlation between tone detection skills and pre-test, which conflicts with previous literature (Tallal, 1980; Reed, 1989; Wang et al., 2005; Wang et al., 2009). For example, Tallal (1980) used auditory processing tasks to test children's phonic knowledge. The two tones in their task were either high or low frequency. Children were asked to repeat the two different tones by pressing buttons. Her results showed a significant relationship between pseudoword reading and tone order judgment skills. Though the current study used similar auditory processing tasks as in Tallal's research, the fundamental difference between the two tones (high or low frequency difference) used in Tallal's study and Chinese tone may be the reason that causes the difference. Chinese tone is more than auditory processing but a more complex phonetic processing. In this sense, testing Chinese tone awareness may involve another level of phonological processing skill. However, a study investigating Chinese tone awareness and English word reading by Wang et al. (2009) provided the same pattern of results as Tallal. Results in Wang et al.'s (2009) study of 78 Chinese-English children showed that Chinese tone awareness predicted 5% of the variance in English word reading ($p < .05$). Wang and colleagues considered Chinese tone as an entirely different level of phonological processing and a good pre-literacy predictor of reading English. They suggested that this reflected some shared phonological sensitivity in learning to read English since Chinese tone processing and English pseudowords reading both ask participants to pay attention to spoken word forms and the constituents-phonemes for English and tones for Chinese (Wang et al., 2005, p.81). However, this significant correlation between Chinese tone processing and English word reading was not found in this research. Meanwhile, it is the only subtest that is not significantly correlated to the mapping performance among the three Chinese phonological subtests. One possible interpretation is that the current study examines a more subdivided level of word reading. Instead of testing pseudoword reading, this study is actually measuring the visual word reading ability to map grapheme-phoneme, that is, to map the letter with the correct sound constraint by its spelling patterns. In this case, tone awareness may be less involved in this cognitive process compared to Chinese onset and rime detection. Therefore, the current study did not find a significant correlation between tone awareness and mapping performance. It should be noted that with a null result, it is always possible that this is a type 2 error, i.e., there is a correlation between tone awareness and mapping performance, and it could be found if the sample is larger. In sum, the findings concerning whether Chinese tone awareness is correlated to English reading are inconclusive. It would be interesting for future research to investigate whether training English-speaking children or dyslexic children in Chinese tone detection may help improve their English word reading.

Apart from the Chinese phonological oddity task, the researcher also conducted an invented Pinyin task adopted from Lin et al. (2010), further measuring participants' Pinyin knowledge. The original utilization of this task contained only five one-syllable Chinese words in Lin et al. (2010) since the task was designed for use with young children. Therefore, the research of the current study increased the number of stimuli. The invented Pinyin task was validated by Ding et al. (2015) in their study of typical readers and readers with reading difficulties in Mandarin, using a 0-1 coding scheme. In order to further test the onset and rime knowledge in Pinyin (e.g., the sequence of onset and rime), this study adopted Lin et al.'s 0-12 coding scheme and made slight changes to the 0-10 coding scheme. The result of this study shows that the invented Pinyin task was significantly correlated to the mapping performance, and it was as significant as English first sound awareness ($r = 0.551$, $p < 0.01$ for both). Invented Pinyin task aims to examine whether participants can write the correct onset, rime, and tone; and the sequence of onset and rime to make a correct combination of pinyin syllables. The ability to write the correct Pinyin syllables may therefore involve knowledge of syllable awareness and phoneme awareness at the suprasegmental level, which is similar to the syllable constitution in English and is considered required for successful orthographic mapping (Miles & Ehri, 2019).

In sum, the results from this study indicate that both English and Chinese phonemic awareness, except Chinese tone awareness, are significantly correlated to orthography-phonology mapping performance. The potential experiment limitations will be discussed in general in the next section.

5.2.2 Correlations between phonemic awareness and gain scores

The discussion above shows that there are evident correlations between phonemic awareness and the orthography-phonology mapping task in this research. This further leads to another question: are participants with better phonemic awareness able to progress more in the post-test? The fourth goal of this research was to answer this question by investigating whether participants' phonemic awareness was correlated with their gains in training. Therefore, only the gain scores from experiment participants were analysed here (N = 30). It was surprising that none of the phonological tasks significantly correlated to the gain scores. Specifically, the direction of English phonemic awareness, English first sound detection, and Chinese invented Pinyin task were found to be negative in this correlation analysis. The potential explanations will be discussed next.

In answering the third research question, it was evident that both English and Chinese phonemic awareness were significantly correlated to the mapping performance in the pre-test. Therefore, it is more possible that participants with better phonemic awareness already score higher in the pre-test. Meanwhile, as discussed earlier, the use of real spelling and pronunciation patterns may be relatively easier compared to the use of a fully artificial language system. Participants in this study are exposed and learn English to a certain extent. It is difficult to control the levels of their familiarity with English words and patterns and their specific proficiency levels. Hence, it possibly results in the close-to-ceiling effect in post-test of experimental participants, especially when the post-test and pre-test were identical. The participants with better phonemic awareness started higher that they scored higher in the pre-test, and their potential progress might be affected by the limited test range as 100% correct. In other words, there is not enough room for them to progress, and by definition, they are more constrained in how much improvement they can gain in the post-test. Therefore, the negative directions were seen in those three variables in this section. There could be another potential explanation in that the gains may be a result of participants memorizing the same word as a whole unit rather than learning the spelling and pronunciation patterns. The hypothesis that participants may not use and analyze the phonological code in the experiment could be one reason that lowered the level of correlations between phonemic awareness and gain scores.

In terms of the methodological limitation, some potential limitations lie in the English and Chinese phonemic awareness task design. Both English and Chinese phonemic awareness tasks were oddity detection tasks with slight changes, adopted from the previous literature targeting child participants. Therefore, the original tasks may be relatively easier for adult participants. Changes were made to increase the difficulty of both English and Chinese stimuli following a few studies that target adult Chinese learners (Bai, 2014; Xu & Zhang, 2015). On the other hand, in Hu's (2018) assessment of Chinese adult learners' English phonological awareness, the oddity task was tested as less effective in reflecting phonemic awareness compared to segmentation, blending, and deletion tasks. In the present study, it is observed that some scores of these oddity phonological tasks were tested not normally distributed since some of the task scores revealed close-to-ceiling effects. Although significant correlations were found in the analysis between these phonological tasks and performance in the pre-test, none of the phonological tests were significantly correlated to the gain scores. One possibility is that there might really be an effect, but the sample size is too small to detect it compared to previous research such as Bai's (n = 178) and Xu and Zhang's (n = 159). It is possible that the effect would be small here as the gains scores are based on the difference that comes from a very brief training event, compared with pre-test scores which are influenced by years of English experience.

6. Conclusion and Implications

To conclude, the current study investigates the learning of orthography-phonology mapping patterns in an L2 context and the correlation between this learning and phonemic awareness. Referring to the literature, it was demonstrated by Samara and colleagues (Samara & Caravolas, 2014; Samara et al., 2019) and Singh et al. (2021) that language learners succeed in generalizing complex orthographic knowledge into their spelling under implicit learning conditions. This study presents consistent findings on learners' statistical learning ability in the learning and generalizing spelling and pronunciation patterns. The main contribution of the current study is the demonstration of this orthographic learning in an L2 context with Chinese EFL learners. It demonstrated that Chinese EFL learners were able to improve their knowledge of spelling and sound patterns from brief exposure to the words embedding the patterns and were able to generalize those patterns to the unseen new words following the incidental exposure. Even those who could not report the correct patterns in the awareness questionnaire improved in the task, which provided evidence for implicit and unconscious learning. However, it should be noted that it is questionable to which extent can such self-report questionnaires examine learners' actual explicit knowledge. It may be an interesting challenge for future studies to establish a more reliable way to measure explicit awareness. On the other hand, participants in this study indeed got very targeted exposure, i.e., lots of examples of words with the same pattern presented one after the other. It would be interesting for future research to explore whether this incidental learning of patterns will still happen in a more naturalistic context, such as learning the patterns when reading texts (e.g., Pacton et al., 2014). Second, even if they could pick up the patterns with incidental exposure, they may still do better if they got explicit teaching considering existing literature provides evidence of the explicit learning advantage (de Graaff et al., 2009; Li & Woore, 2021; Singh et al., 2021; Sobaco et al., 2015). As Kessler (2009) argued, not every aspect of written language can be explained by patterns and rules; there may be exceptions that lie in the patterns. It would be interesting for future studies to explore what makes explicit instruction on graphotactic and orthographic knowledge beneficial in experiments and further extend this benefit to real-life learning contexts. Furthermore, it may also be an interesting challenge for future studies to go beyond defining the learning as purely explicit or implicit as these two mechanisms may interact more complicated in the real literacy learning process. To this extent, future research should further explore how explicit instruction and incidental learning benefit learners' knowledge and proficiency in spelling differently. Therefore, comparable studies could be done using equivalent experiments with additional explicit pattern teaching in the explicit condition to compare the implicit learning and explicit instruction effectiveness (e.g., Singh et al., 2021).

In addition to investigate learning of spellings, the current study also investigates whether English and Chinese phonemic awareness (including Pinyin knowledge) correlate with Chinese EFL learners' knowledge of the patterns and their ability to learn the pattern from implicit incidental exposure. Results showed that both English phonemic awareness and Chinese phonemic awareness (except Chinese tone awareness) were significantly correlated with participants' performance in the English orthography-phonology mapping pre-test. However, no significant correlations were found between phonemic awareness and their gains scores from pre-test to post-test. This first indicates that phonemic awareness is positively correlated to the learning of spelling and pronunciation patterns. Secondly, the current study sheds light on the cross-language transfer in learning those patterns. Not only English phonemic awareness but also phonemic awareness in learners' native language (i.e., Chinese phonemic awareness) correlate to the learning of L2 English orthography-phonology mapping knowledge positively. Referring to the recent literature, Li and Woore (2021) and Castles et al. (2018) both emphasize the benefit of explicit phonics instruction for L2 language learners. In L1 settings, phonics instruction is well established and generally considered via the lens of learning to read (Li & Woore, 2021, p.10). Comparably, there is still limited research testing the effectiveness of phonics or other phonological knowledge instruction in an L2 context. Pedagogically, the findings from this research may imply that teaching both L1 and L2 phonological knowledge can be helpful in improving the learning of orthographic and graphotactic knowledge, especially presenting the beneficial role of L1 phonemic awareness such as Pinyin knowledge taught and used in pedagogical settings in the learning of L2 spelling and pronunciation patterns. Future studies can extend these findings from lab-based studies to a classroom environment, as to explore the effectiveness of teaching explicit phonological knowledge in real-life language learning.

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8. Appendices

Appendix A. CUREC approval

Note: The dissertation project is covered under my supervisor's existing research ethics approval (letter attached below). All names in the letter have been blanked out.

SOCIAL SCIENCES & HUMANITIES INTERDIVISIONAL RESEARCH ETHICS COMMITTEE

Research Services, University of Oxford, Wellington Square, Oxford OX1 2JD
Tel: +44(0)1865 616576 Fax: +44(0)1865 280467
ethics@socsci.ox.ac.uk

UNIVERSITY OF OXFORD

6 January 2021

Department of Education

Dear

Research Ethics Approval (CUREC 2)
Ref No: R73484/RE001
Title: Language learning in adults and children

The above application has been considered on behalf of the Social Sciences and Humanities Interdivisional Research Ethics Committee (IDREC) in accordance with the procedures laid down by the University for ethical approval of all research involving human participants.

I am pleased to inform you that, on the basis of the information provided to the IDREC, the proposed research has been judged as meeting appropriate ethical standards, and accordingly approval has been granted.

Should there be any subsequent changes to the project that raise ethical issues not covered in the original application you should submit details to the IDREC for consideration:

https://researchsupport.admin.ox.ac.uk/governance/ethics/apply/sshidrec#collapse394916.

Please note that your study may be selected for review by the SSH IDREC during an annual audit. You may also be required to submit a brief annual progress report on each anniversary of study approval, until the study is completed.

Yours sincerely,

Research Ethics Manager

cc:

Appendix B. Participant information sheet and consent form (English version)

Department of Education, University of Oxford, 15 Norham Gardens, OX2 6PY

Appendix B: Information sheet and consent for adults participants

INFORMATION SHEET FOR ADULTS

CUREC Approval Reference: **R73484/RE001**

In this study, participants play some language learning games and learn some English words. We use the data to investigate how children and adults learn languages. Please read the following information before you decide whether you wish to take part.

Who?

The language learning tasks used in this study have been designed by researchers under the supervision of [redacted] in the Department of Education and department of Psychology at the University of Oxford. The research is funded by the Leverhulme Trust. The study has been reviewed and approved by the University of Oxford's Central University Ethics Committee for research involving human participants (ref: **R73484/RE001**)

Why?

We have designed this game to better understand language learning. We compare different learning methods to see how well you learn novel words. This will help researchers identify better ways to teach new languages in a variety of settings.

Who can take part?

We would like adults aged between 18 and 45 years to participate. In order to participate, it is important that:

- You are a native speaker of Chinese (any dialect)
- You are not highly proficient in English
- You don't have any history of neurological and language impairment.
- You don't wear spectacles and aren't affected by strabismus.

Please let us know if you have any concerns.

What will happen?

You will learn by reading and hearing English words. Your task is simply to pay attention to them for the duration of the experiment (around [30/45] min). At the beginning of the experiment you will be tested on these words, and you will be tested again later to see what you have learned. You will also asked to do some other tasks which test your knowledge of other words in English and Chinese.

Do I have to take part?

It's up to you to decide whether or not to take part—your participation is entirely voluntary! Your refusal to agree won't result in any penalties or prejudice and you'll still get paid for your time. However, if you do agree in taking part in our experiment, you'll be asked to declare your decision digitally by completing a consent form. Remember that you can always opt-out at any time without giving explanations, and if you do decide to withdraw from the study you'll be asked what you wish to happen to the data you have provided to that point.

Will my taking part in this project be kept confidential?

Your answers will be completely anonymous. All the information that we collect about you during the course of the research are related ONLY to your performance in this experiment. We do not have access to your identity at any point. This information will be kept strictly confidential and you will not be able to be personally identified in any ensuing reports or publications. We make sure that this is the case by assigning you a novel random ID number that is not linked to any of your existing IDs present on Prolific or in Gorilla, moreover we do not ask your age or any other personal information that might connect you to your novel ID.

Who will have access to my data?

We record only your performance in this experiment in the form of button presses and mouse clicks. The Gorilla and Prolific platforms are the data controller with respect to your personal data and, as such, will determine how your personal data is used. Please see their privacy notice here and here. Gorilla shares with the researchers involved in this study part of the University of Oxford only fully anonymised data where a random generated key has been assigned automatically at the beginning of the experiment. We do not have access to your personal data at any time, and therefore it's impossible to link your data to your person.

Data about your performance will be shared with [redacted] as Principal Investigator assigned to the project, and with [redacted] as collaborator to this project. We would also like your permission to use your anonymised data in future studies, and to share data with other researchers (e.g. in online databases such as Online Science Framework) and publish it on scientific journals. There is no personal information that could identify you. Responsible members of the University of Oxford and funders may be given access to data for monitoring and/or audit of the study to ensure we are complying with guidelines, or as otherwise required by law.

What will happen to the results of the research project?

Results will be disseminated to the academic community via presentations in journals and at conferences. As part of a more general move to more transparency and openness in science, pre-processed data is stored indefinitely on public repositories such as Open Science Framework and GitHub. However, this will only happen because the data sets are fully anonymised, so that they contain no information that could potentially be linked to you.

If you wish to be informed of the results of the study, do not hesitate to contact us. However, we must inform you that we won't be able to give you feedback about your own performance, since we won't be able to identify you or match your name with any specific data.

What are the possible disadvantages and risks of taking part?

There are no foreseeable discomforts, disadvantages and risks associated to this experiment. The eye-tracking procedure is non-invasive and will not cause any harm or discomfort] However, if you feel or believe there are any unexpected discomforts, disadvantage and risk which arises during the research, you should immediately contact us via email (see next section).

Who do I contact if I have a concern about the study or I wish to complain?

If you have any queries or concern about any aspect of this study please contact: [redacted] and she will do her best to answer your query within 10 working days to give you an indication of how it will be dealt with. If you remain unhappy or wish to make a formal complaint, please contact the Chair of the Research Ethics Committee at the University of Oxford who will seek to resolve the matter as soon as possible: Chair, Social Sciences & Humanities Interdivisional Research Ethics Committee; Email: ethics@socsci.ox.ac.uk; Address: Research Services, University of Oxford, Wellington Square, Oxford OX1 2JD

If you have read the information above and agree to participate with the understanding that the data (including any personal data) you submit will be processed accordingly, please check the relevant box below to get started.

☐ Yes, I agree to take part

Appendix C. Participant information sheet and consent form (Chinese version)

Department of Education, University of Oxford, 15 Norham Gardens, OX2 6PY

Appendix C: Information sheet and consent for adults participants

实验信息说明表

CUREC Approval Reference: **R73484/RE001**

本次实验中，参与者将会玩一些语言学习游戏并学习一些英语单词。我们使用这些数据来调查儿童和成人如何学习语言。在决定是否参加之前，请阅读以下信息。

研究人员?

本研究中使用的语言学习任务是由研究人员在[redacted]及其同事在牛津大学教育系和心理学系的监督下设计的。该研究由 Leverhulme 基金资助。该研究已获得牛津大学中央大学伦理委员会的审查和批准，可用于涉及人类参与者的研究（ref: **R73484/RE001**）。

研究目的?

我们设计这项实验游戏是为了更好地理解语言学习。我们通过实验比较不同的学习方法来研究调查参与者学习新词的能力如何。这将帮助研究人员找出在各种环境中教授新语言的更好的方法。

参与者要求?

我们希望 18 至 45 岁的成年人参加本次实验。需要注意的是：
- 您的母语是中文（任何方言）
- 您的英语水平未达到精通水准
- 您没有任何神经和语言障碍病史。
- 您不受斜视的影响。

如果您有任何疑虑，请告诉我们。

实验内容?

您将通过阅读英语单词和听英语单词发音来学习。您的任务只需在实验期间（大约 [30/45] 分钟）注意实验中的单词。在实验开始时，您将接受这些单词的测试，稍后您将再次接受测试来检测您学到了什么。您还将被要求做一些其他任务，以测试您对英文和中文其他单词的了解。

参与意愿?

由您决定是否参与本次实验——您的参与完全是自愿的!
您的拒绝不会导致任何处罚或偏见，您付出的时间仍将会获得报酬。但是，如果您同意参与我们的实验，您将需要填写一份同意书，以数码方式宣布您的决定。请记住，您可以随时选择退出而无需提供任何解释，如果您决定退出研究，我们将会询问您希望对您已提供的数据进行什么处理。

参与是否保密?

您的回答将完全匿名。我们在研究过程中收集的有关您的所有信息仅与您在本实验中的表现有关。我们在任何时候都无法获取您的身份。此信息将被严格保密，您将无法在随后的任何报告或出版物中被识别出个人身份。我们通过为您分配一个新的随机 ID 号来确保情况如此，该 ID 号与您在 Prolific 或 Gorilla 中存在的任何现有 ID 无关，此外，我们不会询问任何其他可能与您联系的个人信息你的 ID。

访问数据的人员?

我们仅以按按钮和点击鼠标的形式记录您在此实验中的表现。 Gorilla 和 Prolific 平台是您个人数据的数据控制者，因此将决定如何使用您的个人数据。请在 此处 和 此处 查看他们的隐私声明。 Gorilla 与牛津大学参与这项研究的研究人员只分享完全匿名的数据，其中随机生成的密钥在实验开始时自动分配。我们在任何时候都无法访问您的个人数据，因此不可能将您的数据与您的个人相关联。

您的表现数据将与分配给该项目的首席研究员 [redacted] 以及作为该项目合作者的 [redacted] 共享。我们还希望您允许在未来的研究中使用您的匿名数据，并与其他研究人员共享数据（例如在 Online Science Framework 等在线数据库中）并将其发布在科学期刊上。共享中将不会有个人信息能够识别您的身份。牛津大学的负责成员和资助者将会获得用于监控和/或审计研究的数据，以确保我们遵守指南或法律要求。

Department of Education, University of Oxford, 15 Norham Gardens, OX2 6PY

研究项目结果?

实验结果将通过在期刊和会议上的报告传播给学术界。作为提高科学透明度和开放性的更普遍举措的一部分，预处理数据无限期地存储在开放科学框架和 GitHub 等公共存储库中。因为数据集是完全匿名的，它们将不包含可能与您相关的信息。

如果您希望了解研究结果，请随时与我们联系。但是，我们必须通知您，我们将无法就您自己的表现向您提供反馈，因为我们无法识别您的身份或将您的姓名与任何特定数据相匹配。

参与实验的可能性不利或风险?

该实验没有可预见的不适、缺点和风险。眼动追踪程序是非侵入性的，不会造成任何伤害或不适。但是，如果您感觉或认为在研究过程中出现任何意外的不适、不利和风险，您应该立即通过电子邮件与我们联系（见下部分）。

如果我对研究有疑虑或想投诉，我应该联系谁?

如果您对本研究的任何方面有任何疑问或疑虑，请联系：牛津大学教育系[redacted]问，并指示您它将如何处理。如果您仍然不满意或希望提出正式投诉，请联系牛津大学研究伦理委员会主席，他将尽快解决问题：社会科学与人文学科跨学科研究伦理委员会主席；电子邮件：ethics@socsci.ox.ac.uk；地址：Research Services, University of Oxford, Wellington Square，Oxford OX1 2JD

如果您已阅读上述信息并同意参与，并理解您提交的数据（包括任何个人数据）将会被对应分析处理，请选中下面的相关框以开始。

☐ Yes, I agree to take part

Appendix D. Stimuli – Orthography-phonology mapping task (pre-test, post-test and intervention)

Words for Pre-test and Post-test	**Words for intervention (Set 1 +Set 2)**	**Words for intervention (Set 1 +Set 3)**
caprice	cent	cent
caveat	celebrate	celebrate
cacophony	cede	cede
capricious	cession	cession
curdy	censorious	censorious
cease	cider	cider
civil	ceiling	ceiling
cipher	civism	civism
cedar	civet	civet
cephalic	citric	citric
cuddy	cube	cube
cuff	cast	cast
cosmic	cosy	cosy
contiguous	cable	cable
coax	canker	canker
certain	caboose	caboose
cental	cavalier	cavalier
ceremonious	cache	cache
cirrus	commission	commission
cerebral	coy	coy
	caprice	cuddy
	caveat	cuff
	cacophony	cosmic
	capricious	contiguous
	curdy	coax
	cease	certain
	civil	cental
	cipher	ceremonious
	cedar	cirrus
	cephalic	cerebral

Appendix E. Stimuli – English phonological tasks

English oddity task: first sound detection

Trial	cat	car	hen
1	pin	pig	tree
2	bed	hair	bell
3	box	tray	train
4	coach	farm	coat
5	dog	doll	sun
6	book	hand	hat
7	man	fish	mat
8	nail	peg	pen
9	toad	toast	girl
10	rain	bag	bat

English oddity task: middle sound detection

Trial	sock	hay	tray
1	cat	hat	bell
2	peg	cot	leg
3	fish	dish	book
4	bus	arm	farm
5	cup	sand	hand
6	hen	car	pen
7	duck	hill	pill
8	gun	sun	tap
9	rank	bank	high
10	paw	boat	goat

English oddity task: last sound detection

Trial	found	good	quick
1	cap	pop	old
2	chart	count	cook
3	dark	safe	link
4	deaf	long	half
5	farm	cut	name
6	net	glass	cass
7	pat	loan	moon
8	push	love	live
9	cat	patch	pitch
10	posh	dog	harsh

Appendix F. Stimuli – Chinese phonological tasks

Chinese oddity task: onset detection

Trial	sha	she	che
Trial	bao	ba	dou
1	tian	teng	shang
2	hai	sheng	he
3	you	huang	ye
4	si	tong	sun
5	dao	fang	fa
6	dong	meng	ma
7	shang	xue	xia
8	gei	dian	gou
9	zai	zheng	zeng
10	le	long	shei

Chinese oddity task: rime detection

Trial	chuang	shuang	zai
Trial	zhe	che	sheng
1	ba	da	dao
2	you	tu	tou
3	zai	dui	dai
4	mian	die	tian
5	deng	dong	zhong
6	bao	ben	shen
7	shou	bu	su
8	gei	dao	gao
9	bei	wei	bai
10	yi	xiang	di

Chinese oddity task: tone detection

Trial	声	一	桶
Trial	歌	杯	果
1	喝	危	到
2	词	今	图
3	局	水	盒
4	藏	蛋	人
5	酒	明	可
6	奶	后	水
7	枕	都	草
8	被	好	快
9	猫	袋	是
10	偷	页	树

Appendix G. Stimuli - English LexTALE task (Lemhöfer & Broersma, 2012)

Word list and instructions for use with other software

Materials

Below you find the items for the English version of the LexTALE test. You can implement the test in any experimental software, or as a paper and pencil test.

The columns contain the following information:

- First column: Item number. (Note that the first three items are dummies.)
- Second column: Item.
- Third column: word status; 0=nonword, 1=word.

0	platery	0
0	denial	1
0	generic	1
1	mensible	0
2	scornful	1
3	stoutly	1
4	ablaze	1
5	kermshaw	0
6	moonlit	1
7	lofty	1
8	hurricane	1
9	flaw	1
10	alberation	0
11	unkempt	1
12	breeding	1
13	festivity	1
14	screech	1
15	savoury	1
16	plaudate	0
17	shin	1
18	fluid	1

19	spaunch	0
20	allied	1
21	slain	1
22	recipient	1
23	exprate	0
24	eloquence	1
25	cleanliness	1
26	dispatch	1
27	rebondicate	0
28	ingenious	1
29	bewitch	1
30	skave	0
31	plaintively	1
32	kilp	0
33	interfate	0
34	hasty	1
35	lengthy	1
36	fray	1
37	crumper	0
38	upkeep	1
39	majestic	1

40	magrity	0
41	nourishment	1
42	abergy	0
43	proom	0
44	turmoil	1
45	carbohydrate	1
46	scholar	1
47	turtle	1
48	fellick	0
49	destription	0
50	cylinder	1
51	censorship	1
52	celestial	1
53	rascal	1
54	purrage	0
55	pulsh	0
56	muddy	1
57	quirty	0
58	pudour	0
59	listless	1
60	wrought	1

Appendix H. Age and gender questionnaire

What is your gender?

- ◯ Female
- ◯ Male
- ◯ Prefer to to say

What is your age in years?

Next

Appendix I. Language background Questionnaire

1.请按语言习得的顺序列出所有您所会的语言，包括方言：

2.请列出您目前平均接触每种语言的时间百分比 (例如：中文100%):

3.请列出您在英语国家生活过的所有时期，并给出您在何地，开始时的年龄以及离开时的年龄（例如：英国16-18）：

4.从0到10，请选择您的英语口语水平（1 = 入门水平； 10 = 母语水平）

初级入门	1	2	3	4	5	6	7	8	9	10	母语水平

5.从0到10，请选择您的英语阅读水平（1 = 入门水平； 10 = 母语水平）

初级入门	1	2	3	4	5	6	7	8	9	10	母语水平

6.从0到10，请选择您的英语听力水平（1 = 入门水平； 10 = 母语水平）

初级入门	1	2	3	4	5	6	7	8	9	10	母语水平

7.从0到10，请选择您的英语写作水平（1 = 入门水平； 10 = 母语水平）

初级入门	1	2	3	4	5	6	7	8	9	10	母语水平

Next

Appendix J. Pattern Awareness Questionnaire

本次实验中您看到了许多包含英文字母c的单词。有关这些单词的拼写和发音，有一些固定的规律。我们很想了解您是否知道这个规律。

如果知道 **英文字母c** 的拼写发音规律，请尝试在文字框内输入这个规律：

以下哪一个最好的描述了您对这个规律的了解?

- ◯ 我在实验前已经知道这个规律
- ◯ 我在实验中掌握的这个规律
- ◯ 我不知道这个规律是什么

Next