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Explore the processing unit of L2 Chinese learners in on-line Chinese reading

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Abstract

The present study explored the processing units of high-proficiency second language (L2) Chinese learners in on-line reading in an eye-tracking experiment. The critical aim was to investigate how learners segment continuous characters into words without the aid of word boundary demarcations. Based on previous studies, the embedded words of 2- and 3-character incremental words were manipulated to be either plausible or implausible with the preceding verbs, while the incremental words themselves were always plausible. The results revealed an effect of the plausibility manipulation, which suggested that L2 Chinese learners activated embedded words first and integrated embedded words with previous sentence context as soon as they read them.

Keywords

eye movements, incremental words, L2 acquisition, L2 Chinese reading, word segmentation

I Introduction

In nature reading, words are important in all languages (Perea and Acha, 2009; Rayner, 1998; Rayner et al., 2012) even though languages differ with each other in word boundary demarcation (Li et al., 2022). Most languages (such as English) use inter-word spaces to

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explicitly mark word boundaries. By contrast, languages such as Chinese, do not contain explicit demarcation of word boundaries. Chinese sentences are composed of contiguous equal-width characters with small spaces between every neighboring characters. There is no explicit marker of which characters comprise a word. In this context, the current study aimed to explore how second language (L2) Chinese learners segment continuous character strings into words in on-line reading without the help of explicit word boundary markers.

Though words are important in reading across languages, the mechanisms of word segmentation and identification varied based on scripts' features (Li et al., 2022). When reading alphabetic languages, readers use the inter-word spaces which can be obtained in the parafoveal vision to segment words so that they identify and integrate each set of letters that grouped by spaces. When reading Chinese, however, readers cannot pre-segment words since there is no word boundary marker. Native Chinese readers need to segment words using varied sources of linguistic information (Li and Pollatsek, 2020).

Li and Pollatsek (2020) constructed a model (Chinese Reading Model, CRM) to simulate native Chinese speakers' eye movements while they segmented and identified words during on-line reading. According to CRM, all the characters and the possible words (which can potentially be composed of these characters) within the perceptual span are activated at the same time, and these activated words compete for a winner. The competition strength of each candidate depends on multiple factors such as lexical frequency, orthographic neighbors (visually similar characters/words), and predictability based on prior context. During this process, there exists a strong interaction between bottom-up processing and top-down processing. The character-level representations are activated from visual input and subsequently activate the word-level representations; at the same time, activation from word-level representations feeds back to the character-level representations, boosting activation of the characters that belong to the word and also fit the visual input best. When a word 'wins' the competition, it is simultaneously identified and segmented from the surrounding text. Thus, word segmentation and word identification are a unified process in Chinese reading.

Successful word segmentation is an inevitable and essential step in on-line sentence reading and comprehending, and readers develop different mechanisms of word segmentation and the corresponding eye-movement control adapted to their languages (Li et al., 2022; Liu et al., 2019). What is interesting to us is how L2 Chinese learners whose native language contains explicit word boundary demarcations segment continuous character strings into words when on-line reading Chinese sentences. Due to the script features of their native languages, there is no need to segment words in native language reading. In other words, the simultaneous and unified process of word segmentation and identification is a unique-to-L2 processing mechanism to them (Bertram et al., 2004). Can L2 Chinese learners segment and identify words in a native-like manner? Is it possible that previously observed L2 Chinese learners' difficulties and deficits in processing Chinese be caused by their word segmentation problems? Given the prevalence of L2 Chinese learning and teaching worldwide and studies about L2 Chinese acquisition and processing (Cai et al., 2010; Chan et al., 2022; Ellis, 1997; Ma et al., 2017; Mai, 2016; Winke, 2013; Zhang and Li, 2010; Zhao, 2011), it is somewhat a surprising gap that little has been known about how L2 Chinese learners segment character strings in on-line Chinese

reading. The present study aimed to fill this gap by exploring high-proficiency L2 Chinese learners' on-line processing of Chinese sentences.

II Previous studies in L2 Chinese learning

The lack of word boundary demarcation in Chinese has attracted a lot of research attention in L2 Chinese learning in the past decades. Previous studies found that deliberately inserting inter-word spaces would not facilitate native Chinese readers' on-line processing (Bai et al., 2008), but would facilitate L2 Chinese learners' (Bai et al., 2013; Shen et al., 2012). Bai et al. (2013) used a learning-test task to examine whether inserting inter-word spaces would facilitate elementary-proficiency L2 Chinese learners' acquisition of new Chinese words. They found that in the learning phase, participants read the target words faster in the spaced group than in the unspaced group (with shorter gaze durations and total fixation durations, and fewer fixations), and this benefit was maintained in the test phase. Shen et al. (2012) chose four groups of L2 Chinese learners: American, Korean, Japanese, and Thai (all were primary to medium proficiency), and investigated their on-line processing of four conditions of Chinese sentences (unspaced text, word-spaced text, character-spaced text, and nonword-spaced text). They found that Chinese sentence reading was least disrupted in the word-spaced condition among the four conditions, and this effect was not influenced by native languages. These findings indicated that demarcation of word boundaries through inter-word spacing reduces L2 Chinese readers' uncertainty about the characters that constitute a word, thereby speeding lexical identification and on-line reading. And this inter-word spacing facilitation effect holds regardless of whether L2ers' native language is alphabetic (Korean, English, and Thai) or character (Japanese) based. These previous studies offered solid evidence that inserting inter-word spaces could benefit L2 Chinese learners in on-line Chinese processing. However, it remains unclear in natural reading environment (without inter-word spacing), what is the means by which L2 Chinese learners identify the location of word boundaries, and whether high-proficiency L2 Chinese learners can ultimately acquire the unique-to-L2 processing mechanism that segments and identifies words simultaneously.

Different from linguistic knowledge that can be explicitly taught in language learning classes, the word segmentation mechanisms can only be (if possible) implicitly acquired through a long time of immersive language experience. The Critical Period Hypothesis (Lenneberg, 1967) claims that, after puberty, language learners start to lose their ability to attain 'automatic acquisition from mere exposure' (Lenneberg, 1967: 176). Late L2ers have to explicitly learn their L2, which is different from native children who implicitly acquire their first language (L1). In addition, the L1 Transfer Account proposes that L2 learning is affected by L1–L2 distances. For example, the Morphological Congruency Hypothesis (Jiang et al., 2011) proposes that only the congruent L2 knowledge (the knowledge that exists in both L1 and L2) can be fully acquired by late L2ers; for unique-to-L2 knowledge (the knowledge that exists only in L2 but not in L1), it is extremely difficult, if possible at all, to develop a native-like representation. Thus, even high-proficiency late L2 Chinese learners would have problems in implicitly acquiring the unique-to-L2 word segmentation mechanisms, and would behave differently compared to native Chinese speakers.

On the other hand, some theories argue that even after puberty, L2ers can ultimately acquire native-like knowledge and processing routines with increased proficiency (Dekydtspotter et al., 2006; Hopp, 2006; White, 2003). The Full Transfer/Full Access Model (Schwartz and Sprouse, 1996) proposes that when learning L2, late L2ers already have a mastery of L1, which will definitely affect L2 processing at the initial stage of L2 acquisition. However, when reaching an advanced level of L2 proficiency, late L2ers can eventually recover from the L1 transfer effect and acquire L2 representations through full access to Universal Grammar. From this perspective, high-proficiency late L2 Chinese learners who have long experience of an immersive Chinese-dominant environment would be able to segment continuous character strings in a native-like manner.

By investigating how high-proficiency L2 Chinese learners segment continuous character strings, the current research aimed to tackle the question of whether they can implicitly acquire the unique-to-L2 word segmentation mechanism, which is important for a comprehensive picture of L2 acquisition and processing, as well as providing a scaffold for understanding the script-specific/universal mechanisms of reading.

III The processing of incremental words in Chinese

The range of typical Chinese word length varied from one to four characters. Approximately 6% of Chinese words are formed by a single character, whereas approximately 70% are formed by two characters, and the remainder consist of three or more characters (Lexicon of Common Words in Contemporary Chinese, 2009). Since there are no salient word boundaries, and words vary in the number of characters that constitute them, continuous character strings could be grouped into words in multiple ways, which could cause some ambiguity in on-line processing (Inhoff and Wu, 2005; Ma et al., 2014; Zhou et al., 2018). Classic examples of ambiguous multiple-character strings are incremental words, which are multi-character words containing a subset of characters that constitute another semantically related word (referred to as the embedded word). For example, in a 2-character word *门卫* ‘gate-keeper’, the first character *门* could be an independent 1-character word meaning ‘door/gate’, while it can also combine with the second character *卫* ‘guard’ to constitute a 2-character word. In this case, *门卫* is an incremental word and *门* is an embedded word. In a 3-character word *酒精灯* ‘alcohol-lamp’, the first two characters *酒精* could be an independent 2-character word meaning ‘alcohol’, while they can also combine with the third character *灯* ‘lamp’ to constitute a 3-character word. Such that *酒精灯* is an incremental word and *酒精* is an embedded word. Compared to multi-character but single-morpheme words (e.g. *蝴蝶* ‘butterfly’, *巧克力* ‘chocolate’), the processing of incremental words requires extra resources for readers to determine which characters should be grouped into one word. To be specific, readers need to decide whether to combine the embedded word with the upcoming character or to start the next word with that upcoming character.

Previous studies found that even though the embedded words are activated during the accessing of incremental words (the frequency of constituents affect the whole word processing; Andrews et al., 2004; Juhasz et al., 2003; Zhou et al., 2018), the plausibility of embedded words did not affect the processing of incremental words (Yang et al., 2012; Zhou and Li, 2021). Yang et al. (2012) investigated the processing units (the chunk of letters/characters that readers identify and integrate with previous context incrementally)

of native Chinese speakers in on-line reading. In an eye-tracking reading experiment, the plausibility of the embedded word (the first morpheme in a 2-character word) in the prior context was manipulated to have two conditions (plausible or implausible) while the whole incremental word was always plausible. For example, in the plausible condition, the pre-target verb 踢打 'kick' is plausible with both the embedded word 门 'door' and the incremental word 门卫 'gate-keeper'; while in the implausible condition, the pre-target verb 哀求 'entreat' is plausible only with the incremental word 门卫 'gate-keeper', but not the embedded word 门 'door'. The authors predicted that if the processing unit is character/morpheme but not word, there should be significant differences of the processing patterns in the incremental words (including the embedded words) between the plausible and implausible conditions. In contrast, if the processing unit is word instead of character/morpheme, the processing patterns of incremental words should be similar between the two conditions. They found that the plausibility of the embedded words in the prior context did not affect the processing of the incremental words, which indicated that the processing unit of native Chinese speakers in on-line reading is word but not character/morpheme. Zhou and Li (2021) observed similar patterns using 3-character incremental words (e.g. 酒精灯 'alcohol-lamp') and their 2-character embedded words. This 'whole-word advantage' could be explained by CRM: both the embedded words and the incremental words are activated by the visual input and they compete with each other, and the incremental words would ultimately win because they receive more bottom-up activations than embedded words. These existing studies have shown that the processing unit of native Chinese readers in on-line reading is word, and incremental words have processing advantages over their embedded words. What remains unclear is whether high-proficiency L2 Chinese learners segment and process Chinese sentences (especially ambiguous multiple-character strings) in a native-like pattern. The present study aimed to investigate the processing unit of high-proficiency L2 Chinese learners when they on-line process Chinese incremental words.

IV Three possible accounts

Regarding the processing unit of high-proficiency L2 Chinese learners in on-line Chinese reading, there are three possible accounts. First, the morpheme account suggests that L2 Chinese learners take the morphemes which have the explicit visual boundaries between each other as processing units. According to the Connectionism Approach, the language learning process is a matter of increasing strength of associations, and the strengths of the associations change with the frequency of input (McClelland et al., 1986; Robinson, 1995). In other words, the more frequently an association occurs, the better masterty over it the language learners would have. As a typical logographic script, morphemes are salient and primary writing units in Chinese. There are more than 6,000 characters, most of which have semantic meanings independently and thus represent individual morphemes (Standardization Administration of China, 1980). L2 Chinese learners started to learn Chinese from 1-character meaningful words (morphemes) which is much more frequent than multi-character words. Thus it is highly possible that the frequent occurrence of 1-character words strengthened the associations, and it is more easy for L2 Chinese learners to identify and recognize 1-character words than multi-character words and consequently take individual morphemes as processing units.

Second, the 2-character combination account posits that L2 Chinese learners take the combinations of every two characters as processing units. Different from the Connectionism Approach, the Information Processing Theory suggests that language learning is a procedure of abstracting rules/principles from input, and the input features affect learning efficiency (Schmidt, 1990). Apart from the frequency of items, the perceptual salience of items also plays an important role in language learning. Among all types of Chinese words, 2-character words are the most salient chunk since around 70% of Chinese words are comprised of two characters. In learning Chinese, L2ers may be aware that most Chinese words are 2-character words and then implicitly learn that it is highly possible to segment every neighbouring two characters into a word. In other words, L2 Chinese learners may use a 2-character assembly strategy (Perfetti and Tan, 1999) to segment words. Thus they may prefer to take the combination of two continuous characters as a processing unit.

Third, the word account predicts that just like native Chinese speakers, L2 Chinese learners take words as processing units regardless of the number of characters that comprise a word. The Full transfer / Full access Model (Schwartz and Sprouse, 1996) argues that the restriction from L1 is limited and can be overcome with an increase in L2 proficiency. When L2ers have reached an advanced level of L2 proficiency through an immersive L2-dominant environment, a large quantity of L2 input and positive evidence enable them to reassemble new feature values and eventually restructure their L2 knowledge accordingly. From this perspective, high-proficiency L2 Chinese learners would be able to exhibit native-like patterns that take words as processing units in real time sentence reading.

By testing these three possible accounts, the present study aimed to tackle the question of whether high-proficiency L2 Chinese learners could implicitly adapt the unified word segmentation and identification mechanism in reading Chinese which does not exist in their native languages. To be specific, the present study investigated high-proficiency L2 Chinese learners' on-line processing of four kinds of words: 2-character incremental words (e.g. 门卫 'gate-keeper'), 1-character independent words which are the same as the 1-character embedded words in the 2-character incremental words (e.g. 门 'door'), 3-character incremental words (e.g. 酒精灯 'alcohol-lamp'), and 2-character independent words which are the same as the 2-character embedded words in the 3-character incremental words (e.g. 酒精 'alcohol'). The materials were prepared based on Yang et al. (2012) and Zhou and Li (2021). According to the morpheme account, when processing 2-character incremental words (such as 门卫 'gate-keeper'), the plausibility of the first embedded word (门 'door') would affect the processing of incremental word. This is because during on-line reading, L2 participants would segment and identify 门 first and integrate it with the prior context. They would only realize that they have to give up the original analysis and reanalyse the incremental words until they reached the second character 卫 (meaning 'guard'). In this procedure, it is easier to give up the original analysis when it is implausible than plausible. Thus the processing times on the incremental words would be longer in the plausible condition than in the implausible condition. In addition, the processing patterns of the embedded word 门 should be similar to that of the independent word 门, since L2 participants take individual morphemes as processing units. According to the 2-character combination account, we would expect the plausibility effect of the embedded words on the 3-character incremental words but not on the 2-character incremental words. This is because L2 participants prefer to take

Table 1. Predictions based on the three possible accounts.

		The morpheme account	The 2-character combination account	The word account
Expectation for the embedded word plausibility effect on the incremental words	2-character incremental words	Yes	No	No
	3-character incremental words	–	Yes	No
Expectation for different patterns between the embedded vs. independent words	2-character incremental words	No	Yes	Yes
	3-character incremental words	No	No	Yes

the combinations of two continuous characters as processing units. In processing 3-character incremental words (such as *酒精灯* 'alcohol-lamp'), the embedded words (*酒精* 'alcohol') would be segmented and identified first and then integrated with prior context. Till reached the third character *灯* 'lamp', L2 participants would realize that their original analysis was incorrect and that they need to reanalyse the incremental words. In this procedure, it would take more time to abandon a plausible original analysis than an implausible one. Thus the processing times on the 3-character incremental words would be longer in the plausible condition than in the implausible condition. In addition, the processing patterns of the embedded word *酒精* should be similar to that of the independent word *酒精*, since L2 participants take 2-character combinations as processing units. For the 2-character incremental words (such as *门卫* 'gate-keeper'), on the other hand, there would be no plausibility effect of the embedded words. This is because the 2-character incremental word as a whole would be taken as a processing unit, and the plausibility of the embedded word would not affect the processing of incremental words (Yang et al., 2012). According to the word account, L2 participants would have implicitly acquired the unified word segmentation and identification mechanism and could segment continuous character strings in a native-like manner. In this case, no plausibility effect of the embedded words would be expected in either 2-character or 3-character incremental words. Accordingly, the embedded words would be processed differently from the independent words. Taken together, by investigating whether there is a plausibility effect of the embedded words in the processing of 2- and 3-character incremental words, and whether the processing patterns of the embedded words significantly differ from the according independent words, the present study aimed to explore the processing unit of high-proficiency L2 Chinese learners in on-line reading. The predictions for L2 participants based on the three different accounts are summarized in Table 1.

V Method

1 Participants

Forty L2 Chinese learners (19 female, aged 18–35 years, M_{age} = 25.5) participated.[1] They were students in Chinese-learning major and were studying in a university in Beijing at

the time of the study. They all started learning Chinese after puberty and have the experience of living in mainland China for more than three years. All L2 participants had passed the HSK-C1 (Hanyu Shuiping Kaoshi-advanced level, the standard Chinese language proficiency test for non-native speakers administered by the Ministry of Education of the People's Republic of China), indicating that they were high-proficiency L2 Chinese learners. These L2 participants have different native languages (for example, Korean, Spanish, Russian, Japanese, etc.), but all of these languages have explicit word boundary demarcations (either inter-word spaces or explicit visual cues).

2 Materials

The materials in the present study were prepared based on Yang et al. (2012) and Zhou and Li (2021). There were 40 critical sentence frames containing 2-character incremental words as targets in Yang et al. (2012), and 40 critical sentence frames containing 3-character incremental words as targets in Zhou and Li (2021). For each critical sentence frame, four types of sentences were developed by manipulating the 2-character verb prior to the targets (see Table 2):

- the plausible–plausible condition as in (1a) and (1b), in which the target word is an incremental word and the preceding verb is plausible with both the incremental word and embedded word;
- the plausible–implausible condition as in (1c) and (1d), in which the target word is an incremental word and the preceding verb is plausible with the incremental word but not the embedded word;
- the plausible condition as in (1e) and (1f), in which the target word is an independent word (same as the embedded word in the incremental word) which is plausible with the preceding verb; and
- the implausible condition as in (1g) and (1h), in which the target word is an independent word (same as the embedded word in the incremental word) which is implausible with the preceding verb.

To make sure that the materials were familiar and acceptable to high-proficiency L2 Chinese learners, a familiarity test and an understandability and acceptability test were conducted on 20 high-proficiency L2 Chinese learners (all had passed the HSK-C1 and did not participate in the main eye-tracking experiment). In the familiarity test, L2 participants were asked to highlight the characters/words with which they were not familiar. In the understandability and acceptability test, L2 participants were asked to rate the understandability and acceptability of the whole sentence using a 5-point scale (1 = unacceptable and cannot be understood, 5 = acceptable and understandable). Based on the results of these two tests, 31 sets of sentences (each set contained four conditions of sentences) from Yang et al. (2012) and 31 sets of sentences from Zhou and Li (2021) were selected. In other words, all the characters, words and sentences in the current study were familiar and acceptable to high-proficiency L2 Chinese learners. Among these selected 62 sets of sentences, the mean frequency of the pre-target verbs was 40 per

Table 2. Examples of materials.

Conditions	Target words	Sentences
(1a) plausible–plausible	2-character incremental words	围观的人看着他踢打门卫却无动于衷。 'People were inattentive when he kicked the *gate-keeper*.'
(1b) plausible–plausible	3-character incremental words	陈晓默默地点燃酒精灯以便再次进行实验。 'Chen silently lighted the *alcohol lamp* in order to do the experiment again.'
(1c) plausible–implausible	2-character incremental words	围观的人看着他哀求门卫却无动于衷。 People were inattentive when he entreated the *gate-keeper*.
(1d) plausible–implausible	3-character incremental words	陈晓默默地清洗酒精灯以便再次进行实验。 'Chen silently cleaned the *alcohol lamp* in order to do the experiment again.'
(1e) plausible	1-character embedded words	围观的人看着他踢打门却无动于衷。 'People were inattentive when he kicked the *door*.'
(1f) plausible	2-character embedded words	陈晓默默地点燃酒精以便再次进行实验。 'Chen silently lighted the *alcohol* in order to do the experiment again.'
(1g) implausible	1-character embedded words	围观的人看着他哀求门却无动于衷。 People were inattentive when he entreated the *door*.
(1h) implausible	2-character embedded words	陈晓默默地清洗酒精以便再次进行实验。 'Chen silently cleaned the *alcohol* in order to do the experiment again.'

million in the plausible–plausible and plausible conditions, and 37 per million in the plausible–implausible and implausible conditions, with no significant difference between these two types of verbs, $ps > .5$.

For these selected 62 sets of sentences, another 20 high-proficiency L2 Chinese learners (who did not participate in the familiarity test and the understandability and acceptability test, nor the main eye-tracking experiment) assessed the plausibility of the target words with the preceding verbs. L2 participants were asked to rate the plausibility of the verb–noun phrases on a 5-point scale (1 = very implausible; 5 = very plausible). The mean plausibility ratings of the target words in the plausible–plausible, plausible–implausible, plausible, and implausible conditions were 4.91, 4.93, 4.88, and 1.24, respectively. Plausibility scores in the implausible condition were significantly lower than the other three conditions, $ps < .001$, with no significant difference between any two of the other three conditions.

In total, four material lists were created, each containing 62 experimental sentences and 30 filler sentences. None of the fillers involved implausibility or incremental words. Each list included 15/16 experimental sentences in each of the four conditions, and each condition of the experimental sentence sets appeared once across the four lists.

3 Apparatus

Participants' eye movements were recorded using an EyeLink 1000 eye tracker with a sampling rate of 1,000 Hz. Each sentence was presented in one line in the middle of a 21-inch (53 cm) cathode ray tube (CRT) monitor. Participants were seated 60 cm away from the monitor. Following a 3-point horizontal calibration and validation, the maximum gaze-position error was less than 0.5°. Eye movements were recorded from the right eye, but viewing was binocular.

4 Procedure

Participants were tested individually. The experiment started with a brief instruction and a standard horizontal three-point grid calibration and validation. Then, five practice trials were run to ensure that the participants understood the task and were familiar with the apparatus. Critical experimental trials were run after the practice trials. Participants were required to read sentences on the screen silently. At the beginning of each trial, a drift check was conducted. Each sentence appeared after participants fixated on a character-sized box at the location of the first character of each sentence. After finishing reading one sentence, participants were asked to press a button so that the original sentence disappeared and was replaced by a meaning-related question, to which participants then responded by button press. The entire experiment lasted around 40 mins.

VI Results

There were three regions of interest: the independent words (the target words in sentences in 1e to 1h), the incremental words (the target words in sentences in 1a–1d), and the embedded words (the first embedded words in the incremental words in 1a–1d). For each region, two eye-movement indices were analysed: gaze duration (GD) and total reading time (TT). GD is the sum of the fixation durations before the eyes first move out of a region, reflecting the early stage of processing; TT is the sum of the durations of all fixations in a region, reflecting the late stage of processing. These two measures are classic and important eye-movement indexes in previous studies.

Four participants were excluded from the final analysis due to their low accuracy ($<80\%$) with the comprehension questions. Thus we analysed 36 participants' data in the final analysis ($M_{accuracy}=88\%$, ranged from 80% to 98%). Trials in which participants blinked once or more at the interest regions were excluded from the analysis. This approach resulted in a loss of 2.8% of the trials. Fixations shorter than 80 ms or longer than 1,000 ms (approximately 1.6% of all fixations) were removed.

To investigate whether there is a plausibility effect of the embedded words on the incremental words, linear mixed effects models (Baayen et al., 2008) were constructed on incremental words, with word length (2-character vs. 3-character: −.5 vs. .5), the plausibility of the embedded words with the pre-target verbs (plausible vs. Implausible: −.5 vs. .5) and their interaction as fixed effects, specifying participants as crossed random effects, including intercepts and slopes. To investigate whether there is a significant difference of the processing pattern between the embedded words and the independent words, linear mixed effects models were conducted, with word type (embedded words

Table 3. Mean with SE in parentheses for each index in each region.

Word length of incremental words	Plausibility	Independent words: '门' / '酒精'	Embedded words: '门' / '酒精'	Incremental words: '门卫' / '酒精灯'
Gaze duration:				
2-character	Implausible	394 (22)	386 (21.1)	621 (20.3)
	Plausible	336 (21.4)	333 (22)	689 (20.5)
3-character	Implausible	677 (29.3)	657 (20.7)	762 (29)
	Plausible	609 (28.8)	570 (20.8)	868 (29.4)
Total reading time:				
2-character	Implausible	788 (56)	729 (50.1)	1182 (55.1)
	Plausible	675 (56.1)	560 (50.3)	1294 (55.6)
3-character	Implausible	1274 (68.1)	979 (49.4)	1376 (67.4)
	Plausible	1091 (67.3)	813 (49.3)	1580 (68.3)

vs. independent words: .5 vs. −.5), word length (1-character vs. 2-character: −.5 vs. .5), plausibility with the pre-target verbs (plausible vs. implausible: −.5 vs. .5) and their interactions as fixed effects, specifying participants as crossed random effects, including intercepts and slopes. The statistical procedure was conducted using *lmer* function (Bates et al., 2011) and *lmerTest* function (Kuznetsova et al., 2017) in R (version 3.5.1; R Core Team, 2018). The means and *SE*s for each eye movement index in the three regions are summarized in Table 3. The log-transformed data of fixation measures yield the same patterns of statistical significance as the analysis based on the raw data. In the interest of transparency of effect sizes, we report the analysis of the untransformed data here.

1 The whole incremental words region

The word length of incremental words had a significant effect: compared to the 2-character incremental words, GD and TT were longer on the 3-character incremental words (GD, $b=162$, $SE=25.84$, $t=6.25$, $p<.001$; TT, $b=246$, $SE=55.33$, $t=4.44$, $p<.001$). The plausibility manipulation of the embedded words had a significant effect: compared to the implausible condition, incremental words in the plausible condition had longer GD ($b=-76$, $SE=27.6$, $t=-2.78$, $p<.01$) and TT ($b=-163$, $SE=59.17$, $t=-2.75$, $p<.01$). The interaction between word length and plausibility was not significant for either GD ($b=-47$, $SE=51.84$, $t=-0.91$, $p=.36$) or TT ($b=-139$, $SE=111$, $t=-1.26$, $p=.21$).

These findings indicated that for both 2-character and 3-character incremental words, there was a significant plausibility effect of embedded words: L2 participants spent longer processing times on the incremental words when the embedded words were plausible with the preceding verbs than when the embedded words were implausible with the preceding verbs.

2 The embedded words and independent words region

The word length had a significant effect: compared to the 1-character embedded/independent words, GD and TT were longer on the 2-character embedded/independent words

(GD, $b=266$, $SE=13.04$, $t=20.41$, $p<.001$; TT, $b=352$, $SE=29.56$, $t=11.9$, $p<.001$). The plausibility manipulation had a significant effect: compared to the implausible condition, words in the plausible condition had shorter GD ($b=68.8$, $SE=13.51$, $t=5.09$, $p<.001$) and TT ($b=156$, $SE=30.93$, $t=5.04$, $p<.001$). The word type had a marginally significant effect on GD ($b=-22.78$, $SE=13.19$, $t=-1.73$, $p=.08$), but a significant effect on TT ($b=-195.88$, $SE=29.94$, $t=-6.54$, $p<.001$), with longer processing times on the independent words than the embedded words. The interaction between word type and plausibility was not significant for either GD ($b=0.49$, $SE=26.52$, $t=0.02$, $p=.98$) or TT ($b=-11.48$, $SE=60.37$, $t=-0.19$, $p=.85$). The interaction between word length and plausibility was not significant for either GD ($b=24.33$, $SE=26.07$, $t=0.93$, $p=.35$) or TT ($b=52.62$, $SE=59.15$, $t=0.89$, $p=.37$). The interaction between word type and word length was not significant for GD ($b=-24.69$, $SE=26.06$, $t=-0.95$, $p=.34$), but significant for TT ($b=-196.74$, $SE=59.12$, $t=-3.32$, $p<.01$). Post-hoc analysis revealed that for both 1-character and 2-character embedded/independent words, TT were significantly longer on the independent words than the embedded words, but the difference was larger for 2-character embedded/independent words than 1-character ones ($b=-97.5$, $SE=42.5$, $t=-2.29$, $p<.05$; $b=-294.3$, $SE=41.7$, $t=-7.06$, $p<.001$). The three-way interaction was not significant for either GD ($b=24.36$, $SE=52.29$, $t=0.47$, $p=.64$) or TT ($b=-104.45$, $SE=118.67$, $t=-0.88$, $p=.38$).

This finding indicated that for both 1-character and 2-character embedded/independent words, there was a significant plausibility effect: L2 participants spent longer processing times on the embedded/independent words when they were implausible with the preceding verbs than when they were plausible with the preceding verbs. There was no significant difference of processing patterns between the embedded words and the independent words.

VII Discussion

The present study explored how high-proficiency L2 Chinese learners on-line process incremental words when reading Chinese sentences. To do so, we aimed to tackle the question of whether high-proficiency L2 Chinese learners can acquire the unified word segmentation and identification mechanism, which is unique-to-L2. The results showed that, for both 2- and 3-character incremental words, there was a significant plausibility effect of embedded words: the incremental words in the plausible–plausible condition had longer reading times (GD and TT) than those in the plausible–implausible condition. The results indicated that during on-line reading, L2 participants segmented the embedded words as an independent word, and integrated them with prior sentence context as soon as they appeared. When they kept reading and reached the upcoming character, they realized that their original word segmentation and integration was not appropriate, and they needed to abandon their original analysis and group the embedded words with the right-side character as a whole word. It was more difficult to give up a plausible verb–noun analysis (the plausible–plausible condition) than an implausible one (the plausible–implausible condition). Thus, it took longer reading times in the plausible–plausible condition than in the plausible–implausible condition. In addition, the results revealed

that both 1- and 2-character embedded words and their corresponding independent words were processed in similar patterns: L2 participants spent longer reading times on the embedded/independent words in the implausible condition than in the plausible condition. This pattern indicated that L2 participants took embedded words as processing units. Thus, the implausible verb–noun combinations caused longer processing times than the plausible ones.

Taken together, the present study found that high-proficiency L2 Chinese learners were capable of using plausibility information in on-line reading. More importantly, the plausibility manipulation of embedded words had an effect on the processing of incremental words. And L2 participants processed the embedded words and the corresponding independent words in a similar way. These findings indicated that L2 participants did not process incremental words as a whole like native Chinese speakers did. Instead, they processed embedded words as independent words, and integrated embedded words with previous sentence context as soon as they read them.

It should be noted that, even though L2 participants exhibited similar processing patterns between the embedded words and independent words, they spent longer TT on the independent words than the embedded words regardless of the word length of the embedded/independent words. We assume that this finding may be caused by the right-side characters of the incremental words (the last character of each incremental word). To be specific, in reading incremental words, though participants identified and integrated the embedded words first with the preceding verbs, the parafoveal processing (the very early stage of processing) of the right-side character may affect the late stage processing of the embedded words. Compared to the characters following the independent words, the right-side characters following the embedded words could group with the embedded words and form legit compound words which are plausible with preceding context. In this condition, the lexical processing of the embedded words would be ended faster than the independent words since participants may need to spend some time in processing the right-side characters and the whole incremental words. From this perspective, high-proficiency L2 Chinese learners' processing may be affected by the features of both morphemes and words. Further studies are needed to investigate the possible effects of the possibility of forming a legit compound word by the target word and its following character.

To directly compare the processing patterns of native Chinese speakers and L2 Chinese learners, we summarized the eye movement data for the corresponding index and region from Yang et al. (2012) and Zhou and Li (2021) in Table 4. The results of native Chinese speakers showed no plausibility effect of embedded words on incremental words, and different processing patterns between embedded words and independent words (Yang et al., 2012), indicating that native Chinese speakers take words as processing units. Clearly, the processing pattern of L2 Chinese learners is different from that of native Chinese speakers. Even though the L2 participants have reached a high level of Chinese proficiency in the present study, they had not acquired the unified lexical segmentation and identification processing mechanism.

Although the L2 participants in the present study have reached a high level of Chinese proficiency, they were not as fluent as native Chinese speakers. It is possible that with longer Chinese-learning experience and higher proficiency (near-native), L2 Chinese

Table 4. Native Chinese speakers' eye movement data for the corresponding index and region.

Word length of incremental words	Plausibility	Independent words: '门' / '酒精'	Embedded words: '门' / '酒精'	Incremental words: '门卫' / '酒精灯'
Gaze duration:				
2-character	Implausible	**298 (70)**	259 (53)	320 (68)
	Plausible	**263 (53)**	260 (46)	324 (63)
3-character	Implausible	301 (9)	–[b]	370 (12)
	Plausible	291 (9)	–	352 (12)
Total reading time:				
2-character	Implausible	–[a]	–	–
	Plausible	–	–	–
3-character	Implausible	**470 (17)**	–	519 (24)
	Plausible	**426 (21)**	–	523 (29)

Notes. Native speakers' data on 2-character incremental words (means with *SD*s in parentheses) were from Yang et al. (2012), and their data on 3-character incremental words (means with *SE*s in parentheses) were from Zhou and Li (2021). [a]In Yang et al. (2012), there was no total reading times reported. [b]In Zhou and Li (2021), there was no data on embedded words reported. Data in bold indicates the difference between implausible and plausible conditions was significant.

learners may exhibit similar patterns to native Chinese speakers in word segmentation. Combined with the findings in the current study that high-proficiency L2 participants spent longer TT on the independent words than the embedded words which may indicate that L2 participants' processing may be affected by the features of both morphemes and words, it is likely that the unified lexical segmentation and identification processing mechanism is a developing skill that would be more native-like with increased Chinese proficiency. Further studies should be conducted on near-native L2 Chinese learners to investigate their processing units in on-line Chinese reading. Furthermore, to thoroughly test the role of L1 in L2 acquisition, especially in the acquisition of the word segmentation mechanism, further studies are needed to explore how L2 Chinese learners with different types of L1 (with or without explicit word boundary demarcation) segment continuous character strings in reading Chinese. In addition, further studies should be conducted to explore how simultaneous bilinguals who start to learn Chinese and other languages (with explicit word boundary demarcation, such as English) at the same time (at the very early stage of their life) segment words in on-line reading Chinese and other languages, and the corresponding cognitive mechanisms of their reading patterns.

Combined with previous findings that inserting inter-word spaces could benefit L2 Chinese learners' learning and processing of Chinese words (Bai et al., 2013; Shen et al., 2012), the present study could have some implications on international Chinese teaching and learning. When designing books for L2 Chinese learners, adding inter-word spaces deliberately may be helpful for them to learn and comprehend Chinese in a better way. Further studies should be conducted to explore whether inserting inter-word spaces would benefit L2 Chinese learners' reading of incremental words by reducing the uncertainty of character grouping/word segmentation.

VIII Conclusions

In conclusion, the present study explored the processing units of high-proficiency L2 Chinese learners in on-line Chinese reading to investigate whether they can implicitly acquire the unified lexical segmentation and identification mechanism. The results showed that L2 Chinese learners on-line processed Chinese incremental words in a different way from native Chinese speakers: instead of taking words as a whole, L2 Chinese learners activated embedded words first and integrated embedded words with previous sentence context as soon as they read them. These findings indicated that it is difficult for L2 learners to acquire a unique-to-L2 processing mechanism even with a high level of L2 proficiency.

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Supplemental material

All the materials, data and analysis code can be found at https://osf.io/ym7bq/.

Note

1. The number of participants was decided based on the results of the power analysis on a pilot study of 10 L2 Chinese participants with the exact same materials and procedure. The gaze duration on embedded words of these 10 participants was analysed using a linear mixed effect model focusing on the effect of plausibility (Yao et al., 2021). The powerSim function (Judd et al., 2012) was used to test the statistical power of this model. Results showed that the power would reach .90 with 25 participants.

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