A transposed-word effect in Chinese reading

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Abstract

Studies using a grammaticality decision task suggest surprising flexibility in the processing of the relative order of words in sentences when reading alphabetic scripts like French. In these studies, participants made rapid grammaticality decisions for ungrammatical stimuli created by transposing two adjacent words in either a grammatical or an ungrammatical base sentence, which were intermixed with equal numbers of grammatically correct stimuli. The key finding was that participants made more errors and were slower to reject transposed-word stimuli created from grammatical than ungrammatical base sentences. This suggested that flexibility in the processing of word order allowed participants to access representations of the base grammatical sentences, interfering with their decisions to correctly reject transposed-word stimuli. With the present research, we investigated if a similar transposed-word effect is observed for a non-alphabetic script (Chinese) that uses few grammatical markers and primarily conveys grammatical structure via word order. Such scripts may require stricter processing of word order during reading and so provide a strong test of the cross-linguistic generality of the transposed-word effect. We report three experiments using the same design and procedure as previous research, while varying the length of the transposed words across experiments. In all three experiments, participants made more errors and were slower to reject transposed-word stimuli derived from grammatical than ungrammatical base sentences. This replicates previous findings with alphabetic scripts and provides novel evidence for a transposed-word effect in Chinese reading. We consider the implications for models of reading in alphabetic and non-alphabetic scripts.

Keywords Transposed-word effect · Grammaticality decision task · Chinese reading

Introduction

Recent research using a speeded grammaticality decision task has revealed a novel transposed-word effect whereby word order appears not to be processed strictly in sentence reading (Mirault et al., 2018; Snell & Grainger, 2019a; see also Grainger, 2018). The reported experiments focused on ungrammatical word strings created by transposing two adjacent words in either a grammatical base sentence (e.g., “The white

cat was big” became “The white was cat big”, with solid and wavy underlines highlighting the transposed words) or an ungrammatical base sentence (e.g., “The white cat was slowly” became “The white was cat slowly”). Participants had to make decisions as quickly as possible for these ungrammatical transposed-word stimuli, which were intermixed with equal numbers of grammatical stimuli of similar construction. The findings showed that participants took longer and made more errors rejecting transposed-word stimuli derived from grammatical than ungrammatical base sentences. This suggested that flexibility in the processing of word order enabled participants to access mental representations of the base grammatical sentences, which interfered with their decisions to correctly categorize transposed-word stimuli as ungrammatical.

Such findings are resonant with other evidence showing flexibility in the encoding of letter position information in words (e.g., Andrews, 1996; Chambers, 1979). For instance, research using the lexical decision (i.e., word/nonword) task shows that participants find it harder to reject pseudowords created by transposing two adjacent letters in a real word (i.e., “gadren” from “garden”) than replacing these letters (e.g.,

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“gatsen”). This is taken as evidence that the relative position of letters in words is not always strictly encoded during word recognition. As a result, participants often misread a transposed-letter pseudoword as a real word, interfering with its categorization as a nonword. Such effects have been central to the development of current computational models of visual word recognition, which incorporate a degree of uncertainty (e.g., Gomez, Ratcliff, & Perea, 2008) or flexibility (e.g., Davis, 2010; Grainger & van Heuven, 2003; Whitney, 2001) in letter-position encoding.

This raises the possibility of similar flexibility in the sentence-level positional encoding of words. This would be contrary to theories of syntactic processing that assume that the order in which words are input into the parser is fixed (e.g., Frazier & Fodor, 1978). Substantial evidence nevertheless shows that readers use context and world knowledge to “correct” ungrammatical or implausible input (e.g., Gibson et al., 2013; Sanford & Sturt, 2002). For instance, numerous studies report that readers will often misinterpret passive sentences of the form “The dog was bitten by the man” in terms of a more plausible but syntactically incorrect meaning (e.g., the dog did the biting; see Ferreira, 2001). Such findings are taken to show that structural (i.e., word order) information is underspecified or encoded with a degree of uncertainty (e.g., Ferreira et al., 2002; Sanford & Sturt, 2002), while noisy channel theories of syntactic processing postulate that the parser might edit or reorder elements of the input to achieve a plausible interpretation of its meaning (e.g., Gibson et al., 2013).

A recent computation model of reading (the OB1 reader; e.g., Snell et al., 2018; see also Grainger, 2018; Snell & Grainger, 2019b) is purposely equipped with mechanisms that permit flexibility in word-order processing. Firstly, the model incorporates the assumption that word identities are processed in parallel within a region around each fixation, roughly equivalent to the perceptual span (see, e.g., Rayner, 2009). This assumption is shared by other parallel processing models (e.g., SWIFT, Engbert et al., 2005; and Glenmore, Reilly & Radach, 2006), but is contrary to the serial, word-by-word processing of linguistic input assumed by the E-Z Reader model (e.g., Reichle et al., 1998, 2003, Reichle et al., 2009b). Advocates of serial accounts argue that activation of multiple words during parallel processing limits the system’s ability to keep track of word order (Reichle et al., 2009a; White et al., 2019). However, with OB1, such difficulty is considered inherent to reading (as evidenced by the transposed-word effect). Moreover, it is further assumed that an additional component (a spatiotopic short-term memory representation encoding cues to the length and location of words) is required to compute word order, by associating location-independent lexical activations with sentence-level word locations (Snell & Grainger, 2019b). Incorporating a degree of uncertainty in this mapping between words and their sentence-level locations also allows for top-down syntactic

and semantic constraints to influence word-order processing, such that expectation-driven processes may “correct” word order so that ungrammatical sentences can be assigned a plausible interpretation. This mechanism can therefore account for the transposed-word effect. However, parallel processing may not be necessary to produce such an effect and a version of E-Z Reader designed to account for post-lexical language processing effects on eye movements (Reichle et al., 2009b) might, in principle, be modified to achieve similar effects (see Huang & Staub, 2020).

With the present research, we considered the cross-linguistic generality of the transposed-word effect by examining whether a similar effect is observed for a non-alphabetic script (Chinese) that uses few grammatical markers and primarily conveys grammatical structure via word order. Text in Chinese is composed of a series of equal-sized, box-like logograms called characters. Many of these function as a word on their own, but they more commonly combine with (one or more) adjacent characters to produce multi-morphemic word units, although words in sentences are not separated using spaces or other visual cues (see Li et al., 2015). Crucially, words also lack inflections that specify grammatical information, while the language makes limited use of grammatical markers, so that word order plays a pivotal role in specifying syntactic structure (e.g., Chang, 1992). Given the central importance of word order in this script, we considered that investigations in Chinese would provide a particularly strong test of the generality the transposed-word effect (and see Snell & Grainger, 2019b, for similar arguments advocating an investigation of the transposed-word effect in Chinese to assess its cross-linguistic generality).

Accordingly, we conducted three experiments using Chinese stimuli and the same design, method, and procedure as previous research (Mirault et al., 2018). All three experiments used ungrammatical character strings derived either from a grammatical or an ungrammatical base sentence by transposition of two adjacent words, intermingled with equal numbers of grammatical character strings of similar construction (see Table 1 for example stimuli). Following Mirault et al., we tested for a transposed-word effect by assessing grammaticality decisions for these stimuli, following the logic that participants should make more errors and be slower to reject transposed-word stimuli created from grammatical than ungrammatical base sentences if word order is processed flexibly. We additionally varied the length of the transposed words across experiments. Experiment 1 examined the simplest case, where two one-character words were transposed, whereas Experiment 2 examined whether transposed-word effects might be observed for a multi-morphemic word by transposing two two-character words in each stimulus. Finally, Experiment 3 investigated this further by transposing a one-character word with a three-character word in each stimulus.

Table 1 Example stimuli in Experiments 1, 2, and 3

	Base Sentence	Base Sentence in English	Transposed-Word Sentence
Experiment 1			
Grammatical	她昨天 <u>接我</u> 放学	Yesterday she picked me up after school	她昨天 <u>我接</u> 放学
	她 <u>就是</u> 不 <u>听</u> 劝告	She just didn't listen to the advice	她 <u>就是</u> 不 <u>听</u> 劝告
Ungrammatical	他昨天 <u>接我</u> 劝告	Yesterday she picked me up the advice	她昨天 <u>我接</u> 劝告
	她 <u>就是</u> 不 <u>听</u> 放学	She just didn't listen to after school	她 <u>就是</u> 不 <u>听</u> 放学
Experiment 2			
Grammatical	她在 <u>山止</u> 看见云	On the mountain she saw the clouds	她在 <u>看见</u> <u>山止</u> 云
	她叫 <u>宝宝</u> 不要哭	She told the baby not to cry	她叫 <u>不要</u> <u>宝宝</u> 哭
Ungrammatical	她在 <u>山上</u> 看见哭	On the mountain she saw cry	她在 <u>看见</u> <u>山上</u> 哭
	她叫 <u>宝宝</u> 不要云	She told the baby not to the clouds	她叫 <u>不要</u> <u>宝宝</u> 云
Experiment 3			
Grammatical	他用 <u>探测器</u> 寻宝	He used a detector to hunt for treasure	他用 <u>寻</u> <u>探测器</u> 宝
	他家 <u>看上去</u> 很穷	His family looks very poor	他家 <u>很</u> <u>看上去</u> 穷
Ungrammatical	他用 <u>探测器</u> 寻穷	He used a detector to hunt for poor	他用 <u>寻</u> <u>探测器</u> 穷
	他家 <u>看上去</u> 很宝	His family looks very treasure	他家 <u>很</u> <u>看上去</u> 宝

The table shows examples of grammatical and ungrammatical base sentences and the corresponding ungrammatical transposed-word stimuli created for each experiment. Ungrammatical base sentences were created by swapping the sentence-final words across pairs of grammatical base sentences (where one contained an adjective and the other an adverb in this sentence-final position). Words in the base sentences that were transposed to create the transposed-word stimuli are shown using solid and wavy underlines, although stimuli were shown without any underlining in the experiments. Only grammatically correct sentences and the experimental and control transposed-word stimuli were presented as stimuli in each experiment

Method

The study was approved by the research ethics committee in the Academy of Psychology and Behavior at Tianjin Normal University and conducted in accordance with the principles of the Declaration of Helsinki.

Participants

In total, 195 undergraduate students from Tianjin Normal University, aged 18–26 years ($M = 21.7$ years, $SD = 2.1$), took part (63 in Experiment 1, 54 females; 69 in Experiment 2, 58 females; 63 in Experiment 3, 56 females). All were native Chinese readers with normal or corrected-to-normal vision and were paid a small amount (10 yuan) for participating.

Stimuli and design

Stimuli were constructed following the same procedure as Mirault et al. (2018). Each experiment used 160 five-word strings as stimuli. Of these, 40 were experimental stimuli created by transposing the third and fourth words in a grammatically correct base sentence to create an ungrammatical string (TW sentences), and 40 were control stimuli created by transposing these words in an ungrammatical base sentence to create an ungrammatical string (ungrammatical sentences). In generating these transposed-word stimuli, care was taken to avoid characters in a transposed word combining with adjacent characters to create a multi-morphemic word. For the purpose of the grammaticality decision task, these ungrammatical sentences were intermixed with an equal number of grammatically correct sentences in each experiment (grammatical sentences). The

Table 2 Mean error rates and response times for correct responses for Experiments 1, 2, and 3

	Experiment 1				Experiment 2				Experiment 3			
	TW	Ungrammatical control	Grammatical		TW	Ungrammatical control	Grammatical		TW	Ungrammatical control	Grammatical	
Error rate (%)	27 (.9)	7 (.5)	3 (.2)		25 (.8)	4 (.4)	3 (.2)		22 (.8)	6 (.5)	4 (.3)	
RTs (ms)	1,649 (14)	1,527 (13)	1,368 (8)		1,646 (13)	1,428 (12)	1,310 (8)		1,457 (12)	1,314 (11)	1,217 (7)	

Note. The standard error of the mean is shown in parentheses. TW refers to the transposed-word sentences derived from a grammatical base sentence, ungrammatical control refers to the transposed-word sentences derived from an ungrammatical base sentence, and grammatical refers to the grammatical sentences included in the grammaticality decision task

grammatical sentences were constructed to have the same structure as the grammatically correct base sequences. Table 1 shows example stimuli, illustrating how matched pairs of grammatical and ungrammatical base sentences (differing only in their final words) were used to create experimental and control transposed-word stimuli for each experiment.

Three groups (50 per experiment) of native Chinese readers (undergraduates from Tianjin Normal University who did not take part in the experiments) evaluated the stimuli, judging all the grammatical stimuli to be grammatically correct and all the transposed-word stimuli to be grammatically incorrect. Following Mirault et al. (2018), stimuli were allocated to different presentation lists using a Latin-square design, so that each participant viewed only one (TW or ungrammatical) version of each transposed-word stimulus, but each transposed-word stimulus was viewed equally often across the participant group in each experiment. All participants viewed all the grammatically correct stimuli. For each participant, the experiment began with 14 practice trials using stimuli of similar construction to the experimental trials (50% grammatically correct, 50% ungrammatically incorrect), followed by the 160 experimental trials presented in random order.

Apparatus and procedure

Stimuli were presented using E-Prime (Version 2.0.10; Psychology Software Tools, Pittsburgh, PA, USA) and displayed on a 14-in. LCD screen in 30-pt Song font as black text on a white background. At 60-cm viewing distance, each character subtended approximately 1° of horizontal visual angle and so was of normal size for reading. Responses were recorded via a keyboard connected to the computer, using the ‘F’ key for grammatical decisions and ‘J’ key for ungrammatical decisions.

The procedure was explained to each participant at the start of the experiment. Participants were instructed to use keyboard responses to indicate as quickly and as accurately as possible whether each stimulus was grammatically correct. The display and data acquisition procedures were the same as in Mirault et al. (2018). On each trial, a fixation cross was displayed at screen center for a random duration ranging between 500 and 700 ms, followed by presentation of a stimulus centered on the screen. This remained on the screen until a response was made. Following this, a feedback dot was presented for 700 ms, in green if the response was correct or in red if it was incorrect. The experiment lasted approximately 15 min for each participant.

Results

Response accuracy and latency of correct responses were analyzed for each experiment (see Table 2). Average response

accuracy was high across experiments (Experiment 1, $M = 90.1\%$, $SD = 5.9$; Experiment 2, $M = 91.1\%$, $SD = 4.58$; Experiment 3, $M = 91.1\%$, $SD = 5.89$). Latencies of responses more than 2.5 SDs from each experiment's grand mean were deleted (Experiment 1 = 2.9%, Experiment 2 = 2.9%, Experiment 3 = 2.7%).

Data were analyzed using the lme4 package (Bates et al., 2015) in R (Development Core, 2016). A generalized linear mixed-effects (GLME) model was used to analyze accuracy and a linear mixed-effects (LME) model was used to analyze response times, with participants and stimuli as crossed random effects (Baayen et al., 2008), and the ungrammatical control condition used as the reference. Results for log-transformed response times are reported although untransformed analyses produced the same pattern of effects. Following convention, t or z values greater than 1.96 were considered statistically significant.

Error rates Error rates were lower for the ungrammatical control stimuli than for the TW stimuli across all three experiments (Experiment 1, $b = 1.99$, $SE = 0.18$, $z = 10.84$; Experiment 2, $b = 2.59$, $SE = 0.23$, $z = 11.37$; Experiment 3, $b = 1.78$, $SE = 0.18$, $z = 10.03$).

Latencies for correct responses Response latencies were faster for the ungrammatical control stimuli than for the TW stimuli across all three experiments (Experiment 1, $b = 0.08$, $SE = 0.02$, $t = 4.08$; Experiment 2, $b = 0.15$, $SE = 0.02$, $t = 7.18$; Experiment 3, $b = 0.10$, $SE = 0.02$, $t = 5.04$).

Discussion

The present research provides novel evidence for a transposed-word effect in Chinese reading. This effect was essentially the same as that reported previously for alphabetic languages (Mirault et al., 2018; see also Snell & Grainger, 2019a). Accordingly, as in this previous research, we found that participants in a speeded grammaticality decision task made more errors and were slower to make correct responses for ungrammatical strings created by transposing two adjacent words in a grammatical rather than an ungrammatical base sentence. Such findings are important as they suggest that flexibility in the processing of word order enabled participants to access the base grammatical representation of a transposed-word stimulus, interfering with their categorization of this stimulus as an ungrammatical string. Additionally, across the three experiments, we showed that this pattern of effects was observed regardless of whether the transposed words were mono-morphemic (i.e., single-character) or multi-morphemic (i.e., multi-character). The effect was nevertheless larger in Experiment 2, which transposed pairs of two-character words. Why this difference occurred is unclear, but may reflect

differences in word frequency, as single-character words (used in both Experiment 1 and Experiment 3) typically have very high lexical frequencies, and so may be more easily processed in reading even when transposed. Moreover, while the reaction times we obtained for transposed word stimuli were similar to those reported by Mirault et al., the error rates were higher. This may be attributable to participant-group differences across these studies or, alternatively, this may reflect the lower priority given to syntactic information in Chinese reading. Despite these variations, however, the findings demonstrate the cross-linguistic generality of the transposed-word effect by showing it can be obtained in a non-alphabetic script that contains few grammatical markers and primarily conveys grammatical structure via word order. Moreover, this effect is robust across the transposition of morphologically simple and complex words. Such findings imply that flexibility in word-order processing is common for both alphabetic and non-alphabetic scripts.

Further work is nevertheless required to more fully understand this transposed-word effect. In particular, both the present experiments and previous research with an alphabetic script (Mirault et al., 2018; Snell & Grainger, 2019a) were conducted using a grammaticality decision task in which participants made overt categorization decisions that are not performed when reading normally. Consequently, while the studies demonstrate flexibility in word-order processing, and arguably tap processes likely to be implicated in reading (see Snell & Grainger, 2019b), it remains to be determined whether similar effects are observed under more natural reading conditions. Accordingly, it will be important for future research to use methods, such as measures of eye movements, to establish how word transpositions are processed when sentences are read naturally. A further extension of the present research will also involve establishing limits on word positional uncertainty during Chinese reading. Snell and Grainger (2019a) reported that the transposed-word effect breaks down over non-adjacent words in alphabetic reading (where adjacent word transpositions such as “the can man run” supported a word-transposition effect, but non-adjacent transpositions such as “run man can the” did not). Whether similar effects will be obtained for Chinese reading is unclear, although such findings would help quantify the degree of positional uncertainty experienced in normal reading and whether this differs across scripts.

Further research using eye movement measures may also help establish the locus of the word-transposition effect. Advocates of the OB1 model attribute this to word-order uncertainty caused by the parallel processing of words (Mirault et al., 2018; see also Snell et al., 2018; Snell and Grainger, 2019a). Crucially, this model, like its predecessors (SWIFT, Engbert et al., 2005; Glenmore, Reilly & Radach, 2006), assumes that attention is distributed across words within a region around fixation. This enables words to be processed in

parallel, but also allows for them to be recognized out of order. While this is considered a limitation by proponents of serial processing (e.g., Reichle et al., 2009b), advocates of OBI view it as inherent to reading and propose that words initially are encoded with a degree of positional uncertainty, with subsequent decisions about their relative order guided top-down by syntactic and semantic expectations. Following this account, readers might fail to detect a word transposition because of this initial positional uncertainty, and experience little processing difficulty if the error is corrected by higher-order constraints. However, an alternative possibility is that word order is processed without positional uncertainty, and that higher order syntactic and semantic constraints act rapidly to resolve transposition errors by selecting a plausible interpretation of the input (e.g., in line with noisy channel theories of syntactic processing, e.g., Gibson et al., 2013). In this latter case, the transposition may incur a processing cost, which may be detectable in the eye-movement record. Little research has addressed this issue to date. However, evidence from an unpublished study by Huang and Staub (2020) appears to support the former view, by showing that word transpositions that went unnoticed by readers do not disrupt eye-movement behavior, although clearly further work is required to substantiate this finding.

A final concern will be to establish whether parallel models such as OBI can be applied to Chinese reading (and for broader discussion of this issue, see Zang, 2019). To date, this model has been developed with respect to alphabetic languages such as French, while currently dominant approaches to modelling eye movements in Chinese reading are inspired by the E-Z Reader model (Li et al., 2009; Rayner et al., 2007; see also Li & Pollatsek, 2020). The use of a spatiotopic representation of word length and location as a mechanism for encoding word-positional information presents a particular challenge in applying OBI to Chinese reading. The information encoded by this representation is assumed to be derived from an analysis of low spatial frequency cues supplied by the spaces between words and the size of the “blobs” formed by words. However, Chinese is a naturally unspaced language in which word boundaries are ambiguous. Consequently, it is unclear how the spatiotopic representation would encode word length and location when reading this language. One possible approach, suggested by Mirault et al. (2019) in relation to reading unspaced alphabetic text, is that readers might seek to identify the currently fixated word and use information about its length to estimate the left boundary of the next word, then make a saccade beyond that boundary. However, this implies that readers engage in serial, word-by-word reading of unspaced text rather than the parallel processing that is fundamental to the model, and identified as the key mechanism for supporting word positional uncertainty. Consequently, while the present research provides clear evidence for a transposed-word effect in Chinese reading, it

presently is unclear if such an effect would actually be predicted by the only computational model currently capable of accounting for such effects.

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Open Practices Statement Data files and related resources are available from the University of Leicester online Figshare repository: <https://figshare.com/s/ce0344dbc06b7097a73b>. The experiment was not preregistered.

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