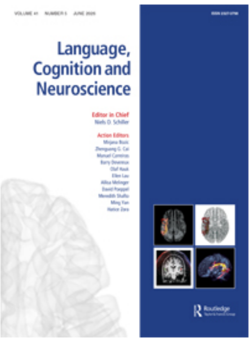

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Processing mechanisms of three-character compound words in Chinese sentence reading: evidence from lexical decisions and eye movements

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ABSTRACT
Reading three-character Chinese compound words was studied in two experiments using the lexical decision task and the eye-tracking technology to examine the extent to which they are recognised via their components. To this end, the frequency of the first character was manipulated in a continuous manner separately for two kinds of word structure: those where the first character formed an independent constituent (A-BC words) and those where it was a part of an embedded compound word (AB-C words). The study found evidence for both compositional and holistic processing. Moreover, A-BC words were read somewhat faster than AB-C words in the sentence context but not in isolation. Word-internal structure also affected the way attention was allocated within words. The pattern of results is consistent with parallel dual route models of compound word reading. It is concluded that Chinese readers demonstrate flexibility in using compositional and holistic processing in reading three-character words.

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Three-character compound words; Chinese; reading; eye-tracking; lexical decision; word recognition

Introduction

Compounding is the most common way in which languages can create new words from existing ones to form novel meanings (Libben, 2006). For example, the Chinese characters "黑" (black) and "板" (board) combine to form the two-character compound word "黑板" (blackboard), which can further combine with "擦" (eraser) to form the three-character compound word "黑板擦" (blackboard eraser). In binding together two or more free morphemes, compound words form morphologically complex lexical items (Huang & Liao, 2006; Marchand, 1969). In Chinese, compound words are numerous accounting for approximately 80% of the lexicon (Institute of Language Teaching and Research, 1986). Of them, two-character, three-character, four-character, and words with more than four characters make up about 72%, 12%, 10%, and 0.3% of all words, respectively (Lexicon of Common Words in Contemporary Chinese Research Team, 2008). Therefore, the study of how compound words are represented and processed is of utmost importance in enhancing our understanding of the mechanisms underlying Chinese word processing.

A long-standing debate on the processing mechanisms of compound words has focused on whether they are processed as whole units or via decomposing them into the component morphemes. Three classes of models offer mutually distinct explanations. The decomposition model posits that compound words are processed via their morphemes to access the word meaning (Taft & Forster, 1976; Zhang & Peng, 1992). Conversely, the holistic processing model maintains that compound words are stored and retrieved as single-unit representations (Butterworth, 1983). Finally, the dual-route model proposes two routes to word identity, the decomposition and holistic route, that operate in parallel during recognition (Baayen & Schreuder, 2000; Caramazza et al., 1988; Pollatsek et al., 2000; Schreuder & Baayen, 1995).

Since the seminal study of Taft and Forster (1976), frequency manipulations have been used as the litmus test in distinguishing between decompositional and holistic processing. An effect of constituent frequency is considered evidence for decomposition, while an effect of whole-word frequency is regarded as evidence for holistic processing. A constituent frequency effect suggests

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that constituents play a significant role in accessing the identity of compound words, whereas a whole-word frequency effect in the absence of a constituent frequency effect provides evidence for the holistic processing model. The co-occurrence of both a constituent and whole-word frequency effect supports the dual-route model.

In reading alphabetic scripts, the evidence favours the dual-route model (for a review, see Hyönä, 2015). According to the model, there is a parallel race between the two routes with the faster route winning the race. Word length has been demonstrated to determine the winning route with short compound words (in terms of visual extent and number of letters) being recognised holistically, while compound word constituents play a more significant role in accessing longer compound words that do not fit in the fovea when fixated or contain more than 10 letters (Bertram & Hyönä, 2003, 2013; Hyönä et al., 2020, 2024).

Unlike alphabetic scripts, the logographic Chinese script consists of characters with small inter-character spaces but no inter-word spaces. More than 90% of characters express morphemes (Lexicon of Common Words in Contemporary Chinese Research Team, 2008). The presence of inter-character spaces combined with the fact that characters denote independent morphological units may encourage the use of the decomposition route. Moreover, the absence of inter-word spaces means that readers of Chinese cannot be sure whether or not the adjacent characters form a compound word before performing word segmentation to identify the word boundaries and subsequently the word. Thus, it may be argued that the aforementioned script properties increase the need for compositional processing of Chinese compound words.

However, the research on Chinese compound word processing has not yielded consistent findings. Some studies have adopted the lexical decision task where the words are presented one at a time. They have systematically manipulated the frequency of the first and second character in two-character compound words while matching for the whole-word frequency. These studies have observed a significant character frequency effect, with higher character frequencies producing shorter reaction times (Taft et al., 1994; Zhang & Peng, 1992). These findings were corroborated by the study of Sun et al. (2018), who conducted a meta-analysis based on lexical decision databases. A similar result was also obtained in normal sentence reading where the target words were embedded in sentences (Yan et al., 2006).

There are also studies that have found more complex patterns of results regarding character frequency effects. Using a mega lexical decision database, Tsang et al. (2018) discovered that high-frequency characters in fact delayed the recognition of compound words (known as the reverse or inverted character frequency effect). These results have been replicated in natural reading (Cui et al., 2021; Sui et al., 2025; Xiong et al., 2023; Yu et al., 2021). For example, Cui et al. (2021) orthogonally manipulated the frequency of the first and second character of Chinese two-character compound words while controlling for whole-word frequency during natural reading with eye-tracking. Their results showed that fixations on the second character were longer when a high-frequency character was presented as the first character compared with when a low-frequency character was presented as the first character. This reversed character frequency effect is assumed to reflect an effect of the words' morphological family size. On the other hand, some studies have observed no significant character frequency effects (Hyönä et al., 2024; Li et al., 2014; Ma et al., 2015). Finally, the study of Sui et al. (2025) observed all three possibilities – a facilitatory, an inhibitory and no effect of character frequency, depending on word frequency. Gaze durations on two-character words were shorter for frequent second characters when word frequency was relatively low, while an inhibitory effect of second-character frequency was observed for frequent compound words. The results were obtained via an analysis of an eye-tracking corpus, where the participants read half of a novel while their eye movements were recorded. In all, the evidence reviewed above paints a rather complex picture of the role of the decomposition route in Chinese compound word recognition. It suggests that word frequency likely plays a significant role in modifying the influence of single characters in compound word recognition.

The research reviewed above all examined the recognition of two-constituent compound words. Considerably less attention has been devoted to examining the processing of compound words comprising more than two components. The present study was designed to fill in this gap. We adopted three-character Chinese compound words as the target stimuli and manipulated the frequency of the first-character to investigate the processing of Chinese compounds during reading. As mentioned above, 12% of the Chinese compound words are three-character compounds. Thus, they are not infrequent in the language. Moreover, accompanied by the emergence of new objects and concepts that need to be named, the quantity and usage of three-character words have gradually increased (Yang, 2005).

Three-character compound words differ from two-character compounds not only by being morphologically more complex, but their internal structure diverges from that of two-character words. In Chinese, most three-character compounds conform to the AB-C structure (69.71%), where the first two characters (AB) combine to form an embedded compound word. On the other hand, the A-BC compounds, in which the last two characters (BC) form an embedded compound word, are less numerous (30.03%). The AB-C words may be called left-branching, as the left part can be further divided into two components, whereas the A-BC words are called right-branching. An example of an AB-C word is "电视机" [television set], its literal translation is electricity vision machine; and an example of an A-BC word is "电风扇" [electric fan], its literal translation is electricity wind fan. Whether the hierarchical structure influences the processing of three-character compounds is crucial for understanding the mental representation and processing mechanisms of polymorphemic compound words (Libben, 1993; Oseki & Marantz, 2020; Song et al., 2019; Yin et al., 2022). Thus, in the present study we used as the target stimuli three-character compounds conforming to both the AB-C and the A-BC structure.

A few studies exist where the processing of three-character compound words have been investigated. Miwa et al. (2017) explored the recognition of three-character Japanese compound words by manipulating the frequency of each character, whole-word frequency, and embedded word frequency (i.e. the frequency of a two-character word within the three-character compound that can stand alone as an independent word, such as "体温" in "体温计"). Twenty-one participants were tested in a lexical decision task combined with eye-tracking. The reaction times revealed a significant frequency effect for the first and third character, whole-word, and embedded word, suggesting that Japanese three-character compound processing aligns with the dual-route model, incorporating both holistic and compositional mechanisms. However, there was no difference in reaction times between left-branching and right-branching compound words even though the left-branching compound words are also more common in Japanese. On the other hand, the eye-fixation data showed an effect of word type: the summed duration of second and third fixation in three-fixation trials and the second fixation duration in two-fixation trials were shorter for left-branching compound words. Yet, this relatively late effect did not translate to a difference in overall latency in the lexical decision task.

Yin et al. (2022) had 40 participants to recognise Chinese left-branching (AB-C) and right-branching (A-BC) compound words (20 of each kind) in a lexical decision task. In addition to an effect of whole-word frequency, they also observed an effect of branching direction with lexical decision latencies being shorter for left-branching (i.e. the more common structure) than right-branching compound words.

In sum, the two lexical decision studies (Miwa et al., 2017; Yin et al., 2022) found some evidence for the view that readers access hierarchical structure information during compound word processing: AB-C compounds are recognised faster than A-BC compounds. The processing advantage for AB-C compounds may stem from their higher proportion in Japanese and Chinese, suggesting that an extensive reading experience may lead to a parsing preference for the more common structure.

However, the sentence-reading eye-tracking study of Luo et al. (2023) could not replicate the word structure effect in reading time. They tested 60 Chinese participants reading 88 pairs of left- and right-branching three-character compound words embedded in a sentence context. They observed no significant difference in fixation time between the two structures. Yet, they did observe an effect of word structure in the initial landing position on the word; a saccade was launched further into the word in A-BC than AB-C words. It was taken to suggest that the longer constituent pulled the eyes toward it.

In the follow-up study to that of Luo et al. (2023), Yan et al. (2025) used the same materials but manipulated the parafoveal preview by replacing the three-character target words by three identical, unrecognisable characters and presented them in two different colours to be consistent (e.g. in previewing the AB-C words, the first two characters appeared in the same colour) or inconsistent (e.g. in previewing the AB-C words, the first two characters appeared in different colours) with the target word structure. Contrary to Luo et al., now the initial fixation landed further into the word for AB-C than A-BC words. It was explained as a perceptual effect: a coloured object consisting of two characters attracted the eyes further than one consisting of a single character. In gaze duration and total time, they observed a structural parafoveal preview effect: the preview consistent with the target word structure led to shorter fixation times than the preview inconsistent with the word structure. This was taken as support for the view that Chinese readers are capable of recognising the word structure parafoveally.

It is noteworthy that Chinese three-character compounds with different hierarchical structure appear in identical written form, depriving readers of low-level visual cues to identify their internal structure. However, in alphabetic writing systems, the structural boundary of trimorphemic compounds may sometimes be visually marked. For example, in English the boundary may be marked by a space (e.g. "watchdog group" vs. "consumer watchdog"), providing readers with a visual cue to parse the compound's structure. A hyphen may also be placed at the structural boundary (Bertram et al., 2011), or interfixes as linking morphemes may appear at structural boundaries, as is the case in German and Dutch (Krott et al., 2004). Such visual or linguistic cues are non-existent in Chinese. On the other hand, individual compound word constituents are visually salient in Chinese, as they appear as separate characters.

In summary, the role of hierarchical structure in processing three-character Chinese compounds remains unclear. To address this, in the present study we manipulated the hierarchical structure of three-character compounds (AB-C vs. A-BC), while matching them pairwise in a number of different lexical features (e.g. "电视机" [AB-C] is paired with "电风扇" [A-BC] to have an identical first character). In addition, we also manipulated the frequency of the first character as a single-character word. In other words, we selected three-constituent compound words, whose initial character can also appear as a separate word. We then varied its frequency as a separate word. It is important to keep in mind that in the target words the initial characters always appeared as compound word constituents, not as separate words. The idea behind this manipulation was as follows: If three-character compounds are processed via the decomposition route, a significant first-character frequency effect will be found (Taft & Forster, 1976). On the other hand, if they are processed holistically, no such effect will be observed.

Furthermore, we hypothesised that if processing differences arise between AB-C and A-BC words, this would support the decomposition account. More specifically, AB-C words were predicted to be recognised faster, as their structure is more common than that of A-BC words (70% vs. 30%). In contrast, if compounds are processed holistically, there is no need for readers to parse their internal structure, and thus no significant processing differences would appear between the two types (as long as their frequencies are matched, which was the case in the present materials).

As argued above, there are reasons to assume the decomposition route to play a significant role in recognising three-character compound words in Chinese. First, most characters comprise independent morphological units. This was exactly the case in the materials of the present study. Second, there are small spaces between characters, so that compound word constituents stand visually apart from each other. Third, when fixated, the entire three-character word may not always fit in the fovea (it extends two degrees of visual angle around the fixation point) encouraging the use of the decomposition route (Bertram & Hyönä, 2003, 2013; Hyönä et al., 2020). This was the case in the present study, where the target stimuli extended horizontally beyond foveal reach (about 4.5° of visual angle in Exp. 1 and about 3° of visual angle in Exp. 2). Fourth, the information density of three-character compound words (each character comprising many strokes; in the present materials, on average 22 strokes) may also encourage the use of the decomposition route. Hyönä et al. (2024) provided support for this view in Finnish. They found that for long Finnish compound words, decompositional processing occurred when the visual density was high (i.e. when the number of letters exceeded 10) even when all letters fell within the fovea. This effect may possibly generalise to three-character Chinese compound words. Thus, a reliable first-character frequency effect may be observed.

Word structure may further modulate the first-character frequency effect: In A-BC compounds, the structural boundary lies between the first character (A) and the embedded compound word (BC), leaving the first character as an independent morpheme. This configuration may make the first-character frequency effect more likely to emerge. In AB-C compounds, on the other hand, a structural boundary occurs between the embedded word (AB) and the final character (C), making the first character a part of a larger embedded unit. This could in turn weaken or even eliminate the first-character frequency effect. Such a pattern of results would provide further evidence for the notion that three-character compound words are not recognised as holistic units, but instead the component structure is used in parsing the word's morphological structure. Finally, observing a processing difference between the A-BC and AB-C words may be considered evidence against the holistic account and in support of the decomposition account.

There are also reasons to argue for the use of the holistic route in reading three-character compound words. First, over 50% of the Chinese characters have multiple meanings (Packard, 1999). In other words, combining constituent meanings into a compound meaning is often not straightforward. Instead, the meaning of character is constrained by the neighbouring characters. Thus, recognising character combinations as holistic units is a viable option. Second, there is evidence that the whole-word frequency of three-character compound words exert an immediate effect observed in the initial fixation made on the word (Miwa et al., 2017; Zhou et al., 2018). Third, even four-character linguistic units such as idioms may be identified as single lexical representations (e.g. Zang et al., 2024), as postulated by the multiple-constituent unit hypothesis (Zang, 2019).

In the present study, two experiments were carried out. In Experiment 1, we presented the three-character compound words one at a time using a lexical decision task (Miwa et al., 2017; Yin et al., 2022). In Experiment 2, we adopted a sentence reading task combined with eye-tracking technology (Luo et al., 2023; Yan et al., 2025). There were two reasons for adopting both a lexical decision task and a sentence-reading eye-tracking task. First, the prior research has used these two tasks. Second, and more importantly, the existing results diverge between the two tasks: A word structure effect has been observed in the lexical decision task (Yin et al., 2022), but not in the sentence reading task (Luo et al., 2023). The present study was designed to further examine effects of word structure. It is worth keeping in mind that the tasks differ in important ways. In lexical decision, there is no need to segment the target word out of the neighbouring characters. Moreover, there is no context that could facilitate or inhibit the recognition of three-character words. In contrast, in sentence reading participants need to segment the target out of the neighbouring characters in order to recognise it as a whole word. On the other hand, prior to fixating it, it appears in the parafovea, which may facilitate the subsequent foveal processing of the word structure (Luo et al., 2023; Yan et al., 2025).

In the sentence-reading experiment, fixation times were used as the primary indices of the effects related to character frequency and word structure. In addition, we also analysed initial landing positions on target words. Prior research has provided evidence for the view that Chinese readers may be capable of extracting parafoveally the structure of three-character words, as revealed by the location of the initial fixation in the word. Yet, the results are inconsistent with one study (Luo et al., 2023) observing the initial fixation to land further into the word in A-BC words, while another study (Yan et al., 2025) obtained an opposite effect. Experiment 2 was planned as a further attempt to examine possible landing position effects in reading three-character compound words.

Experiment 1

In Experiment 1, the recognition of 124 three-character compound words was examined in a lexical decision task. Two variables were manipulated: word structure (AB-C vs. A-BC) and first-character frequency. First-character frequency was manipulated as a continuous variable with four frequency quartiles, instead of using a dichotomous manipulation (high vs. low).

Method

Participants

A total of 80 native Chinese speakers (73 females) participated (university students attending Shandong Normal University) in the experiment. Their ages ranged from 18 to 26 years ($M = 20.89$, $SD = 1.77$). We estimated the priori power of the study using the powerSim and powerCurve functions from the simr package (Peter et al., 2018) to determine the required number of participants. As the eye-tracking experiment was considered the primary source of evidence, the power estimate was done with respect to Experiment 2. We first conducted a pilot study with 10 participants and analysed the pilot data with a linear mixed model (as described in the section on data analysis), where the gaze duration on the whole-word region was the dependent variable. Then, based on the pilot data, we explored how the power varies as a function of the number of participants. The results indicated that 40 participants had a power estimate of 83%, suggesting that 40 participants were enough to detect an effect with an effect size of .80 in this experiment (Brysbaert & Stevens, 2018; Cohen, 2013). However, it should be acknowledged that the observed effect size may have been an overestimate of the true effect, which could potentially result in an underestimation of the required number of participants to attain the targeted power level. The power estimate reached 93% when the sample size increased to 80 participants.

All participants gave their informed consent for taking part in the experiment. The study was approved by the ethics committee of the Faculty of Psychology of Shandong Normal University (SDNU2025081).

Materials

A total of 124 pairs of three-character Chinese compound words was used as the target stimuli. Their internal structure was manipulated. Half of them conformed to an AB-C structure, where the first two characters (AB) form an embedded two-character word, and the other half conformed to an A-BC structure, where the last two characters (BC) form an embedded two-character word. Moreover, the frequency of the first character as a single word was similarly manipulated for both compound word types. This frequency measure departs from character frequency, which sums up the character occurrences regardless of whether or not they form single-character words. The 124 A-BC structure and 124 AB-C structure words were paired with each other so that each pair shared the same first character.

It is important to note that the three-character compound words used in the present study are all so-called incremental words without segmentation ambiguity. Incremental words are multicharacter words containing a subset of characters that constitute another word (referred to as the embedded word; Zhou & Li, 2021). They should be kept separate from so-called overlapping ambiguous strings (OAS; Luo et al., 2002). A three-character OAS is a string in which the middle character (B) can form a word with the character on both its left (word AB) and right (word BC) (Gan et al., 1996). However, no such ambiguity exists in the materials used in the present study. The materials primarily consisted of subordinate (i.e. modifier-head) structures (214 items, accounting for 86.3% of words), with the remainder being verb-noun structures (34 items, 13.7%).

A set of 124 three-character non-words was created by randomly combining a one-character word and a two-character word so that their combination did not have a sensible meaning. Also for the non-words, we manipulated the location of the one-character and two-character words to form an equal number of A-BC and AB-C structures to ensure that the participants did not perceive structural differences between the target words and non-words. An example word pair for the A-BC and AB-C structure is 电-风扇 (electric fan) versus 电视-机 (television set). An example non-word pair for the A-BC and AB-C structure is 陆-黄金 (land gold) versus 日记-面 (diary face). As mentioned above, each word pair shared the same first character.

The lexical properties of the target compounds are shown in Table 1. Whole-word frequency, second-character frequency, third-character frequency and the number of strokes in the target words did not systematically vary between A-BC and AB-C, $ts < 1.44$, $ps > .05$, or between the quartiles of first-character frequency, $Fs < 1.28$, $ps > .05$. For the embedded words, a marginally significant difference was observed between A-BC and AB-C in per-million frequency, $t(1,246) = 1.99$, $p = .05$, but not for log frequency, $t(1,246) = 0.824$, $p = .411$. There was no significant difference in embedded word frequency between the quartiles of first-character frequency, $Fs < 1.61$, $ps > .05$. Word and character frequencies were calculated based on the corpus of Cai and Brysbaert (2010).

Instead of creating a dichotomous variable of the first-character frequency (high vs. low), we treated it as a continuous variable by dividing it into four frequency quartiles. The frequency of the first character ranged from 1.27 to 9977.13 times per million. Due to the left-skewed distribution of the original frequency range, a logarithmic transformation was applied to ensure normality, resulting in a transformed range of 0.31–9.21 times per million. The log frequency of the first character varied significantly between the quartiles, $F(3, 244) = 485.54$, $p < .001$.

Procedure

E-Prime 3.0 software was used to programme the experiment and record participants' responses and reaction times. All materials were presented in 38-point size simple Song font at the centre of the computer screen in white on a black background. Before the formal experiment, six words and six nonwords were presented to help participants familiarise themselves with the task. Each trial started with a 500 ms fixation cross in the centre of the screen, followed by a stimulus that was displayed until the participant responded (or for a maximum of 3000 ms). Participants decided whether or not the three-character string presented on the screen was a word by pressing the keyboard as quickly

Table 1. Logarithmic frequencies (per million values in parentheses) for each character, embedded words and whole word as well as for number of strokes in words for the A-BC and AB-C structure compound words separately for the four first-character frequency quartiles.

Type	Quartile 1	Quartile 2	Quartile 3	Quartile 4	Total
1st character frequency					
A-BC	3.03 (28.2)	4.67 (118)	6.05 (490)	7.71 (3080)	5.34 (905)
AB-C	3.03 (28.2)	4.67 (118)	6.05 (490)	7.71 (3080)	5.34 (905)
2nd character frequency					
A-BC	3.98 (230)	4.14 (150)	3.92 (252)	4.64 (368)	4.16 (248)
AB-C	3.43 (343)	4.21 (511)	3.71 (96.5)	3.91 (361)	3.82 (329)
3rd character frequency					
A-BC	3.81 (158)	4.05 (342)	4.63 (357)	4.44 (556)	4.23 (352)
AB-C	4.38 (452)	4.74 (877)	4.21 (512)	4.38 (346)	4.43 (551)
Embedded word frequency					
A-BC	2.47 (44.7)	2.08 (35.1)	1.57 (29.5)	2.47 (117)	2.14 (56.0)
AB-C	1.87 (26.8)	1.85 (18.2)	2.24 (32.1)	1.80 (23.1)	1.94 (25.0)
Whole-word frequency					
A-BC	−0.68 (1.61)	−0.69 (1.10)	−0.07 (4.20)	−0.61 (5.66)	−0.51 (3.11)
AB-C	−0.92 (1.78)	−0.02 (2.87)	−0.08 (2.98)	−0.63 (1.27)	−0.41 (2.24)
Number of strokes in whole words					
A-BC	22.2	22.6	22.6	21.0	22.1
AB-C	22.8	21.8	21.3	20.9	21.7

and as accurately as possible; they pressed "F" for a "yes" response and "J" for a "no" response. After the response, a 200 ms blank screen was presented followed by a new trial.

Data availability

All data, analysis code, and research materials are available at Open Science Framework: https://osf.io/b2tqv.

Results

The response accuracy exceeded 90% for all participants ($M = 96\%$, range: 90%–100%). Reaction times shorter than 300 ms or longer than 2000 ms, as well as all values exceeding 2.5 standard deviations from the overall mean, were excluded from the analyses (Yin et al., 2022). This resulted in 3.5% of the data being removed prior to conducting the statistical analyses. Only the reaction times of correct responses to the target words were analysed. As response accuracy was at ceiling, accuracy was not statistically analysed (see Table 2 for the descriptive statistics). Linear mixed-effect models were computed using the lme4 packages (Bates et al., 2015) in R 4.2 (see Table 3). Because of the positive skewness of the RTs, the data were log-transformed to meet the distribution assumption of LMMs. The effect of first-character frequency proved significant: responses were longest for words with the lowest first-character frequency. On the other hand, there was no effect of word type, nor did the two variables interact.

Discussion

In Experiment 1, three-character Chinese compound words were recognised in a lexical decision task in combination of non-words that were random combinations of existing characters and two-character combinations. The participants were able to distinguish existing words from non-words with very high accuracy (i.e. with 97% accuracy). The reaction times were affected by first-character frequency: three-character compound words that contained a frequent first character were recognised faster than those containing an infrequent character. On the other hand, compound word structure did not influence reaction times: AB-C and A-BC words produced almost identical reaction times. Moreover, the effect of first-character frequency was similar in size between the two word types.

Table 3. Linear mixed effect model for reaction time (RT, in ms). Statistically significant effect appears in bold.

Measure	Fixed factors	*b*	*SE*	*t/z*	*p*
RT	Word type	−0.001	0.004	−0.27	.789
	First character frequency (log)	**−0.004**	**0.002**	**−2.67**	**.008**
	Word type × First character frequency (log)	−0.003	0.002	−1.12	.261

The results are consistent with those of Miwa et al. (2017) observed for Japanese three-character compound words. Similar to their Experiment 1, lexical decision latencies were affected by first-character frequency but not by word type. On the other hand, the results depart from those of Yin et al. (2022), who found shorter lexical decision latencies for Chinese AB-C than A-BC words. Their result is consistent with the view that structural frequency (AB-C structure is more frequent in Chinese than A-BC structure) can impact the recognition of trimorphemic words.

However, the lexical decision data is of limited value for making conclusions about how trimorphemic words are recognised in continuous reading. As the words are presented in isolation one at a time, the Chinese reader does not need to segment the word out of other surrounding characters. This is the case in normal reading: The reader has to make constant decisions about word boundaries: what characters belong to the same word and what characters should be kept separate. Thus, in Experiment 2, we embedded the target words used in Experiment 1 in a sentence context and had participants read them while their eye movements were registered.

Experiment 2

In Experiment 2, the trimorphemic target words of Experiment 1 were embedded in sentence context.

Table 2. Means and standard deviations (in parentheses) for reaction time (RT, in ms) and accuracy rate (ACC) as a function of word type and first-character frequency.

		First-character frequency quartile				
Measure	Word type	Q1	Q2	Q3	Q4	Mean
RT	A-BC	643 (139)	628 (126)	622 (137)	628 (139)	631 (134)
	AB-C	649 (152)	625 (136)	629 (143)	634 (142)	634 (142)
	Mean	646 (144)	627 (130)	625 (139)	631 (141)	
ACC	A-BC	.96 (.19)	.97 (.16)	.95 (.21)	.96 (.19)	.97 (.17)
	AB-C	.95 (.22)	.96 (.20)	.96 (.19)	.98 (.13)	.96 (.20)
	Mean	.95 (.21)	.97 (.16)	.97 (.18)	.96 (.20)	

Each AB-C word was paired with an A-BC word so that they shared the first character. The sentence frame leading to the target word was identical for each word pair as was the sentence end after the target. The target words were unpredictable from the prior sentence context; moreover, they were equated for plausibility. The participants were asked to read the sentences silently for comprehension while their eye movements were recorded.

Method

Participants

Eighty students of Shandong Normal University participated in the experiment, none of them participated in Experiment 1. Their ages ranged from 19 to 24 years ($M = 20.62$ years, $SD = 1.31$). All of them were native speakers of Chinese with normal or corrected-to-normal vision and were naive to the purpose of the experiment. None reported any neurological disorders. They received monetary compensation for their participation. All participants gave their informed consent for taking part in the experiment.

Apparatus

Readers' eye movements were recorded with a desk-mounted Eyelink 1000 + (SR Research, Ontario, Canada) eye-tracker using a 1000 Hz sampling rate. Movements of the right eye were tracked. The tracker was calibrated using a 3-point calibration grid. The stimuli were presented on a monitor with 1024 × 768 resolution and a frame rate of 120 Hz. The sentences were presented in Simple Song 24 font in black on a white background. The distance between the participant and the screen was 60 cm and each character subtended approximately 0.95° of visual angle.

Materials

Experiment 2 used the same target words as Experiment 1. The target words were now embedded in single sentences. A sentence frame was created for each pair of compound words that was identical except for the target word. The target words were positioned in the middle part of the sentence to avoid the possible sentence-initial and sentence-final effects (Warren et al., 2009). An example sentence pair is presented in Table 4 with an English translation (the target word is bolded for illustration).

To ensure the plausibility of the target words within the sentence context, 20 participants, who did not participate in the eye-tracking experiment, rated how well each target word matched the given sentence frame on a scale from 1 (very implausible) to 5 (very plausible).

Table 4. An example sentence pair for an A-BC and AB-C structure compound word.

Word type	Target	Sentence
A-BC	电风扇 Electric fan	舅舅买的电风扇是今年的最新款。 The electric fan my uncle bought is the latest model this year.
AB-C	电视机 Television set	舅舅买的电视机是今年的最新款。 The television set my uncle bought is the latest model this year.

All target words were rated as plausible within their respective sentence frames. There was no significant difference in plausibility ratings between A-BC ($M = 4.72$, $SD = 0.14$) and AB-C ($M = 4.73$, $SD = 0.15$) compounds, t (246) = 0.61, $p = .544$.

To evaluate the predictability of the target words, another 20 participants, who did not participate in the eye-movement experiment, read the first part of the experimental sentence up to but not including the target word and were asked to predict the next word in the sentence. The predictability of the items was near zero, indicating that the target words were not predictable from their preceding contexts. There was no significant difference in the predictability ratings between A-BC ($M = 0.01$, $SD = 0.09$) and AB-C ($M = 0.00$, $SD = 0.00$) compounds, t (246) = −1.000, $p = .318$.

Procedure

The participants were asked to read the sentences silently for comprehension at their own reading speed, and reading comprehension was assessed by true–false statements. The participants were instructed to press the blue key in the gamepad when the statement was congruent with the meaning of the last read sentence and to press the green key in the gamepad when it was incongruent. The presented comprehension questions were related to the 40 filler sentences. There were 7 practice sentences before the experimental sentences. To avoid repetition of the identical sentence frames, the target sentences were divided into two sets. Both sets contained 124 sentences (62 A-BC and 62 AB-C compound words), with each participant reading only one set. Half of the participants was presented set A and the other half set B. The experiment consisted of 171 sentences in total, including 124 target sentences, 40 filler sentences and 7 practice sentences. The experiment lasted about 28 min.

Results

The accuracy in answering to the comprehension questions exceeded 80% for all participants ($M = 95\%$, $SD = 4\%$), indicating that the participants understood the sentences well. Fixation durations shorter than 80 ms or longer than 1000 ms, as well as all values exceeding 2.5 standard deviations from the overall mean, were excluded from the analyses (Zhou et al., 2018; Zhou & Li, 2021). This resulted in 2.5% of the data being removed prior to conducting the statistical analyses.

We report the analyses first for the whole-word region (ABC) followed by two subregion analyses: one for the first character region (A) and another for the final two-character region (BC). The purpose of separately analysing the two subregions is to examine in more detail the time course of the effects.

For the whole-word region, the following eye movement measures were analysed: first fixation duration (FFD; the duration of the first fixation made on the word), single fixation duration (SFD; the time spent on the word, when only one fixation was made), gaze duration (GD; the sum of all first-pass fixations on the word before moving to another region), total fixation time (TT; the sum of all fixations on the word including any regressions to it), regression path duration (RPD; the summed duration of fixations starting when entering the word until exiting it to the right), initial skipping probability (ISP; the probability that the word was initially skipped), refixation probability (RP; the probability of making more than one fixation on the word during the first-pass reading), initial landing position (ILP; the location of the initial fixation from the word beginning), and saccade length (SL; the length of the incoming saccade to the word).

The fixation duration measures were log-transformed before analysis. We analysed the above eye-movement measures for all the areas of interest using linear mixed models (LMMs) for continuous variables and generalised linear mixed models (GLMMs) for dichotomous variables (Baayen et al., 2008) using the lme4 package (version 1.1–30; Bates et al., 2015) in R (version 4.1.1; R Core Team, 2021). The LMM and GLM models were selected by comparing different random structures with an analysis of variance (ANOVA) and by selecting a parsimonious model which was not overparameterized (Bates et al., 2015). The initial random structures included intercepts for participants and items, all the variables that were included as one-way fixed effects in the model as a random slope for the participant, and a correlation parameter. These models were compared with models in which some or all random effects had been removed, including the correlation parameter. If ANOVA indicated a significant difference between the models, we chose the model which was preferred by at least 2 out of 3 goodness of fit measures (AIC, BIC, Log likelihood). If there was no statistically significant difference between the models, the model with fewer parameters was chosen. All continuous fixed variables were centred to the mean. In the final selected LMMs and GLMMs, first-character frequency was entered as a continuous variable and word type (AB-C vs. A-BC) as a categorical variable as fixed effects, while subjects and items were entered as crossed random effects. We report regression coefficients (*b*s), *SE*s, *t* or *z* values, and corresponding *p* values of the optimal model.

Whole-word region (ABC)

We start out with the analysis for the whole word (ABC). The descriptive statistics of the dependent variables are presented in Table 5 and the modelling results in Table 6. Launch site was added as a covariate to control for its potential influence on the effects of interest. Launch site was the distance between the location of the last fixation prior to fixating the target word and the left edge of the target word. It was used as a proxy for parafoveal processing with near launch sites enabling more extensive parafoveal processing than far launch sites. The extent of parafoveal processing may in turn affect the effects of primary interest. Thus, launch site was used as a covariate in all analyses. Trials with launch sites over 6 characters (4.2%) were discarded, because they may reflect eye-tracker error or atypical saccadic behaviour.

We observed a significant effect of first-character frequency for most dependent variables (FFD, GD, TT, ISP, RP, ILP, SL) indicating that higher frequency of the first character as a single word led to shorter gaze duration, increased skipping probability, lower refixation probability, longer incoming saccade, and initial landing position further into the word. Figure 1(A) illustrates the first-character frequency effect in GD. A significant main effect of word type was also found for gaze duration, refixation probability and total time, with A-BC words showing shorter gaze durations and total fixation times than AB-C words (see Figure 1(B)). None of the two-way interactions between first-character frequency and word type were significant. Finally, launch site entered as covariate was significant in most measures. Near launch sites were associated with more word skipping, shorter incoming saccades, initial landing position being further into the word, shorter gaze durations (see Figure 1(C)), less refixations and shorter total times.

Interestingly, when readers made a single fixation on the target word, the effect of first-character frequency was absent. It is noteworthy that the target words were read with a single fixation in 75% of the trials. To test the credibility of the null effect of first-character frequency in SFD, we computed Bayes Factors using the lmBF function from the Bayes Factor package in R

Table 5. Means and standard errors (in parentheses) of the eye movement measures for the whole word (ABC region).

		First-character frequency quartile				
Measure	Word type	Q1	Q2	Q3	Q4	Mean
FFD	A-BC	216 (2.02)	216 (1.94)	217 (1.96)	208 (1.96)	215 (0.99)
	AB-C	221 (2.02)	215 (1.90)	219 (2.04)	214 (2.13)	217 (1.01)
	Mean	219 (1.43)	216 (1.36)	218 (1.41)	211 (1.45)	
SFD	A-BC	212 (2.37)	214 (2.29)	217 (2.29)	206 (2.26)	212 (1.15)
	AB-C	218 (2.43)	215 (2.33)	218 (2.44)	213 (2.48)	216 (1.21)
	Mean	215 (1.70)	215 (1.63)	218 (1.67)	210 (1.68)	
GD	A-BC	283 (4.09)	272 (3.68)	275 (3.81)	259 (3.82)	272 (1.93)
	AB-C	288 (4.09)	279 (3.83)	280 (3.85)	272 (3.88)	280 (1.96)
	Mean	285 (2.89)	276 (2.66)	277 (2.71)	266 (2.73)	
TT	A-BC	429 (6.69)	431 (6.80)	415 (6.56)	379 (6.44)	414 (3.33)
	AB-C	450 (7.12)	425 (6.67)	417 (6.60)	422 (7.02)	429 (3.43)
	Mean	440 (4.89)	428 (4.76)	416 (4.65)	401 (4.78)	
RPD	A-BC	373 (7.12)	352 (6.62)	341 (6.33)	332 (6.59)	250 (3.35)
	AB-C	370 (6.77)	341 (6.11)	354 (6.65)	350 (6.86)	254 (3.30)
	Mean	371 (4.91)	347 (4.51)	347 (4.60)	341 (4.76)	
ISP	A-BC	.12 (.01)	.12 (.01)	.13 (.01)	.15 (.01)	.13 (.005)
	AB-C	.11 (.01)	.12 (.01)	.13 (.01)	.14 (.01)	.12 (.005)
	Mean	.11 (.01)	.12 (.01)	.13 (.01)	.15 (.01)	
RP	A-BC	.25 (.01)	.23 (.01)	.23 (.01)	.20 (.01)	.23 (.01)
	AB-C	.27 (.01)	.25 (.01)	.23 (.01)	.23 (.01)	.25 (.01)
	Mean	.26 (.01)	.24 (.01)	.23 (.01)	.22 (.01)	
ILP	A-BC	1.28 (.02)	1.32 (.02)	1.35 (.02)	1.41 (.03)	1.34 (.01)
	AB-C	1.31 (.02)	1.34 (.02)	1.39 (.02)	1.39 (.03)	1.36 (.01)
	Mean	1.29 (.02)	1.33 (.02)	1.37 (.02)	1.40 (.02)	
SL	A-BC	3.05 (.05)	3.05 (.05)	3.22 (.05)	3.25 (.05)	3.14 (.03)
	AB-C	3.11 (.05)	2.97 (.05)	3.20 (.05)	3.26 (.05)	3.13 (.03)
	Mean	3.08 (.03)	3.01 (.03)	3.21 (.04)	3.26 (.04)	

Note: FFD = first fixation duration; SFD = single fixation duration; GD = gaze duration; TT = total time; RPD = regression path duration; ISP = initial skipping probability; RP = refixation probability; ILP = initial landing position; SL = saccade length.

(Morey & Rouder, 2015). Following Abbott and Staub (2015) and Yao et al. (2022), we used the default prior for the effect size (Cauchy priors with scale value of 0.5) and ran 100,000 Monte Carlo iterations. In order to use the lmBF function, we removed the random slopes from the models. According to Wagenmakers et al. (2018), Bayes Factors ranging between 0.33 ∼ 1 provide anecdotal evidence to support the null hypothesis, less than 0.33 suggests moderate evidence to support the null hypothesis, and less than 0.1 indicates strong evidence to support the null hypothesis. The analysis revealed moderate evidence (BF = 0.19) against a main effect of first-character frequency in SFD. Below, we provide an explanation for the null effect based on the landing position analyses.

The following observations may be made of the whole-word analyses. When the target word was fixated, the effect of first-character frequency was observed during the first fixation with the effect spilling over to the probability of refixating the word and thus to gaze duration and subsequently to total fixation time. These effects are evidence for compositional processing. Yet, in about 75% of the trials when the word was read with a single fixation, the effect remained absent. Thus, in the majority of cases three-character words seemed to be read as holistic units.

Moreover, sometimes readers were able to read the target word even without fixating on it at all. The target words were skipped in 13% of the cases. This would also suggest their holistic processing. On the other hand, the finding that there was a small but significant effect of first-character frequency in skipping rate suggests that high-frequency first characters encouraged readers to skip over the entire words regardless of compound word structure.

A main effect of word type was also observed. The A-BC words were refixated a bit less often (a 2% increase) than the AB-C words. This translated to shorter gaze durations for A-BC words. An analogous effect was also obtained in single fixation duration and total fixation time. Thus, the compound word structure exerted an effect on both immediate and delayed processing. Yet, the direction of the effect was opposite to what was predicted, as the less frequent structure (A-BC) was associated with shorter fixation times than the more frequent structure (AB-C).

First-character frequency also affected saccade programming: the incoming saccade was longer and it landed further into the word when the initial character was of higher frequency. Landing close to the word centre is optimal for perceiving all three characters of the target word, as by doing so, they are more within foveal reach (the target words extended horizontally about 3 degrees of visual angle). Thus, initially positioning the eyes close to the word centre may have facilitated target word processing. This may explain why

Table 6. (General) Linear mixed effect models for the eye movement measures for the whole word. Statistically significant effects appear in bold.

Measure	Fixed effect	*b*	*SE*	*t/z*	*p*
FFD	Word type	−0.01	0.01	−1.44	.150
	First character frequency (log)	**−0.01**	**0.003**	**−2.20**	**.028**
	Launch site	**−0.01**	**0.003**	**−2.25**	**.025**
	Word type × First character frequency (log)	0.001	0.003	0.29	.773
SFD	Word type	**−0.02**	**0.01**	**−2.01**	**.044**
	First character frequency (log)	−0.004	0.003	−1.32	.186
	Launch site	−0.004	0.003	−1.50	.133
	Word type × First character frequency (log)	0.001	0.004	0.12	.907
GD	Word type	**−0.03**	**0.01**	**−3.01**	**.003**
	First character frequency (log)	**−0.01**	**0.01**	**−2.69**	**.007**
	Launch site	**0.03**	**0.005**	**6.77**	**<.001**
	Word type × First character frequency (log)	0.001	0.004	0.01	.992
TT	Word type	**−0.04**	**0.01**	**−3.46**	**.001**
	First character frequency (log)	**−0.02**	**0.01**	**−2.59**	**.010**
	Launch site	**0.06**	**0.005**	**12.09**	**<.001**
	Word type × First character frequency (log)	−0.004	0.01	−0.61	.541
RPD	Word type	0.02	0.03	0.51	.608
	First character frequency (log)	−0.01	0.01	−1.80	.071
	Launch site	**0.06**	**0.005**	**12.82**	**<.001**
	Word type × First character frequency (log)	−0.01	0.01	−1.05	.292
ISP	Word type	1.04	0.08	0.58	.561
	First character frequency (log)	**1.14**	**0.05**	**3.11**	**.002**
	Launch site	**0.50**	**0.02**	**−21.02**	**<.001**
	Word type × First character frequency (log)	0.98	0.04	−0.58	.561
RP	Word type	**0.89**	**0.05**	**−2.33**	**.020**
	First character frequency (log)	**0.94**	**0.03**	**−2.24**	**.025**
	Launch site	**1.27**	**0.03**	**10.06**	**<.001**
	Word type × First character frequency (log)	0.99	0.03	−0.18	0.859
ILP	Word type	−0.01	0.01	−0.44	.659
	First character frequency (log)	**0.03**	**0.01**	**2.92**	**.003**
	Launch site	**−0.35**	**0.01**	**−55.91**	**<.001**
	Word type × First character frequency (log)	0.01	0.01	1.15	.252
SL	Word type	−0.01	0.01	−0.52	.603
	First character frequency (log)	**0.03**	**0.01**	**3.13**	**.002**
	Launch site	**0.61**	**0.01**	**95.70**	**<.001**
	Word type × First character frequency (log)	0.01	0.01	1.25	.210

Note: FFD = first fixation duration; SFD = single fixation duration; GD = gaze duration; TT = total time; RPD = regression path duration; ISP = initial skipping probability; RP = refixation probability; ILP = initial landing position; SL = saccade length.

there was no effect of first-character frequency for single fixation trials, suggesting holistic processing. To test whether the initial landing position (ILP) was indeed more optimally located (i.e. close to the word centre) for single-fixation trials, we compared their ILPs to those of multiple-fixation trials by including fixation count as an additional predictor in the model. We ran the same model also for saccade length (SL). The descriptive statistics are reported in Table 7 and the modelling results in Table 8.

As expected, initial landing position was farther in the word in trials read with a single fixation than trials that were read with more than one fixation. The difference in ILP was quite noticeable – about half a character – which is almost 20% of the horizontal extent of the compound word. Moreover, it is noticeable that the single fixations landed on average exactly at the word centre (i.e. 1.5 characters from the word beginning). Combined with the finding that single-fixation trials demonstrated no effect of first-character frequency, the ILP result suggests that when the initial fixation lands at the word centre, a three-character word may be recognised holistically. It is noticeable that a comparable difference observed in ILP between single-fixation and multiple-fixation trials was also obtained for the incoming saccade length (i.e. it was about 0.5 characters longer in the single-fixation than multiple-fixation trials).

As the final set of analyses, we conducted separate analyses for the A region (i.e. the character whose frequency was manipulated) and the BC region. The motivation was to examine if we would find effects hidden in the whole-word analyses. Specifically, we were interested to see whether within-word fixation time (gaze duration and total fixation time) is allocated differently as a function of word type (A-BC vs. AB-C). Moreover, the subregion analyses may shed more light in the timing of the first-character frequency effect. The probability of skipping a subregion was also analysed.

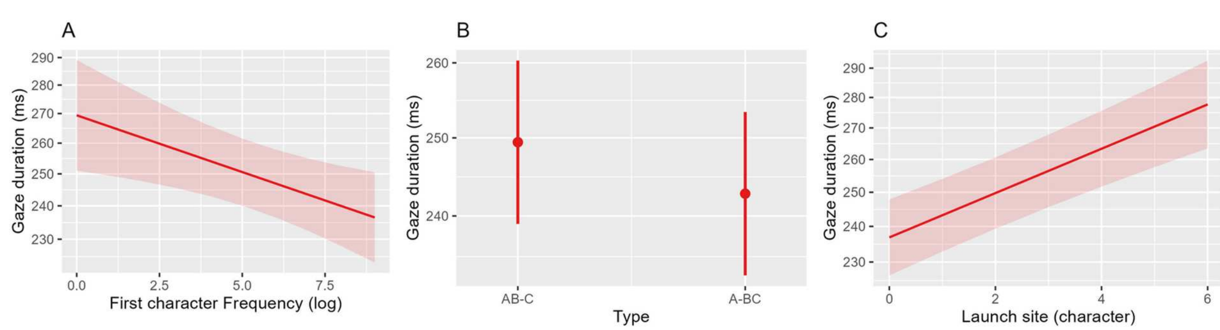

Figure 1. (A) The main effect of first-character frequency in gaze duration (ms). (B) The main effect of word type in gaze duration (ms). (C) The main effect of launch site (characters) in gaze duration (ms).

Table 7. Means and standard errors (in parentheses) for initial landing position (ILP) and saccade length (SL) separately for single-fixation and multiple-fixation trials of the whole word (ABC region).

Fixation count	ILP	SL
Single	1.49 (.01)	3.35 (.02)
Multiple	0.96 (.02)	2.83 (.02)

Table 8. Linear mixed effect models for initial landing position (ILP) and saccade length (SL) for the whole word when also fixation count (single vs. multiple) was entered as a predictor. Statistically significant effects appear in bold.

Measure	Fixed effect	*b*	*SE*	*t*	*p*
ILP	Word type	−0.02	0.02	−1.45	.148
	First character frequency (log)	**0.02**	**0.01**	**2.22**	**.027**
	Fixation count	**−0.33**	**0.02**	**−14.51**	**<.001**
	Launch site	**−0.34**	**0.01**	**−54.23**	**<.001**
	Word type × First character frequency (log)	0.02	0.01	1.72	.086
	Word type × Fixation count	0.04	0.03	1.13	.260
	First character frequency (log) × Fixation count	0.01	0.01	0.93	.350
	Word type × First character frequency (log) × Fixation count	−0.02	0.02	−1.29	.199
SL	Word type	−0.02	0.02	−1.49	.137
	First character frequency (log)	**0.02**	**0.01**	**2.52**	**.012**
	Fixation count	**−0.32**	**0.02**	**−14.60**	**<.001**
	Launch site	**0.62**	**0.01**	**99.48**	**<.001**
	Word type × First character frequency (log)	0.01	0.01	1.65	.099
	Word type × Fixation count	0.03	0.03	1.09	.277
	First character frequency (log) × Fixation count	0.01	0.01	0.58	.560
	Word type × First character frequency (log) × Fixation count	−0.02	0.02	−0.93	.354

First-character region (A)

The descriptive statistics of the measures for the first-character region are presented in Table 9 and the modelling results in Table 10. There was a significant effect of first-character frequency for both fixation duration measures showing that higher first-character frequency resulted in shorter fixation times on the subregion. Moreover, frequent first characters were skipped over more than infrequent first characters. The interaction between word type and first-character frequency was non-significant for the fixation duration measures but significant for the probability of skipping over the A region. Specifically, as shown in Figure 2, for the A-BC words the effect of initial character frequency was strong ($p < .001$), while for the AB-C words the effect remained significant ($p = .034$) but was smaller. For both word types, higher first-character frequency led to higher skipping probability. The main effect of word type was non-significant.

The results of the A region departed from those of the whole-word region in two respects. First, the main effect of word type was not significant. Second, the effect of first-character frequency in skipping rate was stronger for A-BC than AB-C words. That is, frequent first characters were skipped over more than infrequent first characters particularly when they functioned as single constituents in the three-character compound words.

Table 10. (General) Linear mixed effect models for gaze duration (GD), total fixation time (TT) and initial skipping probability (ISP) of the A region. Statistically significant effects appear in bold.

Measure	Fixed effect	*b*	*SE*	*t*	*p*
GD	Word type	−0.01	0.01	−0.58	.562
	First character frequency (log)	**−0.02**	**0.005**	**−3.67**	**<.001**
	Launch site	0.003	0.01	0.49	.624
	Word type × First character frequency (log)	0.004	0.01	0.74	.461
TT	Word type	−0.003	0.01	−0.22	.823
	First character frequency (log)	**−0.02**	**0.01**	**−2.58**	**.010**
	Launch site	0.002	0.01	0.27	.787
	Word type × First character frequency (log)	−0.001	0.01	−0.08	.939
ISP	Word type	0.96	0.05	−0.90	.370
	First character frequency (log)	**1.07**	**0.03**	**2.12**	**.034**
	Launch site	**0.36**	**0.01**	**−38.81**	**<.001**
	Word type × First character frequency (log)	**1.06**	**0.03**	**2.00**	**0.045**

Table 9. Means and standard errors (in parentheses) of gaze duration (GD), total fixation time (TT) and initial skipping probability (ISP) for the first character (A region).

		First-character frequency quartile				
Measure	Word type	Q1	Q2	Q3	Q4	Mean
GD	A-BC	216 (3.01)	215 (3.16)	211 (3.06)	203 (3.12)	212 (1.55)
	AB-C	219 (2.94)	215 (2.95)	213 (3.19)	205 (3.19)	213 (1.53)
	Mean	217 (2.11)	215 (2.16)	212 (2.21)	204 (2.23)	
TT	A-BC	258 (4.53)	252 (4.51)	241 (4.24)	239 (4.51)	248 (2.23)
	AB-C	254 (4.26)	258 (4.75)	245 (4.53)	243 (4.67)	251 (2.28)
	Mean	256 (3.11)	255 (3.37)	243 (3.09)	241 (3.25)	
ISP	A-BC	.61 (.01)	.64 (.01)	.65 (.01)	.68 (.01)	.65 (.01)
	AB-C	.64 (.01)	.64 (.01)	.67 (.01)	.66 (.01)	.65 (.01)
	Mean	.62 (.01)	.64 (.01)	.66 (.01)	.67 (.01)	

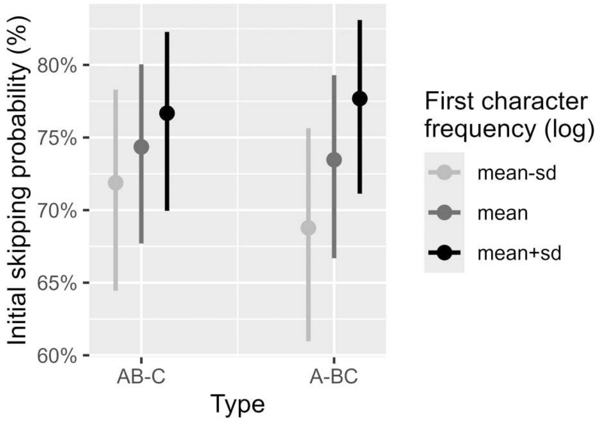

Figure 2. Initial skipping probability (%) of the first character (A region) as a function of word type and first-character frequency (log).

In the whole-word analysis, the effect of first-character frequency in skipping rate appeared as a main effect.

BC region

The descriptive statistics of the measures for the BC region are presented in Table 11 and the modelling results in Table 12. The effect of first-character frequency did not feature in the fixation time measures. On the other hand, they demonstrated a main effect of word type with the BC region receiving less fixation time on A-BC words than AB-C words (see Figure 3).

Moreover, the main effect of first-character frequency was significant in skipping probability, with higher frequency leading to a higher skipping probability. The main effect was modulated by an interaction with word type. Specifically, as shown in Figure 4, for the AB-C words the effect of initial character frequency was strong ($p < .001$), while for the A-BC words the effect remained significant ($p = .034$) but was smaller. For both word types, higher first-character frequency led to higher skipping probability.

Summary of the subregion analyses

The results of the subregion analyses may be summarised as follows. First, for the A region, fixation durations were shorter and skipping rates higher when the first character (A) was frequent than infrequent. In other words, when a fixation lands on a frequent character of a three-character word, gaze duration and total fixation time will be shorter and the region is skipped more often. Second, fixation time on the BC region was shorter and its skipping rate greater when it formed a compound word constituent (A-BC) than when it did not (AB-C). The main effect of word structure emerged in the analysis of the BC region but not in that of the A region, suggesting that it needed some time to emerge. Finally, word structure was also involved in an interaction with first-character frequency in skipping rate for the BC region: the effect of first-character frequency was greater for AB-C than A-BC words. An opposite pattern was observed in skipping rate for the A region. Thus, the frequency of first character affects skipping earlier for A-BC than AB-C words. In the former case, it formed an independent constituent, whereas in the latter case it was a part of an embedded compound word.

Table 12. (General) Linear mixed effect models for gaze duration (GD), total fixation time (TT) and initial skipping probability (ISP) of the BC region. Statistically significant effects appear in bold.

Measure	Fixed effect	*b*	*SE*	*t*	*p*
GD	Word type	**−0.03**	**0.01**	**−3.27**	**.001**
	First character frequency (log)	−0.002	0.004	−0.28	.783
	Launch site	**0.03**	**0.003**	**7.38**	**<.001**
	Word type × First character frequency (log)	−0.001	0.004	−1.03	.305
TT	Word type	**−0.05**	**0.01**	**−4.06**	**<.001**
	First character frequency (log)	−0.01	0.01	−0.96	.337
	Launch site	**0.04**	**0.01**	**8.56**	**<.001**
	Word type × First character frequency (log)	−0.01	0.01	−1.16	.247
ISP	Word type	**1.14**	**0.06**	**2.40**	**.017**
	First character frequency (log)	**1.13**	**0.04**	**3.90**	**<.001**
	Launch site	**0.41**	**0.01**	**−33.92**	**<.001**
	Word type × First character frequency (log)	**0.94**	**0.03**	**−1.97**	**0.049**

Table 11. Means and standard errors (in parentheses) of gaze duration (GD), total fixation time (TT) and initial skipping probability (ISP) for the BC region.

		First-character frequency quartile				
Measure	Word type	Q1	Q2	Q3	Q4	Mean
GD	A-BC	238 (3.24)	238 (3.09)	233 (2.93)	229 (3.10)	235 (1.55)
	AB-C	241 (3.11)	238 (3.05)	244 (3.17)	242 (3.25)	241 (1.57)
	Mean	239 (2.24)	238 (2.17)	239 (2.16)	236 (2.25)	
TT	A-BC	328 (5.57)	334 (5.38)	325 (5.23)	298 (5.13)	322 (2.68)
	AB-C	348 (5.73)	328 (5.08)	329 (5.28)	332 (5.52)	334 (2.70)
	Mean	338 (4.00)	331 (3.70)	327 (3.71)	315 (3.79)	
ISP	A-BC	.30 (.01)	.29 (.01)	.29 (.01)	.31 (.01)	.29 (.01)
	AB-C	.25 (.01)	.27 (.01)	.28 (.01)	.30 (.01)	.27 (.01)
	Mean	.28 (.01)	.28 (.01)	.28 (.01)	.31 (.01)	

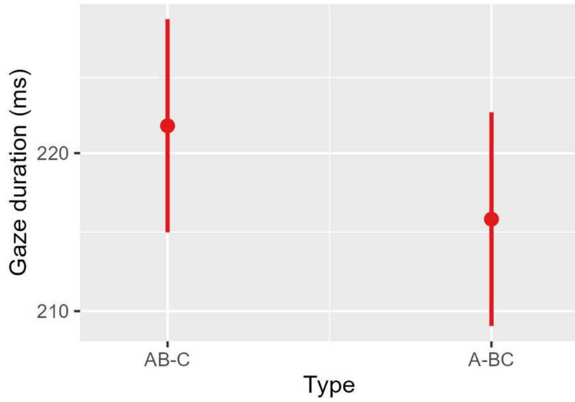

Figure 3. The main effect of word type in gaze duration (ms) of the BC region.

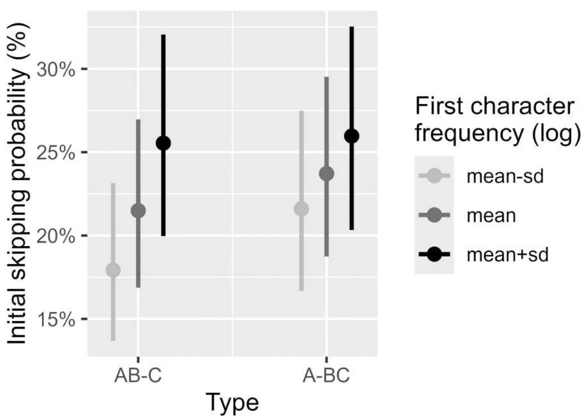

Figure 4. Initial skipping probability of the BC region as a function of word type and first-character frequency (log).

Discussion

In Experiment 2, reading of three-character Chinese compound words was investigated in a sentence context. Eye-tracking was used to tap into their processing. The frequency of the first character as a single-character word was manipulated in a continuous fashion using four frequency quartiles. Two types of three-character compound words were used as the target words: A-BC and AB-C words. In Chinese, three-character compound words are not uncommon, comprising 12% of all words. Of them, approximately 70% conform to the AB-C structure and 30% to the A-BC structure.

Several eye-movement measures for the three-character target words were employed as the primary indicators of compound word processing. Moreover, the processing time-course was further examined by conducting separate analyses for the subregions of A and BC. The target word analyses revealed reliable effects of first-character frequency. Fixation time on the word was the shorter the more frequent the first character was. This was true for first fixation duration, gaze duration and total fixation time. However, in contrast to what was predicted, the effect of first-character frequency was no greater for A-BC than AB-C words despite the fact that the first character served as an independent constituent in the former but not in the latter type of words.

Interestingly, the effect of first-character frequency did not emerge in single fixation time. This is important, as in about 75% of the trials the target words were read with a single fixation, whose duration was not affected by first-character frequency. In other words, this null effect, confirmed by a Bayes Factors analysis, is interpreted as evidence for holistic processing. Yet, it should be noted that in single fixation duration a main effect of word type emerged with shorter fixation times for A-BC than AB-C words. The effect of word type in turn may be taken as evidence against holistic processing. Yet, opposite to what was predicted, words conforming to the less common structure (A-BC) were read with shorter single fixations, gaze durations and total fixation times than words conforming to the more common structure (AB-C).

To sum up, the word-level analyses provided support both for the use of the decomposition and whole-word route. When readers refixated the word, gaze duration and probability of refixation were affected by first-character frequency. On the other hand, when participants were able to read the three-constituent compound words with a single fixation, no effect of first-character frequency was observed. Thus, these data suggest that both the decomposition route and the holistic route are in operation in reading three-characters Chinese compound words. The pattern of results is in line with dual route models (e.g. Pollatsek et al., 2000; Schreuder & Baayen, 1995) that assume both routes to be simultaneously active with the faster route winning the race.

The subregion analyses provided evidence for compositional processing. First, the effects of first-character frequency may be regarded as such. The frequency of the first component of three-character words exerted an immediate effect (apparent in skipping rate and gaze duration for the A region) on compound word processing. Second, gaze duration was shorter and skipping rate greater for the BC region when it formed a compound word constituent than when it did not. Third, the effect of first-character frequency was greater in skipping rate for the A region when the A region formed a constituent (A-BC) than when it did not (AB-C). For the BC region, an opposite pattern was observed in skipping (a greater first-character frequency effect for AB-C than A-BC words), indicating a bit delayed effect for AB-C words.

We also analysed the landing positions of initial fixations on the three-character compound words. The observed results are in line with those of Yan et al. (2010), Li et al. (2011) and Zang et al. (2013), who also found Chinese readers to fixate in the word centre in single-fixation cases and toward the word beginning in multiple-fixation cases when reading compound words. To account for the results, Yan et al. suggested the notion of flexible target selection, according to which successful word segmentation based on parafoveal information results in targeting the saccade to the word centre, while segmentation failure leads to programming a saccade toward the word beginning. An alternative account, coined the dynamic-adjustment hypothesis (Liu et al., 2017, 2025), states that saccade length in Chinese reading is determined dynamically based on the degree of parafoveal processing: more extensive parafoveal processing leads to longer saccades. Thus, it can accommodate the first-character frequency effect observed in incoming saccade length. However, unlike the flexible target selection account, the dynamic-adjustment hypothesis does not assume default targets for the saccades, i.e. either the word beginning or centre depending on the success parafoveal word segmentation.

It is noteworthy that, unlike Luo et al. (2023) and Yan et al. (2025), we found no effect of word-internal structure on saccade programming. In the Luo et al. study, the initial fixation landed further into A-BC than AB-C words. On the other hand, in their follow-up study (Yan et al., 2025), an opposite effect was observed by parafoveally previewing the word structure by coloured previews. The experimental design of Luo et al. was closer to ours. Yet, there is no obvious reason why we could not replicate the word structure effect in initial landing position. One possibility is that our first-character frequency manipulation may have obscured the effect. Luo et al. did not manipulate it, but used identical first characters in matched word pairs (as we also did).

In addition to affecting the foveal processing, first-character frequency also influenced parafoveal processing. This became evident in three findings. First, it influenced the rate of skipping the first character. It is evidence for parafoveal processing, as the incoming saccade is programmed while fixating a text region to the left of the target word. Moreover, the initial landing position and the incoming saccade length were influenced by first-character frequency: The more frequent the first character, the longer the incoming saccade was and the further into the word it landed. All these effects are evidence for parafoveal processing of the first character of three-character compound words. They demonstrate that frequent first characters are parafoveally processed to a greater extent than infrequent first characters. These findings are in line with the dynamic-adjustment hypothesis (Liu et al., 2017, 2025), according to which Chinese readers dynamically adjust saccade length based on the parafoveal processing difficulty.

General discussion

The present study examined whether the decomposition route is in operation when recognising three-character Chinese compound words conforming either to a A-BC or AB-C structure. An effect of first-character frequency was used as an index of compositional processing (Taft & Forster, 1976); first-character frequency was manipulated in a continuous manner. Moreover, it was hypothesised that, if present, the effect may be more robust for A-BC than AB-C words, as the first character functions as an independent constituent in the former but not in the latter type of words. A possible main effect of word type was also considered evidence for compositional processing and against holistic processing. Based on their relative frequency, the more frequent AB-C structure was assumed to lead to faster processing. On the other hand, if the processing is holistic in nature, the word-internal structure should not exert an effect as long as the words are equated for whole-word frequency, as they were in the present study.

Two experiments were conducted. In Experiment 1, the lexical decision task was used combined with isolated word presentation. In Experiment 2, the three-character target words were embedded in single sentences; the participants read them for comprehension while their eye movements were registered.

Experiment 1 established an effect of first-character frequency but no word structure effect. The former effect is consistent with the decomposition account, while the latter result may be considered evidence for holistic processing. Yet, the absence of an effect is weak evidence at best. The pattern of results is in line with that obtained by Miwa et al. (2017) for Japanese three-character compound words. On the other hand, the present results were inconsistent with the study of Yin et al. (2022), who found lexical decision latencies to be shorter for the more common structure.

Experiment 2 was carried out to find out whether the pattern of results could be replicated in continuous reading. The two tasks differ from each other in an important way. In lexical decision, the words are presented one at a time in isolation. Thus, there is no need to segment them out from other words. On the other hand, this is exactly the case in continuous text reading.

Despite the task differences, a reliable effect of first-character frequency was replicated in Experiment 2. It showed up both in fixation time and skipping rate. Thus, it is concluded that the decomposition route is in operation in recognising three-character words in Chinese. On the other hand, unlike Experiment 1, Experiment 2 also established an effect of word structure. Yet, the effect was in the unpredicted direction with the less common structure (A-BC) being associated with shorter fixation time than the more common structure (AB-C). The subregion analyses revealed that the structure effect emerged as a slightly delayed effect in that it was absent for the A region but present for the BC region (yet, still taking place during the first-pass reading). Moreover, the BC region was read with shorter fixation time when it formed an embedded compound word in A-BC words than when the last two characters belonged to two different constituents in AB-C words. This finding reflects an effect of word-internal structure, which may be considered evidence for compositional processing.

A possible interpretation for the unexpected word structure effect in Experiment 2 is that it may be easier to parse the word-internal structure when the first character functions as an independent constituent, as is the case with A-BC words. Parafoveally perceiving the first character may also have benefitted the subsequent foveal processing of A-BC more than AB-C words. Evidence for this was obtained by the separate analysis conducted for the A region. The first-character frequency exerted a greater effect in skipping over the A region for A-BC than AB-C words. Curiously, the pattern in skipping rate was reversed in the analysis of the BC region, suggesting that the effect of first-character frequency was more delayed for AB-C words.

Prior research on the effects of the structure of three-character Chinese compound words has resulted in mixed findings. As noted above, Yin et al. (2022) obtained shorter lexical decision latencies for the more common AB-C words, whereas Miwa et al. (2017) and Experiment 1 of the present study found no word type effect, nor did Luo et al. (2023) in an eye-tracking reading study. By adding the results of Experiment 2, it appears that all three possible outcomes have been observed. Thus, possible effects of word-internal structure in three-character Chinese compound words are yet to be firmly established.

Experiment 2 also provided evidence for holistic processing of three-character compound words. First, the target words were skipped in 13% of the trials, which means that occasionally readers were able to recognise them even without directly fixating on them. Second, most of the time (in 75% of the trials) the three-character words were read with only one single fixation. Third, the mean landing position of the single-fixation trials was exactly at the word centre (i.e. 1.5 characters from the word beginning). It suggests that the fixation located at the word centre was optimal for recognising the three-character word with just one fixation. Combined with the finding that single-fixation trials demonstrated no effect of first-character frequency, it provides further evidence for holistic processing.

In sum, the present study has obtained evidence for both compositional and holistic processing of three-character Chinese compound words. What factors would facilitate the reading of three-character words with a single fixation leading to holistic processing? At least two factors may play a role here. First, Experiment 2 identified one factor – initial landing position in the word. It was located notably further into the word in single-fixation than multiple-fixation trials. This is turn suggests that when a fixation is located in the middle of the word (as was the case in single-fixation trials), known to be the optimal position for word recognition at least in reading different alphabetic scripts (e.g. Hyönä & Bertram, 2011; Nuthmann et al., 2005; Rayner et al., 1996; Vitu et al., 2001), it is more likely that all three characters can be perceived in a single fixation made on the word.

Second, the visual density of the Chinese writing system is likely a key factor in the holistic recognition of compound words. In running text, compound words often fit in the fovea when fixated. This in turn increases the chances of holistic processing (Bertram & Hyönä, 2003). Yet, holistic processing may be possible even when the entire word does not fit in the foveal vision. This became apparent in a study by Hyönä et al. (2024), who found that even when parts of a Chinese compound word fell into the parafoveal vision (e.g. large-font two-character compound words with a visual angle of 4°), holistic processing still persisted. In the present study, the horizontal extent of the three-character compound words was beyond foveal reach (in Experiment 1 about 4.5° of visual angle; in Experiment 2 about 3° of visual angle). Yet, evidence for holistic processing was obtained. Therefore, the spatial extent of compound words does not seem to be a significant factor determining the processing mode of compound words in Chinese reading, at least when it is fixated optimally. This conclusion is also supported by Wang et al. (2023), who used lexicalised compound words as materials and found no evidence of a plausibility effect for either two-character (2° of visual angle) or four-character compound words (4° of visual angle), suggesting that even four-character compound words can be processed holistically. Yet, it should be noticed that visual acuity does not drop to zero in the parafovea, but declines linearly the further the stimulus appears from the centre of fixation.

Finally, we briefly discuss the results in the light of two models of Chinese reading, the Chinese Reading Model (CRM; Li & Pollatsek, 2020) and the Chinese E-Z Reader model (CEZR; Liu et al., 2025; Yu et al., 2021). CRM mainly focuses on modelling word segmentation within continuous arrays of characters for the purpose of word segmentation and identification during continuous reading. It has been tested on its capacity to simulate eye movements including words segmentation from overlapping (i.e. ambiguous) character strings. As Chinese readers move their eyes from left to right, CRM predicts left dominance in segmentation of words with ambiguous boundaries. Applied to the present context, Chinese readers are assumed to have a tendency to regard the first two characters to be a compound word. Thus, CRM assumes a preference to parse three-character compound words conforming to an AB-C rather than A-BC structure. As noted above, the results of Experiment 2 observed an opposite effect. On the other hand, to date, the CEZR has not been tested on ambiguous character strings (see Liu et al., 2025, p. 521), so it is unclear what – if anything – the model would predict about possible AB-C versus A-BC structural differences. As noted earlier, the existing evidence for word structure effects is contradictory. Thus, it may be premature to assess model fits with respect to word structure effects before the exact nature of the effect is more firmly established.

With regard to effects of first-character frequency in reading three-character compound words, the architecture of CEZR is equipped to account for character frequency effects in reading multiple-character compound words. The model makes predictions about the time course and accuracy of word identification in Chinese sentence reading, including character frequency effects in reading two-character compound words. On the other hand, because the CRM focuses on word segmentation, it can readily model word frequency effects. The segmented word takes precedence in processing, suppressing the activation of the individual characters constituting it. Thus, it does not readily model character frequency effects in reading multiple-character words.

Conclusion

The present study investigated the recognition of three-character Chinese compound words in two experiments. In Experiment 1, the target words were presented in isolation in a lexical decision task, while in Experiment 2 they were embedded in sentence context and the participants were asked to read the sentences for comprehension as their eye movements were registered. The study provided evidence for the dual-route model of compound word processing in that both the decomposition and the holistic route are in operation when reading three-character Chinese compound words. Both experiments established a character frequency effect, which is interpreted to support compositional processing. Evidence for holistic processing was obtained in Experiment 2 from single-fixation trials, where the fixation was positioned in the word centre optimal for simultaneously recognising all three characters comprising the word. On the other hand, evidence for compositional processing was evident in multiple-fixation trials, for which the initial fixation was located toward the word beginning. The landing position results are in line with the flexible target selection and the dynamic adjustment account of saccade programming during Chinese reading. Finally, word-internal structure exerted no effect in Experiment 1, whereas in Experiment 2 an effect was observed in fixation time with A-BC words being read with shorter fixation times than AB-C words. At present, the available evidence for word structure effects in recognising trimorphemic Chinese compound words is mixed with all three possible effects (no effect, AB-C < A-BC, AB-C > A-BC) being observed. Thus, it is left for the future studies to determine, which possibility would hold true.

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References

Abbott, M. J., & Staub, A. (2015). The effect of plausibility on eye movements in reading: Testing E-Z reader's null predictions. *Journal of Memory and Language*, *85*, 76–87. https://doi.org/10.1016/j.jml.2015.07.002

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language*, *59*(4), 390–412. https://doi.org/10.1016/j.jml.2007.12.005

Baayen, R. H., & Schreuder, R. (2000). Towards a psycholinguistic computational model for morphological parsing. *Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences*, *358*(1769), 1281–1293. https://doi.org/10.1098/rsta.2000.0586

Bates, D., Kliegl, R., & Baayen, H. (2015). *Parsimonious mixed models*. arXiv. 1506.

Bertram, R., & Hyönä, J. (2003). The length of a complex word modifies the role of morphological structure: Evidence from eye movements when Reading short and long Finnish compounds. *Journal of Memory and Language*, *48*(3), 615–634. https://doi.org/10.1016/S0749-596X(02)00539-9

Bertram, R., & Hyönä, J. (2013). The role of hyphens at the constituent boundary in compound word identification: Facilitative for long, detrimental for short compound words. *Experimental Psychology*, *60*(3), 157–163. https://doi.org/10.1027/1618-3169/a000183

Bertram, R., Kuperman, V., Baayen, R. H., & Hyönä, J. (2011). The hyphen as a segmentation cue in triconstituent compound processing: It's getting better all the time. *Scandinavian Journal of Psychology*, *52*(6), 530–544. https://doi.org/10.1111/j.1467-9450.2011.00914.x

Brysbaert, M., & Stevens, M. (2018). Power analysis and effect size in mixed effects models: A tutorial. *Journal of Cognition*, *1*(1), 9. https://doi.org/10.5334/joc.10

Butterworth, B. (1983). Lexical representation. In B. Butterworth (Ed.), *Language production II: Development, writing and other language processes* (pp. 257–294). Academic Press.

Cai, Q., & Brysbaert, M. (2010). SUBTLEX-CH: Chinese word and character frequencies based on film subtitles. *PLoS One*, *5*(6), e10729. https://doi.org/10.1371/journal.pone.0010729

Caramazza, A., Laudanna, A., & Romani, C. (1988). Lexical access and inflectional morphology. *Cognition*, *28*(3), 297–332. https://doi.org/10.1016/0010-0277(88)90017-0

Cohen, J. (2013). *Statistical power analysis for the behavioral sciences*. Routledge.

Cui, L., Wang, J., Zhang, Y., Cong, F., Zhang, W., & Hyönä, J. (2021). Compound word frequency modifies the effect of character frequency in reading Chinese. *Quarterly Journal of Experimental Psychology*, *74*(4), 610–633. https://doi.org/10.1177/1747021820973661

Gan, K. W., Palmer, M., & Lua, K. T. (1996). A statistically emergent approach for language processing: Application to modeling context effects in ambiguous Chinese word boundary perception. *Computational Linguistics*, *22*(4), 531–553. https://aclanthology.org/J96-4004/

Huang, B. R., & Liao, X. D. (2006). *Modern Chinese* (Rev. 3rd ed.). Higher Education Press.

Hyönä, J. (2015). Are polymorphemic words processed differently from other words during reading? In A. Pollatsek & R. Treiman (Eds.), *The Oxford handbook of reading* (pp. 114–128). Oxford University Press.

Hyönä, J., & Bertram, R. (2011). Optimal viewing position effects in reading Finnish. *Vision Research*, *51*(11), 1279–1287. https://doi.org/10.1016/j.visres.2011.04.004

Hyönä, J., Cui, L., Heikkilä, T. T., Paranko, B., Gao, Y., & Su, X. (2024). Reading compound words in Finnish and Chinese: An eye-tracking study. *Journal of Memory and Language*, *134*, 104474. https://doi.org/10.1016/j.jml.2023.104474

Hyönä, J., Pollatsek, A., Koski, M., & Olkoniemi, H. (2020). An eye-tracking study of reading long and short novel and lexicalized compound words. *Journal of Eye Movement Research*, *13*(4), 3. https://doi.org/10.16910/jemr.13.4.3

Institute of Language Teaching and Research. (1986). *Modern Chinese frequency dictionary*. Beijing Language Institute Press.

Krott, A., Libben, G., Jarema, G., Dressler, W., Schreuder, R., & Baayen, H. (2004). Probability in the grammar of German and Dutch: Interfixation in triconstituent compounds. *Language and Speech*, *47*(1), 83–106. https://doi.org/10.1177/00238309040470010401

Lexicon of Common Words in Contemporary Chinese Research Team. (2008). *Lexicon of common words in contemporary Chinese*. Commercial Press.

Li, X., Bicknell, K., Liu, P., Wei, W., & Rayner, K. (2014). Reading is fundamentally similar across disparate writing systems: A systematic characterization of how words and characters influence eye movements in Chinese reading. *Journal of Experimental Psychology: General*, *143*(2), 895–913. https://doi.org/10.1037/a0033580

Li, X., Liu, P., & Rayner, K. (2011). Eye movement guidance in Chinese reading: Is there a preferred viewing location? *Vision Research*, *51*(10), 1146–1156. https://doi.org/10.1016/j.visres.2011.03.004

Li, X., & Pollatsek, A. (2020). An integrated model of word processing and eye-movement control during Chinese reading. *Psychological Review*, *127*(6), 1139–1162. https://doi.org/10.1037/rev0000248

Libben, G. (1993). Are morphological structures computed during word recognition? *Journal of Psycholinguistic Research*, *22*(5), 535–544. https://doi.org/10.1007/bf01068253

Libben, G. (2006). Why study compound processing? An overview of the issues. In G. Libben & G. Jarema (Eds.), *The representation and processing of compound words* (pp. 1–20). Oxford University Press.

Liu, Y., Huang, R., Gao, D., & Reichle, E. D. (2017). Further tests of a dynamic-adjustment account of saccade targeting during the reading of Chinese. *Cognitive Science*, *41*(S6), 1264–1287. https://doi.org/10.1111/cogs.12487

Liu, Y., Yu, L., & Reichle, E. D. (2025). Towards a model of eye-movement control in Chinese reading. *Psychonomic Bulletin & Review*, *32*(2), 493–527. https://doi.org/10.3758/s13423-024-02570-9

Luo, X., Sun, M., & Tsou, B. K. (2002). Covering ambiguity resolution in Chinese word segmentation based on contextual information. In *Proceedings of the 19th international conference on computational linguistic* (Vol. 1, pp. 1–7). Association for Computational Linguistics. https://aclanthology.org/C02-1055/

Luo, Y., Tan, D., & Yan, M. (2023). Morphological structure influences saccade generation in Chinese reading. *Reading and Writing*, *36*(5), 1339–1355. https://doi.org/10.1007/s11145-022-10325-y

Ma, G., Li, X., & Rayner, K. (2015). Readers extract character frequency information from nonfixated-target word at long pretarget fixations during Chinese reading. *Journal of Experimental Psychology: Human Perception and Performance*, *41*(5), 1409–1419. https://doi.org/10.1037/xhp0000072

Marchand, H. (1969). *The categories and types of present-day English word-formation* (2nd ed.). C. H. Beck'sche Verlagsbuchhandlung.

Miwa, K., Libben, G., & Ikemoto, Y. (2017). Visual trimorphemic compound recognition in a morphographic script. *Language, Cognition and Neuroscience*, *32*(1), 1–20. https://doi.org/10.1080/23273798.2016.1205204

Morey, R. D., & Rouder, J. N. (2015). *BayesFactor: Computation of Bayes factors for common designs* (Version 0.9.12.2).

http://cran.at.r-project.org/web/packages/BayesFactor/index.html

Nuthmann, A., Engbert, R., & Kliegl, R. (2005). Mislocated fixations during reading and the inverted optimal viewing position effect. *Vision Research*, *45*(17), 2201–2217. https://doi.org/10.1016/j.visres.2005.02.014

Oseki, Y., & Marantz, A. (2020). Modeling human morphological competence. *Frontiers in Psychology*, *11*, 2776. https://doi.org/10.3389/fpsyg.2020.513740

Packard, J. L. (1999). Lexical access in Chinese speech comprehension and production. *Brain and Language*, *68*(1-2), 89–94. https://doi.org/10.1006/brln.1999.2102

Peter, G., Catriona, M., & Phillip, A. (2018). *simr: Power analysis for generalised linear mixed models by simulation* (R Package Version 1.0.4). https://CRAN.R-project.org/package=simr

Pollatsek, A., Hyönä, J., & Bertram, R. (2000). The role of morphological constituents in reading Finnish compound words. *Journal of Experimental Psychology: Human Perception and Performance*, *26*(2), 820–833. https://doi.org/10.1037//0096-1523.26.2.820

Rayner, K., Sereno, S. C., & Raney, G. E. (1996). Eye movement control in reading: A comparison of two types of models. *Journal of Experimental Psychology: Human Perception and Performance*, *22*(5), 1188–1200. https://doi.org/10.1037//0096-1523.22.5.1188

R Core Team. (2021). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing.

Schreuder, R., & Baayen, R. H. (1995). Modeling morphological processing. In L. B. Feldman (Ed.), *Morphological aspects of language processing* (pp. 131–154). Lawrence Erlbaum Associates.

Song, Y., Do, Y., Lee, J., Thompson, A. L., & Waegemaekers, E. R. (2019). The reality of hierarchical morphological structure in multimorphemic words. *Cognition*, *183*, 269–276. https://doi.org/10.1016/j.cognition.2018.10.015

Sui, L., Woumans, E., Duyck, W., Boeve, S., & Dirix, N. (2025). The word and character frequency effect in Chinese natural reading. *Reading and Writing*, *39*(5), 1877–1900. https://doi.org/10.1007/s11145-025-10681-5

Sun, C. C., Hendrix, P., Ma, J. Q., & Baayen, R. H. (2018). Chinese Lexical Database (CLD): A large-scale lexical database for simplified Mandarin Chinese. *Behavior Research Methods*, *50*(6), 2606–2629. https://doi.org/10.3758/s13428-018-1038-3

Taft, M., & Forster, K. I. (1976). Lexical storage and retrieval of polymorphemic and polysyllabic words. *Journal of Verbal Learning and Verbal Behavior*, *15*(6), 607–620. https://doi.org/10.1016/0022-5371(76)90054-2

Taft, M., Huang, J., & Zhu, X. (1994). The influence of character frequency on word recognition responses in Chinese. In H.-W. Chang, J. T. Huang, C.-W. Hue, & O. Tzeng (Eds.), *Advances in the study of Chinese language processing* (pp. 59–73). Department of Psychology, National Taiwan University.

Tsang, Y. K., Huang, J., Lui, M., Xue, M., Chan, Y.-W. F., Wang, S., & Chen, H.-C. (2018). MELD-SCH: A megastudy of lexical decision in simplified Chinese. *Behavior Research Methods*, *50*(5), 1763–1777. https://doi.org/10.3758/s13428-017-0944-0

Vitu, F., McConkie, G. W., Kerr, P., & O'Regan, J. K. (2001). Fixation location effects on fixation durations during Reading: An inverted optimal viewing position effect. *Vision Research*, *41*(25-26), 3513–3533. https://doi.org/10.1016/S0042-6989(01)00166-3

Wagenmakers, E. J., Love, J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Selker, R., Gronau, Q. F., Dropmann, D., Boutin, B., Meerhoff, F., Knight, P., Raj, A., van Kesteren, E.-J., van Doorn, J., Šmíra, M., Epskamp, S., Etz, A., Matzke, D., … Morey, R. D. (2018). Bayesian inference for psychology. Part II: Example applications with JASP. *Psychonomic Bulletin & Review*, *25*(1), 58–76. https://doi.org/10.3758/s13423-017-1323-7

Wang, J., Yang, J., Biemann, C., & Li, X. S. (2023). Mechanism of semantic processing of lexicalized and novel compound words: An eye movement study. *Journal of Experimental Psychology: Learning Memory, and Cognition*, *49*(11), 1812–1822. https://doi.org/10.1037/xlm0001255

Warren, T., White, S. J., & Reichle, E. D. (2009). Investigating the causes of wrap-up effects: Evidence from eye movements and E-Z reader. *Cognition*, *111*(1), 132–137. https://doi.org/10.1016/j.cognition.2008.12.011

Xiong, J., Yu, L., Veldre, A., Reichle, E. D., & Andrews, S. (2023). A multitask comparison of word- and character-frequency effects in Chinese Reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *49*(5), 793–811. https://doi.org/10.1037/xlm0001192

Yan, G., Tian, H., Bai, X., & Rayner, K. (2006). The effect of word and character frequency on the eye movements of Chinese readers. *British Journal of Psychology*, *97*(2), 259–268. https://doi.org/10.1348/000712605X70066

Yan, M., Kliegl, R., Richter, E. M., Nuthmann, A., & Shu, H. (2010). Flexible saccade-target selection in Chinese reading. *Quarterly Journal of Experimental Psychology*, *63*(4), 705–725. https://doi.org/10.1080/17470210903114858

Yan, M., Luo, Y., Xi, J., & Hao, Y. (2025). Parafoveal grouping of characters facilitates encoding of morphological hierarchical structure during sentence reading. *Reading and Writing*, *39*(1), 315–332. https://doi.org/10.1007/s11145-025-10642-y

Yang, A. J. (2005). *A study of trisyllabic words in early modern Chinese*. Wuhan University Press. https://doi.org/10.7666/d.Y391690

Yao, P., Staub, A., & Li, X. (2022). Predictability eliminates neighborhood effects during Chinese sentence reading. *Psychonomic Bulletin & Review*, *29*(1), 243–252. https://doi.org/10.3758/s13423-021-01966-1

Yin, H., Libben, G., & Derwing, B. L. (2022). How the Chinese writing system can reveal the fundamentals of hierarchical lexical structure. *Journal of Cultural Cognitive Science*, *6*(2), 199–218. https://doi.org/10.1007/s41809-022-00108-w

Yu, L., Liu, Y., & Reichle, E. D. (2021). A corpus-based versus experimental examination of word- and character-frequency effects in Chinese reading: Theoretical implications for models of reading. *Journal of Experimental Psychology: General*, *150*(8), 1612–1641. https://doi.org/10.1037/xge0001014

Zang, C. (2019). New perspectives on serialism and parallelism in oculomotor control during reading: The multi-constituent unit hypothesis. *Vision*, *3*(4), 1–13. https://doi.org/10.3390/vision3040050

Zang, C., Liang, F., Bai, X., Yan, G., & Liversedge, S. P. (2013). Interword spacing and landing position effects during Chinese reading in children and adults. *Journal of*

Experimental Psychology: Human Perception and Performance, *39*(3), 720–734. https://doi.org/10.1037/a0030097

Zang, C., Wang, S., Bai, X., Yan, G., & Liversedge, S. P. (2024). Parafoveal processing of Chinese four-character idioms and phrases in reading: Evidence for multi-constituent unit hypothesis. *Journal of Memory and Language*, *136*, 104508. https://doi.org/10.1016/j.jml.2024.104508

Zhang, B., & Peng, D. L. (1992). Decomposed storage in the Chinese lexicon. In H.-C. Chen & O. Tzeng (Eds.), *Language processing in Chinese* (pp. 131–149). North-Holland. https://doi.org/10.1016/S0166-4115(08)61890-7

Zhou, J., & Li, X. (2021). On the segmentation of Chinese incremental words. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *47*(8), 1353–1368. https://doi.org/10.1037/xlm0000984

Zhou, J., Ma, G., Li, X., & Taft, M. (2018). The time course of incremental word processing during Chinese reading. *Reading and Writing*, *31*(3), 607–625. https://doi.org/10.1007/s11145-017-9800-y