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Phonological decoding does not affect incidental Chinese novel word learning in Uyghur readers: evidence from eye movements

Yang Han[1,2] · Yongsheng Wang[1,2,3] · Feifei Liang[1,2,3] · Xin Li[1,2,3] · Jie Ma[4] · Xuejun Bai[1,2,3]

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Abstract

Vocabulary is an important foundation for reading skills. Dual-route cascaded model believes that when form-sound correspondence is irregular, phonetic decoding is a necessary but not sufficient condition for word acquisition. Lexical access in syllabic scripts involves a morphological-phonetic-semantic approach, where phonological decoding is crucial. However, in ideographic scripts, pronunciation plays a relatively small or even no role. Further exploration is needed to determine whether the morphological-phonetic-semantic approach is commonly used as a lexical access strategy in second language learning, particularly when considering two significantly different languages like Uyghur and Chinese. These languages differ in terms of language systems, lexical morphology, and writing direction. In the paradigm of repeated learning novel words, two-pseudocharacter words were constructed as novel words to control the readability of novel words' phonetic radical, which was classified into readable and unreadable categories. Readers deduced the words meaning in different contexts. There was no difference in semantic selection correctness between phonetic radical readable and unreadable conditions, and in terms of dwell time, total fixation duration, and fixation counts, the unreadable gaze time and fixation counts were significantly less than the readable condition, and the refixation ratio was lower than the readable condition. These results show that phonological decoding doesn't change how well Uyghur readers' make semantic inferences from Chinese incidental novel word learning. They also show that Uyghur readers can rapidly activate the lexical-semantic pathway when they can't complete phonological decoding and quickly inhibit the phonological decoding process. When phonological decoding is successful, they rapidly activate the lexical-phonological-semantic.

Keywords Incidental novel word learning · Phonetic decoding · Second language learning · Uyghur readers · Chinese

Extended author information available on the last page of the article

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Introduction

Novel word learning is a common phenomenon that continues until over 70 years old (Brysbaert et al., 2015). Due to the rapid development of the Internet and technology, many novel words are created every year, and the latest version of the "Modern Chinese Standard Dictionary" has been supplemented with nearly a thousand new words (Li, 2022). Incidental novel word learning refers to the process of learning novel words in the absence of a clear learning goal and combining them with existing knowledge and experience (Nagy et al., 1985; Shu et al., 1997; Webb, 2019; Hulstijn, 2003), whereas intentional learning is a deliberate attempt to memorize words and their meanings. In daily life, learning the meaning of new words is usually done by inferring the meaning of the novel word from the surrounding context (Batterink & Neville, 2011) rather than through intentional memory. About a third of the words are acquired in natural reading (Nagy & Anderson, 1984; Nagy et al., 1985). Through natural reading, Chinese second language learners acquire a large number of novel words. Repeatability and progressiveness are key characteristics of reading learning, that is, the acquisition of the meaning of novel words requires repeated learning in different contexts and a cumulative process (Frishkoff et al., 2011; Joseph et al., 2014; Nagy et al., 1985; Pickering & Gambi, 2018; Stafura & Perfetti, 2017; Xu & Zhang, 2020).

In syllabic script, the self-teaching hypothesis (Share, 1995) that phonetic decoding is the basis of orthographic learning plays a core role in self-teaching. Children learn the corresponding orthographic rules while decoding sounds, and they use the orthographic rules they already know when decoding novel words. This way, they keep their orthographic knowledge base up-to-date. They can learn novel words and increase the depth and breadth of our vocabulary in this way (Share, 2008). With alphabetic writing, phonological decoding refers to the ability to match speech to the corresponding character and is directly related to the ability to write orthographically (Wang et al., 2012). In Hebrew and languages with a shallow orthographic writing system, learning novel words' orthographic knowledge can be done through morphophonemic switching rules in one or two visual contacts (Share, 1999, 2004). In English, learning to spell regular words is much more effective than learning to spell irregular words (Wang et al., 2011; Wegener et al., 2018); and in languages with deep orthographic writing systems, such as Chinese, Li et al. (2018) and Li et al. (2020) found that phonetically pronounced regular novel words were learned better than phonetically pronounced irregular novel words. It can be seen that phonetic decoding is the key to novel word learning.

The relationship between pronunciation, morphology, and semantics in Chinese is complex, Chinese is ideographic and the role of phonetic decoding is not as direct as in the syllabic script (Davelaar et al., 1978; Taft & Van Graan, 1998; Frost, 1998; Braun et al., 2009; Tan & Peng, 1991; Zhang, Wang, & Liu, 2011). Chinese morphophonetic correspondences are much more arbitrary, such as the same phonetic character in a Chinese character, which is pronounced differently in different characters, and morphophonetic characters may be pronounced completely differently and have completely different semantic meanings. Chinese

vocabulary is highly context-dependent in terms of semantics and pronunciation. Wholeness, imagery, meaningfulness and ambiguity characterize the language processing style of native Chinese readers (Ma, 2011). Therefore, the role of phonetics in semantic access remains controversial (Gao & Peng, 2005; Chi et al., 2014; Chen & Peng, 2000). Some researchers believe that phonetics plays a mediating role in the process of semantic access (Pollatsek et al., 2000; Ren et al., 2007). However, some researchers believe that semantic information can be activated directly by morphology, ranging from phonetics playing a limited role (Feng et al., 2001) to not involving phonetics at all (Davelaar et al., 1978; Seidenberg, 1985).

Pritchard et al. (2018) proposed the computational model of the self-teaching hypothesis based on the dual-route cascaded model of reading (ST-DRC). This model offers new explanations for how people learn in syllabic scripts with low orthographic transparency, like English, where many morphological sounds correspond to irregular words. When novel words don't have regular morphophonemic correspondences, phonological decoding is necessary but not sufficient for the self-teaching process (Tunmer & Chapman, 1998). When recognizing irregular novel words with morphophonemic correspondences, the reader can only rely on partial phonetic decoding, and then information from the semantic system can assist the reader in completing the novel word recognition. In the ST-DRC model, the information of the semantic system mainly comes from contextual cues co-appearing with novel words, and the contextual information and sublexical phonetic decoding jointly contribute to novel word learning. The semantic layer is directly activated by the contextual input. It then activates the phonological dictionary. Each node in the semantic layer has an excitatory connection to the corresponding word in the phonological dictionary and an inhibitory connection to other words. When a novel word appears in context, both its visual representation layer and its semantic layer are activated.

The ST-DRC model suggests a specific hypothesis for the novel word learning mechanism in syllabic script: when the reader is an "ideal learner," that is, the reader who has mastered all the morphological and phonological correspondence rules, grapheme parsing, phoneme identities, and all monosyllabic spoken words. All of this sub-lexical knowledge provides the basis for vocabulary identification through interactional phonetic decoding and contextual information during self-instruction. When "ideal learners" learn regular morphological-phonological novel words, phonetic decoding is sufficient for self-teaching, i.e., they do not need to rely on contextual cues, whereas when they learn irregular morphological-phonological novel words, they need contextual cues to help them learn the accompanying incidental novel word learning. Moreover, readers can identify whole words through the visual processing of written novel words, i.e., the process of orthographic vocabulary recognition can be independent of pronunciation.

The above hypothesis comes from syllabic script, mainly focusing on the influence of phonetic decoding when native speakers acquire words. Chinese is an ideographic script, often containing both ideographic and phonetic components with irregular morphophonetic correspondences. When the native language is a syllabic script (Uyghur) that is very different from Chinese, it is worth exploring whether the

way phonological decoding plays a role when native Uyghur readers acquire Chinese novel words in natural reading is consistent with the ST-DRC model.

Uyghur and Chinese belong to different language systems, and their linguistic characteristics differ greatly. First, Chinese belongs to the ideographic script; Uyghur belongs to the syllabic script. Previous studies have shown that in the early stages of learning words, children whose first language is syllabic rely more on phonological awareness, whereas children whose first language is Chinese rely more on morphemic awareness to access lexical representations (Mcbride-Chang et al., 2005). Second, in terms of lexical morphology, the same Chinese character has no morphological changes from one word to another, whereas Uyghur lexical morphology is very complex, with different positions of the same letter in words and different forms of writing. According to statistics, the Uyghur language has 32 letters, but there are 126 forms of writing. In addition, in Uyghur, affixes also contain rich grammatical information, such as „بولمايدىغانلىقىنى" meaning "impossible," which consists of roots and affixes (Yan et al., 2014; Yang, Wang, & Zhang, 2019). Third, in terms of writing direction, Chinese scripts are written horizontally from left to right, whereas Uyghur scripts are written horizontally from right to left. It has been found that differences in writing direction affect the position of initial fixation on words (Rayner, 1979) and that fixation position affects lexical processing efficiency (Liu & Li, 2013).

The results of several studies confirmed that the number of sentences is one of the important factors in inferring the meaning of novel words in natural reading (Elgort et al., 2014; Godfroid et al., 2018; Pellicer-Sánchez, 2016; Pigada & Schmitt, 2006; Waring & Takaki, 2003). Acquiring relatively comprehensive semantic information about a novel word requires multiple contexts (Joseph et al., 2014; Liang et al., 2015, 2017). A one-to-four-time study using supportive single-sentence contexts shows that acquiring the meaning of a word works (Elgort et al., 2014); acquiring the meaning of a word from a passage or short text needs at least six encounters (Vidal, 2011).

Learning novel words incidentally in different contexts is more effective than repetitive context learning. This is because different contexts facilitate the semantics of more diverse and meaningful associations while also aiding in the rejection of incorrect or misleading inferences about the word's meaning (Bolger et al., 2008; Joseph & Nation, 2018; Rodriguez-Fornells et al., 2009). Participants who learn the meaning of a word from a passage or a short text need at least some encounters. These encounters in different contexts are better for learning well (Rosa et al., 2022).

Eye-tracking technology can accurately record a participant's fixation path during natural reading, including fixation duration and fixation position (Starr & Rayner, 2001). In the field of incidental learning of novel words, eye-tracking technology lets researchers clearly observe the reader's eye movement while reading naturally, without any additional task or speech output interfering with the learning (e.g., vocabulary judgment task or reporting out loud). This is an excellent way to examine the cognitive processing mechanisms of novel word acquisition while reading naturally. Recent studies have confirmed that readers' eye movements in reading can well reflect their cognitive processing process in reading novel words. With the exposure of novel words in context, readers gradually build up their knowledge

of the morphology, phonology, and semantics of novel words in their minds. As a result, their eye movements show that their fixation time gradually gets shorter, their fixation probability, their backward probability, and the count of fixations gradually go down (Godfroid et al., 2018; Joseph et al., 2014; Nation et al., 2007; Share, 2004; Tamura et al., 2017). The cognitive processing of novel word learning can be fully reflected by analyzing readers' eye movements when encountering novel words (Conklin & Pellicer-Sánchez, 2016; Abdel, 2019). For example, Pellicer-Sánchez (2016) believes that the gradual decline of the fixation duration of novel words reflects the gradual establishment process of the connection between the form and the meaning, and when the fixation duration is kept in a relatively stable interval, it indicates that the connection between the form and the meaning is fully consolidated. The different stages of vocabulary processing can be reflected by different eye movement indicators. For example, gaze duration refers to the duration between the start of the first gaze point and the first departure of the gaze point from the current area of interest within a given area of interest in the first reading. This includes return glances within the area of interest. Gaze duration reflects cognitive processing at a relatively late stage of lexical processing (Yan et al., 2013).

Existing studies have already explored the effects of the number of context exposures (Godfroid et al., 2018; Joseph et al., 2014; Pellicer-Sánchez, 2016) on novel word acquisition, as well as the context richness (Joseph et al., 2018; Bolger et al., 2008) and internal lexical cues (Xu et al., 2020). Most of these studies focused on syllable scripts, and some studies also examined the role of phonetic decoding in Chinese vocabulary learning (Li et al., 2018), the role of semantic and phonetic decoding in novel word learning in native Chinese-speaking children (Li et al., 2020), or the role of phonetic decoding in intentional vocabulary learning in native English-speaking readers learning Chinese (Zhang, 2017). These studies tested participants after they learned the vocabulary and could not examine real-time processing during reading. This study uses eye-tracking technology to ensure that participants' real-time processing is measured in a natural way. The participants' native language is Uyghur. Uyghur is a special syllabic script. The difference between Uyghur and Chinese is greater than the difference between English and Chinese. Obviously, this study enriches the research on the characteristics of ideographic scripts learned by learners with a syllabic script background. More importantly, there is currently no research that explores the role of phonetic decoding in the acquisition of incidental novel words in the Chinese second language by Uyghur native speakers.

We manipulate the difficulty of phonetic decoding by manipulating the readability of pseudo-character phonemic symbols. Chinese characters containing morphology and phonetics account for 81% of the 7000 commonly used Chinese characters (Li & Kang, 1993). 2/3 of these characters are of left–right structure, of which 90% are of left-form-right-sound structure and 10% are of left-sound-right-form structure. Some researchers believe that Chinese texts are made up of Chinese characters one by one, but skilled readers can process the parts of Chinese characters as the basic orthographic units. According to the ST-DRC model, we assume that when Uyghur readers acquire novel Chinese words' meaning in natural reading, the phonetic decoding can be successfully completed through the bottom-up learning path.

This is activated by morphology-phonology-semantics processing, whereas the top-down learning path is activated by the morphology-semantics processing approach. This assumes that when there are difficulties in phonetic decoding, they can complete the phonetic decoding automatically when the phonetic symbols can be read but spend a long time gazing at the novel words to deduce their meaning. However, when the phonetic symbols are unreadable, they inhibit the bottom-up pathway to establish the morphology-semantic connection directly and spend a shorter time gazing at the novel words by inferring the meaning from the sentence context.

Method

Participants

Thirty-four Uyghur college students (20.29 ± 1.49 years old) from a university participated in this experiment. All participants had normal or corrected-to-normal vision; the purpose of the experiment was not known beforehand, and participants were told that they would have to read some sentences silently, and if they encountered words they did not know, they were asked to skim them as they would in everyday life and answer the questions that followed the sentences. Everyone was paid a small amount of money at the end of the experiment.

The Language History Questionnaire (LHQ, Li Sepanski, & Zhao, 2006) tests the Chinese reading level of Uyghur readers. The average year of using Chinese for Uygur readers was 14.01 ± 3.88 years. The questionnaire results are shown in Table 1. The results showed that the Uyghur participants studied Chinese for a long time and had a high Chinese level.

Procedure

Using the repeated learning novel word paradigm, a novel word is placed in six different sentences for the participants to form the lexical representation of the novel word. The contextual differences in these sentences provided participants with a context for incidental novel word learning. We did not tell participants that they needed to infer and memorize the semantics of the new words, and participants spontaneously learned the novel words during reading, consistent with the features of incidental novel word learning.

2 (phonological readability: phonological unreadable, phonological readable) $\times$ 6 (sentence: 1, 2, 3, 4, 5, 6).

The participant's task was to read the six sentences that contained a novel word in turn. Then, without being given feedback on whether their answer was right or wrong, they had to click the mouse to select the correct response to the semantic category choice question that contained four items. The novel words occurred in six different contexts. To avoid participant fatigue, the 18 novel words were learned in 2 sessions, with a 5 min break between each session. At the end of the experiment, participants completed LHQ (Li et al., 2006; Yan et al., 2014).

Table 1 Mean and standard deviation ($M \pm SD$)

	Chinese language	Uygur language
Proficiency%	68.71 ± 18.61	65.68 ± 20.21
Immersion%	67.79 ± 17.70	79.0 ± 23.11
Leading rate%	40.50 ± 17.72	50.79 ± 16.64
Dominance ratio	1.38 ± 0.51	

1. Proficiency scores are calculated by weighting a participant's self-ratings for their ability to listen, speak, read, and write in a given language. Scores range between 0 and 1, with 1 representing native-level proficiency

2. The immersion score for each language known by the participant is based on their age, age of acquisition, and years of language use. The score ranges from 0 to 1, with 1 indicating the level of native-like immersion in a language

3. The Leading Rate (Dominance) score is based on the participant's reported proficiency and the daily hours spent using each language. The higher the score, the more time is spent using that language in daily life

4. The dominance ratio score gives the relative ratio of each language in comparison to that of the first language

Detailed calculations of the fraction are provided at the URL below

https://lhq-blclab.org/static/docs/aggregate-scores.html#language-proficiency

Materials

72% of the 56,008 commonly used Chinese words are two-character words. 22.3% are words with more than two characters (State Language Affairs Commission, 2008). As the majority of words consist of two characters, our material was composed of two-character pseudo-words. In A Dictionary of Chinese Characters Information (Science Press, 1988), 18 familiar and unreadable semantic radicals, 18 familiar and readable phonetic radicals, and 18 unreadable radicals were selected. The readability of a phonetic component is based on whether or not the pronunciation component exists in the Modern Chinese Dictionary (5 Edition) (The Commercial Press, 2005); if the component is independently readable, it is considered to be readable, and if it is independently absent from the dictionary, it is considered to be unreadable. Control the radical's character-building ability, stroke count, and familiarity with readable and non-readable phonetic radicals. Familiarity: to figure out how familiar someone is with a word, the character frequency of the character formed by the phonetic radical that has the highest character frequency is used. The corpus of the frequency is SUBTLEX-CH (Cai et al., 2010).

Two independent-sample T test was conducted on the radical's character-building ability, stroke count, and familiarity (the highest character frequency) with readable and non-readable phonetic radicals. The results showed that there was no significant difference in the radical's word-building ability, stroke count, or familiarity (see Table 2).

Table 2 Mean and standard deviation of the material ($M \pm SD$)

	Readable	Unreadable	t	p
Character-building ability	36.28 ± 52.60	33.22 ± 50.64	0.18	> 0.05
Stroke count of phonetic radical	4.11 ± 1.88	4.11 ± 1.68	0	> 0.05
Stroke count	7.67 ± 1.19	7.67 ± 1.46	0	> 0.05
Maximum character frequency (times/million)	594.45 ± 1523.65	792.51 ± 2078.13	0.33	> 0.05

The phonetic and semantic radicals above are combined into 18 two-character words, which are divided into 9 groups, each containing one phonetic radical readable word, e.g., "就枫" and one phonetic radical unreadable word, e.g., "怖歧." Each group of words belongs to a semantic category, e.g., the above two words belong to the food category, which are assigned a semantic meaning, "cheese" and "ice powder," respectively, and the two semantic meanings are balanced in the two blocks.

The radicals we used in the experiment are as follows (see Table 3):

According to previous studies, after encountering a novel word three times, the decline of fixation duration tended to level off, so the count of sentences was selected as 6, and each novel word was given a specific meaning by the six sentences.

For the 18 new words, a total of 9 semantic categories were defined: metal, machines, insects, plants, transportation, food, buildings, animals, and urban landscape. The above semantics refer to objects that do not really exist in real life but have many similarities to common objects in life, and each semantic category includes 2 novel words.

The 18 words were embedded in 108 sentences. The sentence lengths ranged from 15 to 32 characters. Sentence fluency and difficulty were rated on a 5-point scale (1 means that the sentence is not very fluent or that the sentence is very difficult, 5 means that the sentence is very fluent or that the sentence is very easy) by ten Uyghur readers who did not participate in the formal experiment. Liang et al. (2019) suggested replacing novel words in sentences with their equivalent common words when testing fluency and difficulty. For example, the formal experiment sentence for"小吃店里一份精加工过的透明怖歧卖三十多元钱"was changed to "小吃店里一份精加工过的透明冰粉卖三十多元钱 (A single serving of processed clear **ice powder** costs more than 30 yuan at a snack bar)" to remove the effect of novel words on sentence fluency and difficulty. Uyghur readers rated the average fluency as 4.13 ± 0.31 and the average difficulty of the rated sentences as 4.26 ± 0.32, indicating that the sentences were very fluent and easy to understand. To ensure that different contexts provide the same amount of information for novel word meaning inference,

Table 3 Radicals

	Radicals
Familiar and Unreadable Semantic Radicals	衤 疋 车 阝 礻 饣 彳 扌 忄 氵 讠 亻 纟 冫 冖 刂 岁 辛
Familiar and Readable Phonetic Radicals	力 乃 丁 丈 才 及 寸 丹 办 专 尤 贝 本 东 司 吏 求 妻
Familiar and Unreadable Phonetic Radicals	彐 彡 丐 刂 讯 阝 充 冂 卩 攵 支 无 豕 臣 朱 东 羊 西

five native Chinese readers were selected for the word-filling test, participants were provided with complete sentences, and the position of the novel word was asked to fill in as a fill-in-the-blank, and one point was awarded for a correct answer out of a total score of 108 points. ANOVA showed that there was no significant difference in the accuracy of the six-sentence word category fill-in-the-blanks ($F=0.55$, $P>0.05$).

A reading comprehension question was randomly designed for each novel word to test whether the participants had read the sentence carefully. To investigate the participants' mastery of the semantic category of novel words, the semantic category choice question was designed for each novel word, which appeared after sentence number 6. Examples of material sentences are as follows (see Table 4):

Apparatus

Participants' eye movement trajectories were recorded with an Eyelink 1000 eye-tracker system (SR Research Ltd., Ottawa, Ontario) at a sampling rate of 1000 Hz. The screen resolution was 1024×768 with a refresh rate of 75 Hz, and the distance between the participant's eyes and the screen was 65 cm. The experimental material was presented in 18-point Sung font, with each Chinese character 25×25 pixels in size and a horizontal viewing angle of 0.74°.

Five-point mode calibration was applied with an average error less than 0.35° and a maximum error less than 0.5°. The task was to read the six sentences containing novel words in turn and select the correct answer by clicking the mouse. Whether the answer was correct or not, there was no feedback. After completing the reading task, participants filled out the LHQ questionnaire.

Table 4 Examples of material sentences

Sentence number	Example sentence
1	中医说，夏天多吃常温怖汶可以防止人们中暑。 Chinese medicine says that eating more room temperature 怖汶 in summer can prevent people from getting heatstroke.
2	想减肥的女生喜欢在饭前吃几口怖汶来控制自己的体重。 Girls who want to lose weight like to take a few bites of 怖汶 before meals to control their weight.
3	为做出彩色面皮，有人把水果汁和怖汶粉末拌在一起。 To make a coloured crust, some people mix fruit juice with 怖汶 powder.
4	店老板说，加了奶油的甜味怖汶更受外地游客的欢迎。 The shop owner said that the sweetness 怖汶 with cream is more popular with foreign tourists.
5	小吃店里一份精加工过的透明怖汶卖三十多元钱。 A single serving of processed clear 怖汶 costs more than 30 yuan at a snack bar.
6	在磨碎的冰块上倒一碗怖汶就能做出一份简单的特色小吃。 Pour a bowl of 怖汶 over grated ice for an easy speciality snack.

Data analysis

Based on earlier research (Bai et al., 2019; Liang et al., 2017; Yan et al., 2012, 2013), the present study looked at how Uyghur readers' eyes moved continuously for novel word acquisition in naturalistic reading. It focused on the readers' first fixation duration, dwell time, total fixation duration, fixation count, and refixation rate.

Results

The data were analyzed in a Linear Mixed Model (LMM) with participants and items as cross-random effects. The LME 4 data processing package in R environment version 3.5.1 (Bates, Maechler, & Bolker, 2012) was used. In order to investigate the change of the eye movement and the semantic category accuracy with the number of sentences during the acquisition of novel words, the sentence number, phonological readability, and their interaction as fixed factors. We started with a maximum random effects model and gradually simplified it until it fit the data. The model was adjusted to account for any lack of fit in the data. For significant findings, a 95% confidence interval (CI) is also reported.

After a linear mixed model analysis of the reading comprehension accuracy, there was no significant difference between the unreadable condition (86% SD = 35%) and the readable condition (87% SD = 35%). The participants completed the task carefully and showed no difference between the two conditions.

Results of semantic category accuracy

There was no significant difference between unreadable conditions 90.8% (SD = 98.9%) and readable conditions 90.5% (SD = 29.3%) ($p > 0.05$, 95% CI = [0.76, 0.60]).

Results of eye movement

Data were removed according to the following conditions: (1) loss of eye movement data tracking; (2) duration of a single gaze point less than 80 ms or greater than 1200 ms of data (Bai et al., 2008; Liversedge et al., 2016; Rayner, 2009).

First fixation duration, dwell time, total fixation duration, fixation count, and refixation rate were selected for analysis, with the novel words as the area of interest. The time indicators were analyzed using log-transformed data to ensure a linear distribution of the data as far as possible. The analysis methods were consistent with those used for reading comprehension and semantic category accuracy. Report the model results that can be fitted.

Results of the analysis of eye movement (see Table 5).

Table 5 Results of the analysis of eye movement ($M \pm SD$)

	Sentence number	First fixation duration (ms)	Dwell time (ms)	Total fixation duration (ms)	Fixation count	Refixation rate
Unreadable	1	275 ± 95	378 ± 190	726 ± 484	2.73 ± 1.71	0.42 ± 0.50
	2	256 ± 82	313 ± 140	482 ± 365	1.90 ± 1.27	0.23 ± 0.42
	3	253 ± 82	314 ± 148	473 ± 298	1.98 ± 1.15	0.28 ± 0.45
	4	259 ± 85	317 ± 161	477 ± 343	1.88 ± 1.24	0.31 ± 0.46
	5	256 ± 88	310 ± 140	448 ± 329	1.87 ± 1.28	0.26 ± 0.44
	6	252 ± 80	300 ± 150	436 ± 281	1.79 ± 1.12	0.26 ± 0.44
Readable	1	274 ± 96	404 ± 227	741 ± 459	2.83 ± 1.61	0.48 ± 0.50
	2	263 ± 89	329 ± 165	545 ± 400	2.05 ± 1.27	0.33 ± 0.47
	3	260 ± 86	343 ± 186	502 ± 327	2.02 ± 1.19	0.31 ± 0.47
	4	260 ± 88	324 ± 169	493 ± 378	1.93 ± 1.27	0.24 ± 0.43
	5	255 ± 86	318 ± 158	488 ± 329	2.03 ± 1.33	0.27 ± 0.45
	6	257 ± 91	323 ± 176	479 ± 350	1.92 ± 1.28	0.27 ± 0.45

(1) First fixation duration. The main effect on phonological readability was not significant. The sentence number main effect was significant; the reader's first fixation duration on the novel word gradually decreased with an increasing number of sentences ($b = 0.04$, $SE = 0.01$, $t = 3.80$, $p < 0.001$, 95%CI = [0.06, 0.02]).

(2) Dwell time. The main effect was significant; the phonologically unreadable condition's dwell time was significantly shorter than the phonologically readable condition ($b = 0.04$, $SE = 0.02$, $t = 2.32$, $p = 0.02$, 95% CI = [0.001, 0.06]). The sentence number main effect was significant; the reader's first fixation duration on the novel word gradually decreases with an increasing number of sentences ($b = 0.12$, $SE = 0.01$, $t = 7.84$, $p < 0.001$, 95% CI = [0.14, 0.08]).

(3) Total fixation duration. The main effect of phonological readability was significant ($b = 0.06$, $SE = 0.02$, $t = 2.95$, $p = 0.003$, 95% CI = [0.02, 0.09]); the total fixation duration of the unreadable condition was significantly shorter than the readable condition. The sentence number main effect was significant; the total fixation duration gradually decreased with sentence number ($b = 0.24$, $SE = 0.03$, $t = 8.45$, $p < 0.001$, 95% CI = [0.29, 0.18]).

(4) Fixation count. The main effect of phonological readability was significant ($b = 0.05$, $SE = 0.02$, $t = 2.89$, $p = 0.004$, 95% CI = [0.02, 0.08]); the fixation count in the unreadable condition was significantly less than the readable condition. The main effect of sentence number was significant, with a gradual decrease in fixation count with an increasing number of sentences ($b = 0.19$, $SE = 0.02$, $t = 8.08$, $p < 0.001$, 95% CI = [0.24, 0.14]).

(5) Refixation rate. The main effect of phonological readability was significant ($b = 0.20$, $SE = 0.08$, $z = 2.51$, $p = 0.012$, 95% CI = [0.04, 0.36]), and the refixation rate was significantly higher in the phonologically readable condition than in the phonologically unreadable condition. The main effect of sentence number

was significant, and the refixation decreased with context number ($b = 0.62$, $SE = 0.08$, $z = 7.57$, $p < 0.001$, 95% CI = [0.79, 0.47]).

The results of the Linear Mixed Model analysis of first fixation duration, dwell time, total fixation duration, fixation count, and refixation rate are shown in Fig. 1.

Discussion

The experiment demonstrated that Uyghur readers can acquire the semantics of these novel words through natural reading. This was confirmed by their high accuracy in answering semantic category-choice questions. The high correct accuracy rate can be attributed, in part, to certain context words like "eat," which facilitate the association of the novel word with food. Additionally, the phonetic radical readability did not affect the inference of semantics. Consistent with previous research (Bai et al., 2019; Liang et al., 2017, 2019; Pellicer-Sánchez, 2016), with the increase of sentence number, whether in the early vocabulary processing (first fixation duration, dwell time), or in the late vocabulary processing (total fixation duration), readers' gaze time on the novel words all decreased, and the rate of decrease was shown to be fast and then slow, and the rate of refixation gradually decreased, indicating that readers gradually acquired the morphology

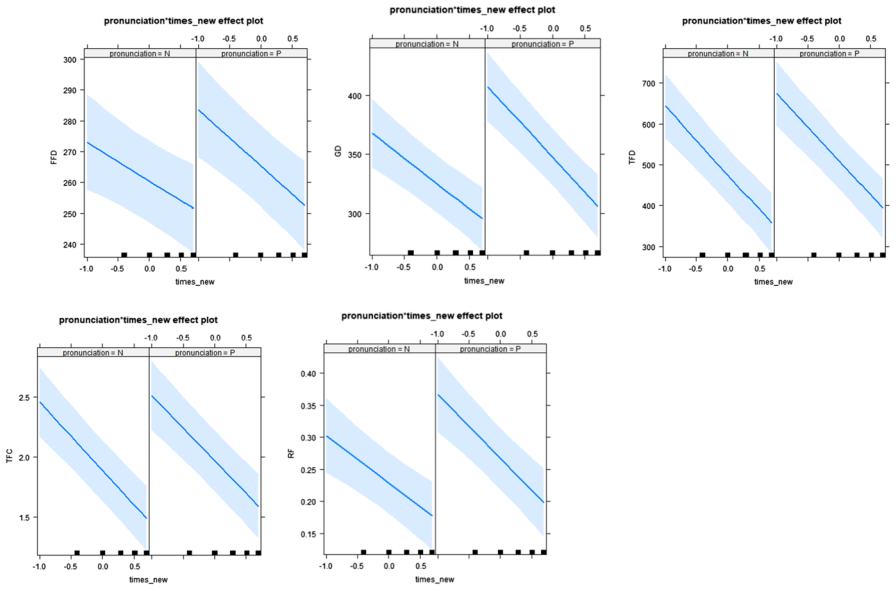

Fig. 1 Results of the Linear Mixed Model. Times_new means centering the sentence number, and Pronunciation = P represents phonologically readable. Pronunciation = N represents phonologically unreadable. FFD, GD, TFD, TFC, and RF indicate the first fixation duration, dwell time, total fixation duration, fixation count, and refixation rate, respectively

and semantics of the novel words, made a connection between the morphology and semantic information, and established the word form and semantic information connection. In dwell time and total fixation duration, the phonetic radical unreadable condition's gaze time was significantly shorter than the phonetic radical readable condition. The refixation rate for phonetic radical readable condition's was significantly higher than the unreadable condition. This showed that phonetic decoding is an important process in novel word learning, but when it's difficult, it can be quickly inhibited in incidental Chinese novel word learning. The results supported the ST-DRC model proposed by Pritchard et al. (2018) and were consistent with previous studies that have argued that phonetic decoding plays a limited role in Chinese lexical access (Davelaar et al., 1978; Feng et al., 2001; Seidenberg, 1985).

Cognitive processing in incidental Chinese novel word learning

Uyghur readers can use the contextual information to acquire the meaning of novel Chinese words. According to Pellicer-Sánchez (2016), the gradual decrease in readers' fixation duration on novel words reflected the gradual connection between form and meaning becoming established. When fixation duration remained at a relatively stable interval, it was an indication that the connection between form and meaning was fully consolidated. The results of this study showed that in Chinese reading, readers can quickly connect the form of novel words with the meaning after encountering novel words for the first time, and then revise and consolidate with the number of contexts, supporting the connectionist model (Share, 2004). Based on research in syllabic scripts and Chinese, this study suggested that incidental novel word learning is consistent with the connectionist model and is universal across languages. No matter how different the language, readers can quickly acquire parts of the word form, pronunciation, and semantics of a novel word when they encounter it for the first time and integrate them into a psychological dictionary.

According to the four-stage model of incidental novel word learning proposed by Fukkink (2005), when readers notice a new word for the first time in reading, they need to characterise the morphological and phonological information of the vocabulary through the visual and phonological features of the new word from the bottom-up perspective, and also need to infer the semantic information of the new word through the contextual information from the top-down perspective, and at this time, they gaze at the novel word for a long period of time; the second time they encounter the novel word, the readers' gaze duration decreases significantly, and it can be assumed that at this time, the readers have completed the preliminary speculation of the category to which the novel word belongs; next, with the increase in the number of encounter the novel word, they continue to accumulate and consolidate the meaning of the novel words, and the word form, phonology and word meaning connections are constantly consolidated, and the cognitive resources needed are reduced continuously, and the gaze duration shortens, and the gaze duration tends to be steady after the lexical form and semantic connection have been fully consolidated.

The role of phonetic processing in incidental Chinese novel word learning

Phonetic decoding influences the acquisition process of identical Chinese novel words. Dwell time is an indicator that reflects the early stage of lexical accessibility, and total fixation duration is an indicator that reflects the late stage of lexical accessibility (Yan et al., 2013). We speculate that phonological readability can affect phonetic decoding in the early stages of identical Chinese novel words learning, and then affect semantic accessibility in the later stages. Dwell time was shorter when the phonetic radicals were unreadable than when the phonetic radicals were readable. We assume that the Uyghur readers who learned Chinese novel words by naturally reading were able to directly establish a morphology-semantics pathway. This supports the idea that phonology plays a limited role in the visual processing of lexical acquisition (Zhou, Wu, & Shu, 1998; Zhang & Yang, 2004).

Much of the research on phonological processing has focused on children (Chambrè et al., 2020), and the strength of the phonological role can be influenced by the language level of the participants. The participants in this study were L2 readers with a high level of Chinese language proficiency. They were able to infer novel words' semantics through the context and their morphology. Phonetic processing didn't play an important role when the phonetic radical was not able to provide semantic information for the novel words (Zhou & Marslen-Wilson, 2002). However, when the phonetic radical is readable, the reader engages in phonological decoding, and the morpho-phonological-semantic pathway is activated, hence the increase in gaze time.

Some studies have shown that phonological decoding plays a significant role in Chinese reading for learners at the early stages of Chinese language learning, with a declining impact on proficient Chinese speakers and an elevated role in orthographic processing (Song, Zhang, & Shu, 1995). The effect of phonetic decoding varies across populations with different levels of language proficiency (Elhassan et al., 2017). Moreover, proficiency in the Chinese language influences Uyghur readers' acquisition of novel words in accompanying Chinese reading (Aini et al., 2023). We speculate that there may be greater differences in the way in which phonetic decoding affects novel word acquisition among readers with low Chinese proficiency and high Uyghur proficiency.

Based on the above, it is supposed that the effect of phonetic decoding in Chinese novel word acquisition may be affected by Chinese language proficiency, and the failure of phonetic decoding does not prevent readers from acquiring novel word meaning information through context.

Readers inferring the meaning of a novel word in context can be divided into two pathways: the top-down pathway (i.e., inferring the meaning of a novel word using contextual clues) and the bottom-up pathway (i.e., inferring the meaning of a novel word on the basis of the morphemes that make up the word itself) (Chen, 2019). Uyghur belongs to the syllabic script and Chinese belongs to the ideographic script, and phonological awareness plays a more significant role in learning the alphabetic script, while morphemic awareness plays a more significant role in learning the Chinese language (Hsu et al., 2019; Mcbride-Chang et al., 2005), because the novel words in this study consisted of pseudowords, none of

which used parts with significant meanings, participants were unable to use the morphemes themselves to infer the meaning of the novel words, and thus Uyghur readers could benefit more by using more contextual information to infer the meaning of the novel words when they first encountered them, and had to resort to the top-down method of inferring the meaning of the novel words by using the context.

We argue that the pathway that is activated is characteristic of Chinese language (Perfetti et al., 2013; Zhou et al., 2002), and it is affected by native language background (Zhang, 2017) and Chinese language proficiency (Elgort et al., 2014; Elhassan et al., 2017; Zhou et al., 1998), not by anything that makes Uyghur readers special. Some studies have shown that native Chinese speakers can activate either the morpho-semantic pathway or the morpho-phonological-semantic pathway during lexical processing (Chen et al., 2000). It is reasonable to hypothesize that native Chinese speakers can also show similar characteristics with Uyghur readers during incidental novel word learning, and it is possible that native Chinese speakers may activate each pathway more rapidly. It has also been found that when native Chinese readers and native English readers learn vocabulary in English, phonological decoding directly predicts English literacy in native English speakers, whereas phonological decoding and morphology indirectly predict English literacy in Chinese-English bilinguals (Hsu et al., 2019). There is also evidence that phonological decoding and orthographic processing in Chinese are different from syllabic writing (Feng et al., 2001). It was discovered that morphological radicals play a dominant role in the acquisition of Chinese novel words by native English beginner Chinese learners through word-figure matching tasks (Zhang et al., 2016). Phonetic radicals also play a significant role, which can interrupt their vocabulary acquisition if the labeled pronunciation does not match the phonetic radicals (Zhang et al., 2021).

When learning Chinese, Uyghur or other second language learners of Chinese should pay more attention to morphological awareness and orthographic rules in addition to phonological awareness training. This study demonstrated that Uyghur readers can quickly and directly activate the morphological-semantic pathway when there are difficulties in Chinese phonological decoding. It shows that phonological decoding is not a necessary condition for semantic access in Chinese, and unlike the important role that phonological decoding plays in alphabetic scripts, phonological decoding plays a weaker role in Chinese (Perfetti et al., 2013). Some studies have shown that Chinese language learners of different ages and levels of proficiency have different levels of acceptance of morphological awareness, phonological awareness, and orthographic processing. Phonological awareness plays a more important role in the early stages of learning a second language, but it becomes less important for semantic access after a certain level of Chinese language knowledge, with the learning of morphology and orthographic processing being more important (Li et al., 2012; Zhang, 2017). Consequently, teachers should adapt their teaching approaches based on students' proficiency levels. This insight can be augmented by scrutinizing previous teaching methods and leveraging this research to identify effective instructional strategies. The present study suggests that learners of second language Chinese should focus on morphological and orthographic processing in addition to phonological awareness training.

Research perspectives and limitations

The level of Uyghur and Chinese reading experience of the Uyghur readers may be a factor influencing their learning of novel Chinese words in natural reading. Individuals with more Uyghur reading experience and less Chinese reading experience may rely more on phonological decoding, expend more effort to complete phonological decoding, and have more difficulty establishing a morphology-phonological-semantic pathway when acquiring novel words that are phonologically unreadable. In future research, Uyghur readers with more experience in Uyghur and those with less experience in Chinese can be selected to learn novel words accompanied by Chinese to understand the role of phonological decoding in the process. In addition, brain imaging technology can be combined to analyze cognitive processing in the process of learning novel Chinese words.

Conclusion

Whether or not phonetic decoding can be successfully completed does not affect the accuracy of semantic inference in Uyghur readers' Chinese incidental novel word learning. Uyghur readers can quickly activate the morpho-phonetic-semantic pathway and quickly inhibit the phonetic decoding process when they are unable to successfully complete phonetic decoding, whereas the morpho-phonetic-semantic pathway is quickly activated when phonetic decoding can be completed.

Appendix

Attachment: Words and materials

Number	Category	Semantic		Readable	Unreadable
1	Metal	Vibranium	Electrical Bar	衯趸	邢钾
2	Machine	Machine Nanny	Machine Nurse	钞救	衧祁
3	Insect	Beetle	Winged Insect	财极	纪杉
4	Plant	Breadfruit	Shrub	付徊	趾郛
5	Vehicle	Balanced Vehicle	Convertible Vehicle	劫怃	洋馋
6	Food	Cheese	Ice Powder	耽狈	怖汝
7	Structure	Pavilion	Floating Bridge	诎侈	徙抆
8	Animal	Wild Bear	Susliks	绚浈	诵呸
9	Urban Landscape	Geyser	Wetland Town	冻痿	陇侪

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Authors and Affiliations

Yang Han[1,2] · Yongsheng Wang[1,2,3] · Feifei Liang[1,2,3] · Xin Li[1,2,3] · Jie Ma[4] · Xuejun Bai[1,2,3]

✉ Xuejun Bai
bxuejun@126.com

Yang Han
hanyangpsyc@163.com

Yongsheng Wang
wangyongsheng@tjnu.edu.cn

Feifei Liang
feifeiliang_329@126.com

Xin Li
lixinpsy1983@126.com

Jie Ma
majie@link.cuhk.edu.hk

[1] Key Research Base of Humanities and Social Sciences of the Ministry of Education, Academy of Psychology and Behavior, Tianjin, China

[2] Tianjin Normal University Faculty of Psychology, Tianjin, China

[3] Tianjin Normal University Tianjin Social Science Laboratory of Students' Mental Development and Learning, Tianjin, China

[4] The Chinese University of Hong Kong, Hong Kong, China