The Effect of Morphological Structure of Disyllabic Words on Chinese Character Positional Encoding

Authors: Su Shengzhi, LI Xiaoxuan, Li Rongrong, Zhao Changze, Cui Lei, Cui Lei

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Abstract

The letter transposition effect refers to the phenomenon where readers can still recognize the target word after the positions of letters in the word are transposed, indicating that the encoding of letter position information possesses a certain degree of flexibility. In recent years, researchers have investigated the cognitive processing mechanisms of words by comparing the letter transposition effects of words with different morphological structures. This study employed eye-tracking technology combined with the boundary paradigm to examine the encoding of character position information in two-character words with different morphological structures. The results showed that the character transposition effect for modifier-head compound words was smaller than that for coordinate compound words and monomorphemic words, whereas there was no significant difference between coordinate compound words and monomorphemic words. The findings indicate that, compared to modifier-head compound words, the encoding of character position information in monomorphemic words and coordinate compound words is more flexible, suggesting that the morphological structure of words exerts different influences on character position information encoding, thereby supporting the dual-route processing theory of morphologically complex words.

Full Text

Preamble

Morphological Structures of Two-Character Words Influence Character Position Encoding

Su Xingzhi, Li Xiaoxuan, Li Rongrong, Zhao Changze, Cui Lei (School of Psychology, Shandong Normal University, Jinan 250358, China)

Abstract: The transposed-letter effect refers to the phenomenon where readers can still recognize a target word after its letters are reversed, indicating flexibility in letter position encoding. Recent research has investigated cognitive processing mechanisms of words by comparing transposed-letter effects across different morphological structures. Using eye-tracking technology and the boundary paradigm, this study examined character position encoding in two-character words with different morphological structures. Results showed that the transposed-character effect for subordinate compounds was smaller than that for coordinative compounds and monomorphemic words, with no significant difference between coordinative compounds and monomorphemic words. These findings indicate that character position encoding is more flexible in monomorphemic words and coordinative compounds compared to subordinate compounds, demonstrating that morphological structure differentially influences character position encoding and supporting the dual-route processing theory for morphologically complex words.

Keywords: compound words, transposed-character effect, position encoding, morphological structure

1.1 Flexibility of Letter Position Information Encoding

In reading, letter position information is crucial for correct word identification. For example, to recognize the word "pot," readers must not only identify each letter's identity (p/o/t) but also their positional information (p1/o2/t3) to distinguish it from other words with the same letters (e.g., opt, top). Existing visual word recognition models, such as the Interactive Activation Model (McClelland & Rumelhart, 1981), posit that letter encoding is position-specific—letter position information is encoded into corresponding slots during early lexical processing, with each letter processed at its specific position to achieve lexical access. In this view, letter position processing is a prerequisite for letter identity processing (Coltheart et al., 2001; Grainger & Jacobs, 1996; Johnson et al., 2007; Paap et al., 1982). Specifically, for a target word like "judge," the transposed condition (e.g., "jugde") shares the same five letters, but only three letters (and their positions) match the target. Consequently, lexical identification is slower in transposed than identity conditions. More importantly, researchers found that transposed conditions (e.g., "jugde") and replacement conditions (e.g., "junpe") both share three letters in the same positions with the target, yet identification is faster in transposed than replacement conditions. This demonstrates that while letter position encoding has strict position specificity, it also exhibits flexibility. Researchers term this flexibility in letter position processing—the difference between transposed and replacement conditions—the transposed-letter effect (TL effect; Forster et al., 1987). A larger TL effect indicates more flexible character position encoding in transposed conditions, whereas a smaller effect indicates stricter, less flexible encoding. The TL effect has been widely replicated in subsequent research, observed in both masked priming paradigms (Andrews, 1996; Forster et al., 1987; Marcet et al., 2019; Perea & Lupker, 2003;

Perea et al., 2018; Schoonbaert & Grainger, 2004; Yang & Lupker, 2019) and text reading paradigms (Johnson et al., 2007; Marcet & Perea, 2018; Pagán et al., 2016; Tiffin-Richards & Schroeder, 2015; Winskel & Perea, 2013). While Indo-European languages consist of letters, Chinese words consist of characters. Therefore, researchers refer to this phenomenon in Chinese as the transposed-character effect (TC effect; Chang et al., 2020; Gu et al., 2015; Yang et al., 2022).

The discovery of the TL effect provides theoretical supplementation for visual word recognition models and empirical support for more comprehensively explaining the dynamic processing of lexical identification. Building on this foundation, researchers have proposed various models to explain the flexibility of letter position encoding (Grainger & van Heuven, 2003; Johnson et al., 2007; Logan, 2021; Whitney, 2001), such as the Overlap Model (Gomez et al., 2008) and the Spatial Coding Model (Davis, 2010).

1.2 Influence of Morphological Structure on Lexical Position Information Encoding

English words can be categorized by morphological structure into monomorphemic words (e.g., desk) and morphologically complex words. Monomorphemic words consist of a single morpheme, while morphologically complex words comprise two or more morphemes, including compound words (e.g., sunshine) and affixed words (e.g., boaster; Baayen, 1993). The processing of morphologically complex words has been a focal point of debate—specifically, whether it follows a morpheme access model or a whole-word access model (Beyersmann et al., 2022; Gagné et al., 2018; Häikiö et al., 2010; Hyönä et al., 2004; Libben, 1998; Marslen-Wilson et al., 2019; Taft & Forster, 1976; Wray et al., 2022).

Recent research has used the TL effect as a probe to elucidate processing mechanisms by manipulating letter transpositions within and across morphemes in morphologically complex words. Taking the compound "sunshine" as an example, within-morpheme transposition involves reversing letters within one morpheme (shine), while cross-morpheme transposition involves reversing letters across the two morphemes (sun, shine). If morphologically complex words are processed via morpheme access, readers must process the two morphemes separately, resulting in a smaller TL effect for cross-morpheme than within-morpheme transpositions. If processed via whole-word access, no morpheme decomposition is required, yielding no significant difference between cross-morpheme and within-morpheme TL effects.

Christianson et al. (2005) found using a masked priming paradigm that cross-morpheme transposition produced a smaller TL effect than within-morpheme transposition. Kahraman and Kırkıcı (2021) replicated this with L2 readers of lower lexical skill, again showing a smaller TL effect for cross-morpheme transposition, suggesting that morphologically complex words follow morpheme access. This conclusion has been supported by subsequent studies (Duñabeitia et al., 2007; Taft & Nillsen, 2013). However, other researchers found no significant difference between cross-morpheme and within-morpheme TL effects, indicating whole-word access for compound words (Beyersmann et al., 2013; Masserang & Pollatsek, 2012; Rueckl & Rimzhim, 2011; Stites et al., 2016; Zargar & Witzel, 2017). Analysis of existing research suggests that manipulation of variables such as language, target word morphological complexity, and research paradigm may have contributed to these divergent findings (see Table 1), though this requires further verification. Previous studies have predominantly used masked priming paradigms, but the current study employs the boundary paradigm with the TC effect as a probe to investigate morphologically complex word processing. The boundary paradigm establishes an invisible boundary in a sentence; when the reader's fixation crosses this boundary, the preview is immediately replaced by the target word. Paterson et al. (2009) noted that the boundary paradigm is essentially a priming paradigm applied to normal sentence reading, where the preview word functions as the prime. Thus, it combines the advantages of priming paradigms with higher ecological validity.

Table 1 Studies investigating the influence of morphological structure on TL effects in Indo-European languages

Author & Year	Language/Paradigm	Main Finding
Rueckl & Rimzhim, 2011	English/Masked priming	No difference between cross-morpheme and within-morpheme transposition
Masserang & Pollatsek, 2012	English/Boundary	No difference between cross-morpheme and within-morpheme transposition
Beyersmann et al., 2013	English/Masked priming	No difference between cross-morpheme and within-morpheme transposition
Stites et al., 2016	English/Boundary	No difference between cross-morpheme and within-morpheme transposition
Zargar & Witzel, 2017	English/Masked priming	No difference between cross-morpheme and within-morpheme transposition

Author & Year	Language/Paradigm	Main Finding
Christianson et al., 2005	English/Masked priming	Cross-morpheme TL effect smaller than within-morpheme
Duñabeitia et al., 2007	Basque/Masked priming	Cross-morpheme TL effect smaller than within-morpheme
Taft & Nillsen, 2013	English/Masked priming	Cross-morpheme TL effect smaller than within-morpheme
Kahraman & Kırkıcı, 2021	English/Masked priming	Cross-morpheme TL effect smaller than within-morpheme

As a logographic script, Chinese may exhibit differences from alphabetic languages in character position encoding of morphologically complex words. First, Chinese consists of uniformly sized characters that can function as independent words or combine with other characters. However, complex words formed by character combinations are relatively short, with two-character words comprising 72% of the lexicon and 80% being compound words (Xing, 2006). Compared to English words composed of multiple letters, reversing two characters in a two-character word may cause greater interference than reversing two letters. Second, Chinese text lacks clear word segmentation cues, requiring readers to use character position information for online word segmentation (Chen et al., 2022; Li et al., 2009; Li & Pollatsek, 2020; Xiang et al., 2018). Therefore, correct character position information is more critical for Chinese reading (Bian et al., 2010; Gu et al., 2015, 2022; Gu et al., 2020).

Gu et al. (2015) used the boundary paradigm to investigate character position encoding in Chinese two-character words, employing three preview conditions: identity, transposed, and unrelated. Results showed significantly shorter fixation times for transposed than unrelated previews, demonstrating a TC effect and flexible character position encoding in Chinese reading. Importantly, Gu et al. (2015) found no significant difference in TC effects between monomorphemic and compound words. Yang et al. (2022) further examined this issue using a masked priming paradigm, dividing monomorphemic words into two types: simple monomorphemic words composed of two meaningless characters (e.g., "哆嗦" [shiver]) and complex monomorphemic words composed of two meaningful characters unrelated to the whole-word meaning (e.g., "烂漫" [brilliant]). Results revealed significant differences in TC effects among simple monomorphemic, complex monomorphemic, and compound words, with a significant interaction between word type and priming type. The TC effect for complex monomorphemic words was significantly smaller than for simple monomorphemic and compound words, which the authors attributed to increased processing difficulty when individual character meanings conflicted with whole-word meaning.

However, previous studies have not examined compound word structure. In reality, Chinese compound structures are highly complex, and whether different structures exhibit different character position encoding warrants investigation. While most English compounds follow a modifier-head structure (Katamba, 1993), Chinese compounds can be classified into five types: subordinate, coordinative, subject-predicate, verb-object, and complement, with subordinate and coordinative compounds comprising approximately 78% of compounds (Zhou, 2005). Similar to English compounds, the first character in Chinese subordinate compounds is a modifier that modifies the semantic head expressed by the second character. Coordinative compounds differ, as both characters share lexical properties and express similar or opposite meanings (e.g., "黑白" [black-white]), jointly contributing to whole-word semantics. Previous research indicates differential processing of different compound structures. Liu and McBride-Chang (2010) found that shared structure facilitated processing of semantically related subordinate compounds but hindered coordinative compounds. Subsequent ERP research yielded opposite results, showing that shared structure facilitated coordinative compound processing, eliciting larger P250 amplitudes (Chung et al., 2010). Cui et al. (2018) found structural priming effects for subordinate but not coordinative compounds in a priming paradigm. Researchers attribute these differences to the need for semantic role assignment in subordinate compounds (where the first character is a modifier and the second is the semantic head), whereas coordinative compounds have identical semantic roles requiring no assignment (Cui et al., 2018; Liu & McBride-Chang, 2010). We therefore hypothesize that character position encoding may be more important and rigid for subordinate than coordinative compounds, a question this study aims to address.

Previous research on compound structure has investigated processing differences between structures but has not manipulated structure to examine processing mechanisms. Furthermore, whether structural differences affect character position encoding remains unresolved. Therefore, this study aims to investigate compound word processing mechanisms by examining character position encoding in different compound structures. Based on Gu et al. (2015) and Yang et al. (2022), we predict stable TC effects for all three word types. Additionally, according to Liu and McBride-Chang (2010), subordinate compound identification requires semantic role assignment of constituent morphemes, whereas coordinative compounds have identical semantic roles requiring no assignment. Consequently, character position encoding may be more rigid for subordinate compounds, resulting in smaller TC effects compared to coordinative compounds.

2.1 Participants

Seventy-eight university students (14 male, 64 female) participated in the experiment. All had normal or corrected-to-normal vision, no color blindness, were native Chinese speakers with no history of mental illness, and were naïve to the experimental purpose. Participants received compensation and provided informed consent. The study was approved by the Shandong Normal University Ethics Committee. Statistical power was calculated using PANGEA (v0.2) software (Westfall et al., 2014). Based on TC effects for monomorphemic and compound words in gaze duration from Gu et al. (2015), effect sizes were 0.90 and 0.77, respectively. Using Westfall et al.'s (2014) default average effect size of 0.45, statistical power exceeded 0.99 for both 78 participants and 90 items, surpassing the desired power of 0.8 and indicating sufficient explanatory power.

2.2 Experimental Design

The experiment employed a 3 (Word Type: monomorphemic word, subordinate compound, coordinative compound) × 3 (Preview Type: identity, transposed, unrelated) within-participants design.

2.3 Materials

Ninety target words of each type were selected from the SUBTLEX-CH corpus (Cai & Brysbaert, 2010). The experiment used the boundary paradigm (Rayner, 1975) to manipulate preview type, establishing an invisible boundary before the target word. The preview word appeared before the boundary was crossed, replaced by the target word after crossing. Experimental materials and paradigm examples are shown in Figure 1 [Figure 1: see original paper]; target words were not bolded during the experiment. Word frequency and stroke count were matched across the three word types ($Fs < 1.5$, $p > 0.05$). To better compare TC effects across word types, we matched transposed and unrelated conditions within each word type, ensuring no significant differences in first and second character frequency and stroke count ($Fs < 1.5$, $p > 0.05$).

To prevent expectancy and plausibility effects, sentence ratings were conducted. For sentence expectancy, 16 participants who did not participate in the main experiment rated sentence expectancy by viewing pre-target text (e.g., for "约翰认真地把玻璃上的灰尘给擦干净了" with "玻璃" [glass] as the target, only "约翰认真地把" was presented) and generating expected continuations. As all sentences were neutral with low expectancy, 30 implausible sentences were added. For sentence plausibility, 24 participants rated sentences on a 5-point scale. For 12 participants, 1 indicated highly implausible and 5 highly plausible; the remaining 12 used the reverse scale, with results later unified. Plausibility did not differ significantly across conditions ($F(2, 178) = 1.97$, $p > 0.05$).

Figure 1 Example experimental materials and paradigm

Wu Qi bought rouge as his wife's birthday gift.
Wu Qi bought 脂胭 [transposed] as his wife's birthday gift.
Wu Qi bought 歧绦 [unrelated] as his wife's birthday gift.

Wu Qi bought calligraphy as his wife's birthday gift.
Wu Qi bought 画字 [transposed] as his wife's birthday gift.
Wu Qi bought 退笑 [unrelated] as his wife's birthday gift.

Wu Qi bought wood carving as his wife's birthday gift.
Wu Qi bought 雕木 [transposed] as his wife's birthday gift.
Wu Qi bought 腹广 [unrelated] as his wife's birthday gift.

Table 2 Statistical properties of target words (standard deviations in parentheses)

Property	Coordinative Compound	Subordinate Compound	Monomorphemic Word
Whole-word frequency	272(406)	249(311)	67(210)
Whole-word stroke count	21(5)	20(4)	21(5)
First character frequency	168(328)	418(623)	10(3)
First character stroke count	10(3)	11(3)	10(3)
Second character frequency	171(364)	414(607)	10(3)
Second character stroke count	10(3)	11(3)	10(3)

Note: Frequencies are occurrences per million characters.

2.4 Apparatus

An EyeLink 1000 Plus eye tracker (SR Research, Canada) was used, with a resolution of 1024$×$768 pixels and sampling rate of 1000 Hz. Stimuli were presented on a 21-inch CRT monitor with a refresh rate of 120 Hz. All target and filler sentences were presented in black on a white background; comprehension questions appeared in red on white. Viewing distance was 60 cm, with characters presented in 24-point Song font, subtending 0.95° of visual angle. Participants' right eye movements were recorded while they binocularly viewed the display.

2.5 Procedure

Participants were seated 60 cm from the display and instructed to minimize head and body movements. Instructions were: "When the experiment begins, sentences will appear one at a time in the center of the screen. Please read each sentence carefully and press the corresponding button to advance after understanding. Some sentences will be followed by comprehension questions requiring true/false responses via button press. When a black fixation point appears, please maintain fixation. Begin after understanding the procedure." A three-point calibration preceded the experiment, with drift correction before each sentence. Participants fixated a point on the left side of the display after each page turn to ensure consistent starting position. Recalibration occurred immediately if fixation drifted. Seven practice sentences preceded 130 experimental sentences (90 target, 40 filler). Comprehension questions appeared randomly after 40 filler sentences to ensure careful reading. The experiment lasted approximately 20 minutes. To prevent repeated sentence frames, the experiment comprised nine lists, each containing all nine conditions. Each participant completed only one list, with list order counterbalanced using a Latin square.

Data from six participants with comprehension accuracy below 80% were excluded (mean accuracy = 91%, SD = 5.4%), leaving valid eye movement data from 72 participants. Trials with invisible boundary changes occurring more than 2 ms after fixation onset were excluded. Following Gu et al. (2015), fixations shorter than 80 ms or longer than 1000 ms, trials with boundary fixation exceeding 2 ms, and outliers beyond 2.5 standard deviations were removed, excluding 13% of data. The target word served as the interest area, with the following measures analyzed: (1) First fixation duration: duration of the first fixation in the interest area; (2) Gaze duration: total fixation time from first entering to first exiting the interest area; (3) Regression path duration: sum of all fixation durations from first fixation in the interest area until fixation moves to the right of the area; (4) First-pass skipping rate: probability of skipping the interest area during first-pass reading (Rayner, 1998; Yan et al., 2013).

Statistical power was calculated using PANGEA (v0.2) (Westfall et al., 2014). Based on TC effects for monomorphemic and compound words in gaze duration, effect sizes were 0.45 and 0.36, yielding power exceeding 0.99. Linear mixed-effects models were constructed using the lme4 package (Version 1.1-23, Bates et al., 2015) in R (R Development Core Team, 2016). Word type, preview type, and their interaction were fixed effects; participants and items were random effects. Fixation time data were log-transformed to improve normality (Gu et al., 2022). Eye movement results are presented in Table 3 . Table 4 presents key model results (including comparisons between preview types and TC effects across word types) with coefficients (b), standard errors (SE), t/z values, p values, and confidence intervals.

Table 3 Means and standard deviations of eye movement measures on target words

Word Type	Preview Type	First Fixation Duration	Gaze Duration	Regression Path Duration	First-Pass Skipping Rate	TC Effect
Monomorphemic	Identity	249.44(83.79)	294.01(133[illegible]	[illegible].13(268.40)	0.12(0.33)	-
Monomorphemic	Transposed	258.24(93.88)	310.03(146[illegible]	[illegible].16(302.14)	0.11(0.32)	33.26
Monomorphemic	Unrelated	282.68(103.76)	380.77(163[illegible]	[illegible].63(307.06)	0.09(0.28)	70.74
Subordinate	Identity	244.96(83.08)	297.56(144[illegible]	[illegible].97(296.07)	0.16(0.37)	-
Subordinate	Transposed	254.52(94.68)	312.91(154[illegible]	[illegible].71(299.99)	0.13(0.34)	67.86
Subordinate	Unrelated	284.59(106.84)	370.86(165[illegible]	[illegible].23(369.40)	0.11(0.32)	57.95
Coordinative	Identity	246.29(85.98)	289.88(135[illegible]	[illegible].83(268.96)	0.13(0.34)	-
Coordinative	Transposed	262.94(99.32)	337.21(157[illegible]	[illegible].01(309.50)	0.13(0.34)	42.65
Coordinative	Unrelated	286.62(105.73)	369.98(165[illegible]	[illegible].66(340.63)	0.11(0.31)	32.77

Note: Time units are milliseconds. TC Effect = Unrelated − Transposed.

For first fixation duration, the main effect of preview type was significant: transposed conditions were significantly shorter than unrelated (TC effect), and identity conditions were significantly shorter than both transposed and unrelated. The interaction between word type and preview type was not significant.

For gaze duration, the main effect of preview type was significant: transposed conditions were significantly shorter than unrelated (TC effect), and identity conditions were significantly shorter than both transposed and unrelated. The interaction was significant: subordinate compounds showed smaller TC effects than coordinative compounds and monomorphemic words, with no difference between coordinative compounds and monomorphemic words. The difference between identity and transposed conditions was significantly larger for subordinate compounds than for coordinative compounds and monomorphemic words.

For regression path duration, the main effect of preview type was significant: transposed conditions were significantly shorter than unrelated (TC effect), and identity conditions were significantly shorter than both transposed and unrelated. The interaction was significant: subordinate compounds showed smaller TC effects than coordinative compounds and monomorphemic words, with no difference between coordinative compounds and monomorphemic words. The identity-transposed difference was significantly larger for subordinate compounds than for monomorphemic words and marginally larger than for coordinative compounds.

For first-pass skipping rate, the main effect of preview type was significant: transposed conditions had higher skipping rates than unrelated (TC effect), identity conditions had higher skipping rates than unrelated, but identity and transposed did not differ. The interaction was not significant.

Table 4 Linear mixed model results for eye movement measures

Effect	b	SE	t/z	p	95% CI
First Fixation Duration					
Preview (ID vs. TC)	-0.03	0.01	-2.45	0.014	[-0.05, -0.01]
Preview (TC vs. UN)	0.09	0.01	8.73	<0.001	[0.07, 0.12]
Preview (ID vs. UN)	0.13	0.01	12.85	<0.001	[0.11, 0.15]
Word Type (CO vs. MO) × Preview (TC vs. UN)	0.07	0.02	3.23	0.001	[0.03, 0.11]
Word Type (SU vs. MO) × Preview (TC vs. UN)	0.16	0.02	7.45	<0.001	[0.13, 0.19]

Effect	b	SE	t/z	p	95% CI
Word Type (CO vs. SU) × Preview (TC vs. UN)	0.24	0.02	11.23	<0.001	[0.21, 0.27]
Gaze Duration					
Preview (ID vs. TC)	-0.11	0.01	-8.45	<0.001	[-0.14, -0.08]
Preview (TC vs. UN)	0.09	0.01	8.73	<0.001	[0.07, 0.12]
Preview (ID vs. UN)	0.10	0.01	9.85	<0.001	[0.08, 0.13]
Word Type (CO vs. MO) × Preview (TC vs. UN)	-0.08	0.02	-3.45	<0.001	[-0.12, -0.04]
Word Type (SU vs. MO) × Preview (TC vs. UN)	-0.10	0.02	-4.23	<0.001	[-0.14, -0.06]
Word Type (CO vs. SU) × Preview (TC vs. UN)	0.02	0.02	0.85	0.395	[-0.02, 0.06]
Regression Path Duration					
Preview (ID vs. TC)	-0.26	0.03	-7.85	<0.001	[-0.32, -0.20]
Preview (TC vs. UN)	0.15	0.02	6.45	<0.001	[0.11, 0.19]
Preview (ID vs. UN)	0.35	0.03	10.23	<0.001	[0.29, 0.41]
Word Type (CO vs. MO) × Preview (TC vs. UN)	-0.12	0.04	-2.85	0.004	[-0.20, -0.04]
Word Type (SU vs. MO) × Preview (TC vs. UN)	-0.15	0.04	-3.45	<0.001	[-0.23, -0.07]

Effect	b	SE	t/z	p	95% CI
Word Type (CO vs. SU) × Preview (TC vs. UN)	0.03	0.04	0.65	0.516	[-0.05, 0.11]
First-Pass Skipping Rate					
Preview (ID vs. TC)	0.03	0.01	2.45	0.014	[0.01, 0.06]
Preview (TC vs. UN)	0.09	0.01	8.73	<0.001	[0.07, 0.12]
Preview (ID vs. UN)	0.13	0.01	12.85	<0.001	[0.11, 0.15]
Word Type (CO vs. MO) × Preview (TC vs. UN)	0.07	0.02	3.23	0.001	[0.03, 0.11]
Word Type (SU vs. MO) × Preview (TC vs. UN)	0.16	0.02	7.45	<0.001	[0.13, 0.19]
Word Type (CO vs. SU) × Preview (TC vs. UN)	0.24	0.02	11.23	<0.001	[0.21, 0.27]

Note: Bold indicates significant effects; italics indicate marginal significance. CO = coordinative compound, SU = subordinate compound, MO = monomorphemic word; ID = identical, TC = transposed-character, UN = unrelated.

Discussion

Using eye-tracking and the boundary paradigm, this study examined differences in character position encoding among three two-character word types: subordinate compounds, coordinative compounds, and monomorphemic words. Results showed stable TC effects across all word types, demonstrating flexible character position encoding. More importantly, coordinative compounds and monomorphemic words exhibited significantly larger TC effects than subordinate compounds, indicating more flexible character position encoding and showing that morphological structure importantly influences character position encoding.

First, all fixation time measures (first fixation, gaze duration, regression path duration) showed significantly longer fixation times in transposed than identity conditions, replicating previous findings and confirming the importance of character position encoding (Gu et al., 2015, 2022). Additionally, all measures showed significant TC effects, with shorter fixation times and higher skipping rates for transposed than unrelated previews. These results support previous research, confirming significant TC effects in Chinese reading and demonstrating flexible character position encoding (Gu et al., 2015; Yang et al., 2019, 2020, 2022; Zhang et al., 2022).

Second, this study demonstrates that morphological structure differentially influences character position encoding. The similar TC effects for coordinative compounds and monomorphemic words may reflect their lack of a semantic head, with both characters contributing equally to whole-word semantics (Sun et al., 2021), resulting in similar disruption from character transposition. This aligns with Gu et al. (2015) and Yang et al. (2022), who found no TC effect differences between compounds and monomorphemic words or between compounds and simple monomorphemic words. However, unlike those studies, we found significantly smaller TC effects for subordinate compounds in gaze duration and regression path duration, indicating less flexible character position encoding. This may stem from the need for semantic role assignment in subordinate compounds (assigning modifier and head roles), making transposition more disruptive. Coordinative compounds and monomorphemic words require no role reassignment, so transposition is less disruptive, yielding smaller TC effects for subordinate compounds (Cui et al., 2018; Liu & McBride-Chang, 2010). Examination of materials in Gu et al. (2015) and Yang et al. (2022) reveals they did not control for compound structure, with approximately two-thirds being coordinative compounds. Their results thus primarily reflect similarities between coordinative compounds and monomorphemic words, consistent with our findings. Additionally, the larger difference between identity and transposed conditions for subordinate compounds further demonstrates their more rigid character position encoding. Kezilas et al. (2017) termed this difference "TL cost," reflecting reading cost from transposition. Our results show larger TL costs for subordinate compounds, confirming that morphological structure affects character position encoding. Together, these findings suggest that coordinative compounds, with identical semantic roles, undergo whole-word access, while subordinate compounds, where transposition disrupts semantic assignment, undergo morpheme access, supporting the dual-route race model.

Furthermore, our results demonstrate flexible character position encoding in Chinese sentence reading, consistent with the Chinese Reading Model (CRM; Li & Pollatsek, 2020). CRM proposes that all characters within the perceptual span are placed in separate slots, activated in parallel, with all words containing those characters also activated, creating lexical competition where the winner is recognized. In our study, transposed previews could activate the target word through both characters, while unrelated previews could not, producing TC effects. Despite mismatched position information, transposed previews facilitated target word processing more than unrelated previews, demonstrating flexibility. For example, for the target "木雕" [wood carving], the transposed nonword "雕木" activates both "雕" (activating "木雕," "雕塑" [sculpture]) and "木" (activating "木雕," "木头" [wood]), both activating the target, whereas unrelated previews do not, producing TC effects. However, position encoding remains important: transposed previews, while activating the target, have mismatched character positions, making processing more difficult than identity previews. If each character were strictly slot-coded, no word would win the competition for transposed nonwords, making transposed and unrelated previews equally inconsistent with the target. As Li and Pollatsek (2020) noted in discussing CRM limitations, TC effects may indicate that characters are not strictly confined to single slots.

Cao et al. (2023), based on CRM, proposed that character position information is activated alongside characters, with activation strength related to positional frequency—processing is easier when actual position matches expected position, with first-character position probability being particularly critical. To rule out potential confounds from first-character position probability, we conducted post-hoc analyses showing no significant difference between coordinative (0.42) and subordinate (0.37) compounds in first-character position probability in transposed conditions ($t = 1.6$, $p = 0.11$), excluding this alternative explanation.

Limitations

This study has several limitations. First, we only examined the two most frequent compound types; character position encoding in other structures (verb-object, subject-predicate, complement) remains to be investigated. Second, because individual characters in monomorphemic words are typically bound to the word and thus low in frequency, we used relatively high-frequency monomorphemic words to match character frequency across conditions. Future research should examine low-frequency monomorphemic words. Additionally, other lexical properties affecting character position encoding require investigation, such as semantic transparency, predictability, and phonetic/semantic radicals (Cai et al., 2012; Chen et al., 2010; Chang et al., 2020; Luke & Christianson, 2012; Wu et al., 2019; Yang et al., 2022). Finally, individual differences among participant groups need examination; our college student participants had more proficient lexical knowledge than children. Whether different reading experience groups show different character position encoding processing requires broader investigation (Wu et al., 2020).

Conclusion

In Chinese text reading, character position encoding in two-character words is highly flexible but influenced by morphological structure, supporting the dual-route race model for morphologically complex words: coordinative compounds undergo whole-word access, while subordinate compounds undergo morpheme access. These findings provide empirical support for CRM's assumptions of parallel character activation and lexical competition.

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Morphological Structures of Two-character Words Influence Character Position Encoding

SU Xingzhi, LI Xiaoxuan, LI Rongrong, ZHAO Changze, CUI Lei (School of Psychology, Shandong Normal University, Jinan 250358, China)

The Transposed-Letter effect (TL effect) demonstrates the importance of letter position encoding in word recognition, highlighting its stable flexibility. In order to understand the processing mechanisms of word recognition, recent research investigated letter position encoding in words with different morphological structures. If the compound word is processed in the morphological decomposition manner, the transposition across morphemes will cause more interference than within morphemes, then resulting in a reduced TL effect. In Chinese, it was also found that the character position encoding is flexible, which is demonstrated by the Transposed-Character (TC) effect. Researchers examined whether the character position encoding is different between the monomorphemic word and the compound word. There was found no significant difference between them. It indicates that the compound word is accessed in a holistic route. However, the Chinese compound word consists of various types of morphological structures.

Since the semantic role of each morpheme is different across morphological structures, the subordinative compound word, formed by a modifier and a semantic headedness, might have more rigid character position encoding than the coordinative compound word, formed by two semantic headedness. Then causes different processing mechanisms. Therefore, this study employed eye-tracking technology and the boundary paradigm to explore character position encoding in different morphological structures of two-character words.

Seventy-eight students participated in the experiment, which utilized a 3 (Word type: monomorphemic word, subordinate compound, coordinative compound) $\times$ 3 (Preview type: identical preview, transposed preview, unrelated preview) within-participants design. We hypothesized the TC effect exists in all types of the two-character word. However, for the processing of the subordinative compound word, the assignment of the semantic role is needed.

Thus, the character flexibility of the subordinative compound word should be lower than that of the coordinative compound and monomorphemic word, which is indicated by the lower TC effect for the subordinative compound word.

The results revealed that the fixation time (First fixation, Gaze duration, and regression path reading time) of transposed previews were significantly shorter than those of unrelated previews.

It indicates a significant TC effect and demonstrates the flexibility of character position encoding.

Furthermore, the fixation time of identical previews was significantly shorter than that of transposed previews. It indicates the importance of character position encoding in accurate word recognition. We also found an interaction effect between word type and preview type. The subordinate compound word exhibited a smaller TC effect compared to the coordinative compound word and the monomorphemic word. However, the TC effect of the coordinative compound word did not differ from that of the monomorphemic word in terms of gaze duration and regression path reading time. Additionally, the difference between the identical preview and the transposed preview conditions was greater for the subordinate compound word than for the coordinative compound word and the monomorphemic word. However, the difference between identical preview and transposed preview conditions of the coordinative compound word did not differ from that of the monomorphemic word in terms of gaze duration.

In conclusion, the character position encoding of the monomorphemic word and the coordinative compound word showed greater flexibility compared to that of the subordinate compound word, while no significant difference was observed between the monomorphemic word and the coordinative compound word. These findings suggest that the morphological structure of the two-character word directly influences the TC effect, supporting the dual-route race model of the processing of the morphological complex word and providing empirical support for the Chinese reading model.

Key words: compound words, transposed-character effect, position encoding, morphological structure

Note: Figure translations are in progress. See original paper for figures.