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An Investigation on Transposed-word Effect Under No Speed Pressure

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ABSTRACT

Readers' processing model has long been discussed in the field of reading study. Recently, the novel finding of transposed-word effect provides a new perspective into this issue. Since previous research concerning this effect all employ speeded decision task which does not fit the normal reading process, the present study sets out to investigate transposed-word effect through grammaticality judgment task taken under no speed pressure to test its validity with normal reading. The experiment result shows that participants do respond slower and make more errors when encountering transposed-word sentences, which means transposed- word effect does exist even when there is no speed pressure. It is then further argued that this effect reflects the flexibility in the processing of word order and there is a combination of top-down processing of the overall sentence structure and a noisy bottom-up processing of each word's identity during the readers' sentence reading.

Keywords: Transposed-wordEffect, Processing Model, Reading Speed, Grammaticality Judgment

1. Introduction

Being a skilled reader is harder than one might assume. As a complex cognitive process, reading requires delicate allocation of attention and effort. Within the study of reading, there has been a longstanding controversy over readers' processing model: whether one processes strings of words serially or in a parallel way. Serial processing argues that words are recognized strictly according to the coded sequential order, which means words are processed one at a time during reading, whereas parallel processing contends that multiple words can be recognized simultaneously.

The divergence of the two reading models essentially stems from the study of attention for two types of reading models share different views regarding attention distribution (Ma Guojie & Li Xingshan, 2012). Serial processing sets its basis on the spotlight theory. According to this theory, just like a spotlight, attention is with limited capacity, the processing efficiency is high where the light is focused (Posner et al.,1980) and information acquisition from the periphery is limited and almost negligible. Daily object-based attention shift is sequential, so does the attention allocation during the reading (Morrison,1984). In the field of reading, serial-attention shift model is represented by E-Z Reader model(Reichle et al., 1998, Reichle et al., 2003) which posits that lexical processing is completed on only one word at a time. Different from serial processing, parallel processing assumes attention is allocated as a asymmetrical gradient across the perceptual span. According to the gradient distribution of attention, attention is graded across the visual region, with the center of fixation having the fastest processing speed. As for the study of reading, processing models such as SWIFT (Saccade generation With Inhibition by Foveal Targets) (Engbert et al., 2005) and OB1-reader (Snell et al., 2018) are attention-gradient models. Attention-gradient reading models posit that attention during reading is allocated as a gradient. Under one gaze, all the words within the perceptual span are processed simultaneously, but attention is graded across this region with greater attention allocated to words that are closer to fixation. Though parallel processing provides accounts for phenomena as skipping, regression, etc. in reading which serial model cannot explain, supporters of serial processing nevertheless argues that parallel encoding is implausible as it is against the writing order at the first place. Despite the problem of whether the type of lexical order processing that occurs during natural reading is more consistent with the assumptions of serial-attention or attention-gradient models has not been settled in the literature, a newly reported discovery may shed some light on this issue.

Inspired by transposed-letter effect, in *You That Read Wrong Again! A Transposed-Word Effect in Grammaticality Judgments* (Mirault et al., 2018), researchers report that readers easily fail to notice the ungrammatical structure caused by switching of two adjacent words within the sentence and call it transposed-word effect. This effect is displayed through speeded grammaticality judgments of short sentences consisting of five words in French. Within the test, all the ungrammatical sentences are formed by transposition but their bases are different. Base forms of the sentences were either grammatical (e.g., “The white cat was big” becomes “The white was cat big”) or ungrammatical (e.g., “The white cat was slowly” becomes “The white was cat slowly”). It is found that participants responses slower and made more errors for stimuli derived from grammatical base sentences. In other words, transposition of grammatically correct sentences is somewhat ignored during the processing. Based on this, researchers further argue that the transposed-word effect reflects parallel processing of words during the written sentence comprehension and that the encoding of word order retains a certain amount of uncertainty.

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This novel finding of transposed-word effect has attracted bunches of scholarly attention ever since its first publication. Motivated by Mirault et al.'s (2018) finding, a growing amount of research has further investigated the transposed-word effect (Huang & Staub, 2021; Liu et al., 2020, 2021, 2022; Mirault et al., 2020; Pegado et al., 2021; Sara V. Milledge et al., 2023; Snell & Grainger, 2019; Wen et al., 2021, 2022). Huang and Staub (2021) replicated the grammaticality test of Mirault et al. (2018) in English and found a similar result in a reading-for-meaning experiment. Different from above mentioned experiments conducted in alphabetic languages, Liu et al. (2020, 2021, 2022, 2025) further investigated if a similar transposed-word effect is observed for a non-alphabetic script such as Chinese which uses few grammatical markers and primarily conveys grammatical structure via word order. Such logographic script may require stricter processing of word order during reading and so that can provide a more valid test of the cross-linguistic generality of the transposed-word effect. In their research, the universality of transposed-word effect has been confirmed. But it is further argued that transposed-word effect does not necessarily suggest parallel processing. Though transposed-word effect was statistically larger with parallel presentation than with serial presentation, it can also be significantly observed in serial process (also seen in Mirault et al., 2020; Sara V. Milledge et al., 2023, Wen, Y., & Grainger, J, 2025). Despite whether transposed-word effect can provide evidence for which processing model, it is undeniable that this effect manages to provide a new way to look into the nature of readers' perception and comprehension during the reading.

However, almost all the former studies test transposed-word effect through speeded decision task during which participants are asked to answer the required grammatical or comprehensional task as rapidly and accurately as possible. This kind of task requires participants to negotiate the competing demands of reading speed and decision accuracy. According to the theory of speed-accuracy trade off (SAT) (Wickelgren, 1977; Schouten&Bekker, 1967), the negotiation of speed and accuracy greatly affect the processing. Also, the speeded setting does not fit the normal reading process and it has been speculated that reading speed may be one of the variables that might modulate transposed-word effects. Given all these, this study sets out to investigate transposed-word effect through grammaticality judgement tests which are free from speed pressure to see whether this effect would drastically decrease with participants' normal reading speed and to explore whether reading speed can modulate this effect. Hopefully, it can provide implications for the further study.

2. Experiment Design

2.1. Participants

Twenty-one participants (9 women) aged 21 to 24 years (M = 21.8 years, SD = 0.8) are recruited

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in this experiment. Reported having normal or corrected-to-normal vision, all of the participants are native Chinese speakers with English as their second language and major. Before the experiment, an informed-consent form has been signed by all. It takes each participant about twenty minutes to finish the test. Data from 2 participants are excluded from the analyses because of their low overall accuracy rates (< 30%).

2.2. Stimuli Design

The stimuli design is similar to that of Mirault et al. (2018)' s. For each set of stimuli, a pair of grammatically correct five-word sentences is generated first to form the corresponding ungrammatical sentences. The ungrammatical sentences are formed by switching the last word of the two sentences in the pair (e.g. "is lovable", "sails smoothly" becomes "is smoothly", "sails lovable"). By now, a set of four base sequences has been generated, two of which are grammatical and the other two ungrammatical. Using these four base sequences, transposed-word versions of each sentence are then created by transposing the words at Positions 3 and 4 of each base. Every set of stimuli within the experiment is generated this way. There are two critical conditions in this experiment: the transposed-word condition (i.e. ungrammatical sentences formed by transposing two words in a grammatically correct base sentence) and the control condition (i.e. ungrammatical sentences formed by transposing two words in an ungrammatically correct base sentence, where transposing any two words could not generate a grammatically correct sentence). By comparing behavioral results of the recruited participants under these two conditions, transposed-word effect can be detected. The correct sentences served to meet the task requirement are not the focus of the statistical analyses.

Altogether, there are 80 five-word English sentences (40 grammatically correct, 20 ungrammatical transposed and 20 ungrammatical controls) deployed in the grammatical decision task. The grammatically correct sentences are randomly mixed with the ungrammatical sentences. And the experimental trials are presented to each participant in a different random order. Examples of each condition can be found in Table 1.

Table 1. Examples of the stimuli

Sentence		Example
Base	Grammatical	The little puppy is lovable.
		The steel boat sails smoothly.
	Ungrammatical	The little puppy is smoothly.
		The steel boat sails lovable.

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Test	Transposed-word	The little is puppy lovable.
		The steel sails boat smoothly.
	Control	The little is puppy smoothly.
		The steel sails boat lovable.

2.3. Apparatus

The stimuli are presented through experiment tool E-prime 3.0 and displayed on a 13-in. LCD screen. The sentences are set in 26-point Times New Roman font in black against the white background. The distance between the screen and participants is 55cm. Responses of the grammatical decisions are recorded via the keyboard: "T" stands for grammatically correct and "F" stands for grammatically wrong.

2.4. Procedure

Before the actual test, there are instructions both given by the experimenter and shown on the screen. Participants are asked to read at their own normal reading speed and respond as accurately as possible. A training round is performed ahead to ensure participants' comprehension of the task and to build their familiarization with it. Each trial starts with a fixation cross for 500 ms and followed by the stimulus shown in the center of the screen. Participants have to decide if sentence on the screen is grammatically correct or not by pressing "T" or "F" on the keyboard. The sentence remains on the screen until a response is given. Feedback on the responses will not be given to avoid its interference with the later decisions.

3. Result and Discussion

Participants' response accuracy and response times will be analyzed in this section. Data from two participants are excluded from the analyses because their response accuracy is below three standard deviations from the mean. The mean error rates and response times of the participants' correct responses in each condition are shown in Table 2 and Fig. 1.

Table 2. Error Rate and Response Time under Each Condition

	Transposed-word	Control	Grammatically Correct
Error Rate(%)	21.6	4.2	3.5
Response Time(ms)	2140	1660	1330

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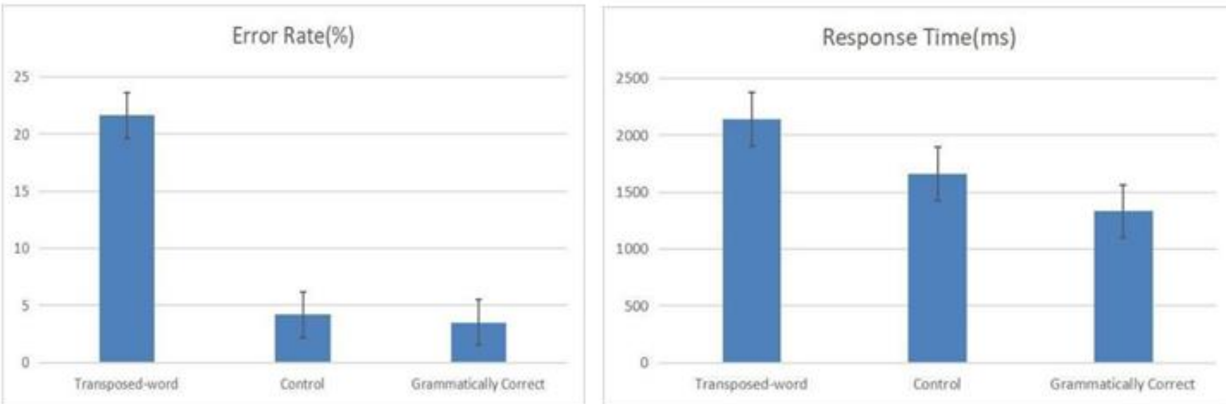
Figure 1. Error Rate and Response Time under Each Condition



Transposed-word effect can be observed through the above data. It can be seen from the error rate that participants obviously have more trouble in detecting the transposition within the grammatically correct sentences than that in the control condition. And as for the response time, participants significantly respond longer when dealing with the grammatically correct sentences with transposed-words than towards control groups ($t=8.48$, $p<0.01$), which means participants struggle at classifying transposed-word sentences as being ungrammatical. Results from both error rate and response time resonate with former research on the transposed-word effect. It can be seen that transposed-word effect also exists even when there is no pressure on reading speed. The reading speed can not modulate this effect.

Since the experiment setting in the present study fits more with the normal reading scene because there is no demand on speed, it serves to provide valid evidence that the transposed- word effect can provide implications for readers' way of processing linguistic information during the reading. It is then argued that there does exist flexibility in the processing of word order during sentence reading. In the experiment, it has been confirmed that readers are inclined to conceive sentences like "You that read wrong" as "You read that wrong". The dislocate of the words does not necessarily affect reader's comprehension of the target sentence. Most of the time, they are not aware that there has been a transposition. The flexibility and uncertainty in the spatial encoding of words allows readers to access a mental representation of the base forms of transposition, which interferes with their ability to correctly detect ungrammaticality of the presented sentences. This can also explain why reader has no difficulty in finding sentences of the control group grammatically incorrect because their bases are wrong in themselves (i.e. transposing any two words within those sentences could not generate a grammatically correct sentence) so the mental representation of the sentence is still wrong.

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The imprecision of the mental spatiotopic representation of sentences actually implies there is a combination of a top-down processing of the overall sentence structure and a noisy bottom-up processing of each word's identity during the readers' reading process. The bottom-up process is considered noisy because that top-down syntactic and contextual knowledge is always here to mediate word-level processing. This noisy path of sentence processing complies with the assumption that perceptual input is typically imperfect, and that the syntactic processor can edit or reorder elements of the input to achieve a plausible interpretation of its meaning (Gibson et. al., 2013). So the integration of top-down constraints on the sentence level and the noisy bottom-up processing of word identities and word order facilitates the transposed-word effect. Visual cues to top-down syntactic structure and noisy bottom-up word identity together activate the semantically plausible and grammatically correct sentence representation in the working memory. Within this processing model, the interpretation of ungrammatical sentences is expectation-driven, so that the ungrammatical sentence "You that read wrong" can be taken as "You read that wrong". Actually, the transposed-word effect also converges with the sentence-superiority effect (Snell & Grainger, 2017), which contends that during sentence reading, feedback from a sentence-level representation to individual word positions guides identification of these words via semantic and syntactic constraints.

4. Conclusion

This study has investigated transposed-word effect through grammaticality judgement task with no speed pressure. The experiment result shows that participants do respond slower and make more errors when encountering transposed-word sentences with grammatically correct base. In other words, participants fail to detect the transposition within the sentences even with their normal reading speed. The fact that transposed-word effect is still notable without the speeded setting suggests that reading speed does not significantly modulate transposed word effect. Since this effect concerns the mechanisms used by skilled readers to encode for linguistic information during reading, it is further argued that there does exist flexibility in the processing of word order and a combination of top-down processing of the overall sentence structure and a noisy bottom-up processing of each word's identity during the readers' sentence reading.

In terms of practical implications, this finding might provide insights for the design of reading intervention programs for individuals with reading difficulties, as it reveals the inherent flexibility and noise in word order processing that could be targeted to improve reading accuracy and fluency. Additionally, the study's results could inform the development of natural language processing (NLP) technologies, particularly in optimizing text correction tools and machine reading comprehension models, by incorporating the understanding of how human readers process word order variations.

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But the study still has many limitations. For one, the recruited participants are not enough to provide robust evidence for the finding. For another, there is no thorough examination of the relationship between the effect and reading speed. It would be better to test each participant's normal reading speed and also compare their error rate at the normal speed with the speeded one to see whether there is a correlation or not. Future research may conduct the related investigation into the reading speed and consider more factors that might modulate transposed-word effects, such as sentence length, etc.

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