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A transposed-word effect on word-in-sequence identification

Yun Wen[1] · **Jonathan Mirault**[1] · **Jonathan Grainger**[1,2]

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Abstract
The present study investigated transposed-word effects in a post-cued word-in-sequence identification experiment. Five horizontally aligned words were simultaneously presented for a brief duration and followed by a backward mask and cue for the position of the word to be identified within the sequence. The five-word sequences could form a grammatically correct sentence (e.g., *The boy can run fast*), an ungrammatical transposed-word sequence (e.g., *The can boy run fast*) or an ungrammatical control sequence (e.g., *The can get run fast*), and the same target word at the same position (e.g., the word 'run') was tested in the three conditions. Consistent with previous studies using a grammatical decision task and a same-different matching task, a transposed-word effect was observed, with word identification being more accurate in transposed-word sequences than in control sequences. Furthermore, here we could show for the first time that word identification was more accurate in correct sentences compared with transposed-word sequences. We suggest that the word identification advantage found for transposed-word sequences compared with ungrammatical control sequences is due to facilitatory feedback to word identities from sentence-level representations, albeit with less strength compared to the feedback provided by correct sentences.

Keywords Transposed words · Rapid parallel visual presentation (RPVP) · Parallel processing · Interactive processing · Reading

Introduction

A recent finding in the reading comprehension literature is that readers are resilient to small distortions of word order within a sentence. This is evidenced in the transposed-word effect initially reported by Mirault et al. (2018). Using a speeded grammatical decision task, Mirault et al. (2018) found that participants took longer and made more errors in deciding that a transposed-word sequence (e.g., *The can boy run fast*) was ungrammatical compared with a control sequence where transposing any two words does not generate a correct sentence (e.g., *The can boy run desk*). These results indicate that participants tended to pursue a grammatical reading of the transposed-word sequences (e.g., "The can boy run fast" is understood as "The boy can run fast"), thus making ungrammatical decisions more difficult.

The presence of transposed-word effects converges nicely with recent theorizing that suggests that readers do not always construct a veridical representation of sentence structure (for a review, see Christianson, 2016). Mirault et al.'s (2018) findings demonstrated that approximate or noisy information about word order might be one characteristic of such "good-enough" sentence representations (e.g., Ferreira & Lowder, 2016). As proposed in the theoretical work of Snell et al. (2017, 2018), when multiple words are processed at the same time, word positions are flexibly encoded. That is, a word identity is associated not only with its actual position but also with neighbouring positions, which mimics the noisy letter position coding during word recognition hypothesized in certain models of orthographic processing (e.g., Gómez et al., 2008). Crucially, this noisy word position coding does not prevent the rapid construction of an elementary, approximate syntactic representation, which subsequently provides top-down feedback to word identities and guides the allocation of word identities to probable positions. The combination of positional flexibility and syntactic constraints on word position coding accounts for

✉ Yun Wen
wywenyun@gmail.com

[1] Laboratoire de Psychologie Cognitive, Aix-Marseille University and Centre National de la Recherche Scientifique, Campus St Charles, 3 Place Victor Hugo, 13331 Marseille, France

[2] Institute for Language Communication and the Brain, Aix-Marseille University, Marseille, France

readers' tendency to interpret ungrammatical transposed-word sequences as being grammatical.

Motivated by Mirault et al.'s (2018) findings, a growing body of research has further investigated transposed-word effects in order to elucidate the mechanisms involved in assigning word identities to their positions in a sequence (Huang & Staub, 2021a; Liu et al., 2020, 2021; Mirault et al., 2020; Pegado et al., 2021; Pegado & Grainger, 2019, 2020, 2021; Snell & Grainger, 2019; Wen et al., 2021a, 2021b). For example, the studies by Snell and Grainger (2019) and Wen et al. (2021b) revealed two key constraints on transposed-word effects: (1) the distance separating the two transposed words (the effect was only significant with adjacent words in the Snell and Grainger study); and (2) the role of syntactic phrase boundaries (the effects were greater when transpositions occurred within a syntactic phrase relative to transpositions across a syntactic phrase in the Wen et al. study). Huang and Staub (2021a) replicated the grammatical decision results of Mirault et al. (2018) in English and found a similar pattern in a more natural reading-for-meaning experiment. Mirault et al. (2020) showed that transposed-word effects are not caused by reading the transposed words out of order, and Liu et al. (2020, 2021) reported transposed-word effects when reading a logographic script (Chinese). Finally, Pegado and Grainger (2020) found transposed-word effects in a same-different matching task (are two sequences of words composed of the same words in the same order or not?) that does not require the computation of syntactic structure. Transposed-word effects were found to be affected by the grammatical nature of the sequences to be compared (e.g., more errors were made when matching "he wants these green apples" and "HE THESE WANTS GREEN APPLES" compared with "green wants these he apples" and "GREEN THESE WANTS HE APPLES"), but only when the matching process was hard enough.

Taken together, these findings fit with a model of sentence reading according to which a certain amount of parallel word processing[1] enables the rapid association of several word identities to their positions in the sentence, followed by the rapid computation of an initial primitive sentence-level representation that then provides feedback to on-going word identification processes. Within a cascaded-interactive processing framework (McClelland & Rumelhart, 1981), transposed-word effects can be due to noise in the bottom-up association of word identities to their positions in a sequence, and also due to the fast computation of a sentence-level representation forcing a grammatical interpretation of the transposed-word sequence via top-down constraints. Alternatively, transposed-word effects can be accounted for in models of sentence reading that apply a strictly one-word-at-time serial reading by assuming that on some trials participants actually read the transposed-word sequence as a correct sentence (see Huang & Staub, 2021a, for evidence for this from eye-movement patterns). Such serial processing accounts point to re-ordering word identities during post-lexical integration process as the locus of transposed-word effects (Huang & Staub, 2021a, 2021b). In line with the serial reading interpretation, Liu et al. (2022) have shown that transposed-word effects in Chinese can be observed under conditions of rapid serial visual presentation (RSVP) of the word sequence, but only in error rates and not in response times for a grammatical decision task. Based on an extensive replication of this finding in French, Mirault et al. (2022) concluded that the fact that under conditions of serial processing the effects were only observed in error rates in their study and the Liu et al. (2022) study is most likely due to the role played by top-down constraints in forcing a re-ordering of words into a grammatically correct sequence.

The present study provides a test of transposed-word effects in conditions that are expected to encourage parallel word processing by using the word-in-sequence identification paradigm with rapid parallel visual presentation (RPVP) of word sequences. In the RPVP paradigm, a sequence of words is presented simultaneously for a short duration (250 ms or less) in order to minimize eye movements (Asano & Yokosawa, 2011). Prior work using this paradigm has found post-cued word identification to be more accurate when the target word is embedded in a syntactically valid context compared to a syntactically invalid context formed by changing the order of words in the correct sentence condition (Declerck et al., 2020; Snell & Grainger, 2017; Wen et al., 2019). This 'sentence superiority effect' is interpreted as reflecting feedback from a sentence-level representation to on-going word identification via cascaded-interactive processing.

The present study had two main aims. First, we examined whether post-cued word identification in the RPVP paradigm would be higher in transposed-word sequences (e.g., *The can boy run fast*) compared with an ungrammatical control sequence (e.g., *The can get run fast*), with the same target word tested at the same position (e.g., *run*) in the two conditions. Target words could appear at either position 2 or 4 in the five-word sequence and were never part of the transposed-word manipulation. Both the cascaded-interactive and the serial processing accounts of transposed-word effects, discussed above, appeal to sentence-level constraints on word-order encoding as being one major mechanism driving such effects, and therefore potentially both predict that a transposed-word manipulation will impact on target word identification.

[1] We often simply refer to parallel processing in opposition to serial processing, but this parallel processing must clearly be limited to a relatively small number of words given the constraints imposed by visual acuity during sentence reading.

The second goal of the present study was to test whether the support provided by a transposed-word sequence context is equivalent to the support provided by a correct sentence context. Finding a significantly smaller sentence superiority effect with transposed-word sequences compared with true sentences would provide support for our hypothesis that transposed-word effects reflect the partial activation of sentence-level structures that then provide feedback to ongoing word identification processes. However, a serial "reordering" account of transposed-word effects should predict no difference between transposed-word sequences and grammatical sentences. Concerning this specific contrast, it is important to note that comparing transposed-word sequences and grammatically correct sentences would involve different responses in a grammatical decision task. That is another reason why the word-in-sequence identification task was used in the present study (i.e., participants are performing exactly the same task in these two conditions).

In sum, we predicted, on the basis of our cascaded-interactive account of the sentence superiority effect, that word identification would be more accurate in transposed-word sequences (e.g., the target *run* in the sequence: *The can boy run fast*) compared with ungrammatical control sequences (e.g., *The can get run fast*), and most accurate in grammatical sequences (e.g., *The boy can run fast*).

Methods

Participants

One hundred and twenty-four native English speakers (65 females; mean age = 30.75 years, SD = 9.99) were recruited online via Prolific (Palan & Schitter, 2018). Data from 16 additional participants were excluded from the analyses because of their low overall accuracy rates (< 30%, N = 12), their first language (≠ English, N = 3), or zero accuracy for targets in position 4 (N =1).

Materials and design

First, we constructed 144 grammatically correct English sentences that consisted of five words. The average word length was 4.38 letters (SD = 1.31) and the average word frequency was 5.60 (SD = 1.14) in Zipf values (van Heuven et al., 2014). For each sentence, two types of ungrammatical versions were created. First, the transposed-word condition was generated by swapping words at positions 2 and 3 (e.g., *He the throws glass there*) or at positions 3 and 4 (e.g., *Please put jacket the here*). Second, following Pegado and Grainger (2020), the control condition was generated by replacing one transposed word with a word of the same word length (e.g., *He the jacket glass there/Please put throws the here*). Sentences were paired so that an identical set of words was used in the two ungrammatical conditions (e.g., "He throw the glass there" paired "Please put the jacket here" to generate previous examples), thus minimising lexical-level impacts across conditions. Words at positions 2 or 4 that stayed in the same position in the grammatical and ungrammatical versions were used as the target word (e.g., the word "glass" is the target word for *He throws the glass there/He the throws glass there/He the jacket glass there*). Thus, the same word targets were tested in the three levels of the factor Context (grammatical, transposed-word, ungrammatical control). The design was therefore a 3 (Context) × 2 (Position) factorial. The targets consisted of 144 different words with an average word length of 4.74 letters (SD = 1.00) and an average word frequency of 5.22 (SD = 0.90) in Zipf values (van Heuven et al., 2014). Three counterbalanced lists were created to ensure that only one condition of the 144 sequences was presented in each list and all conditions (grammatical/transposed-word/control) were presented across lists. Participants were randomly assigned to one of counterbalanced lists. The complete list of stimuli is provided in the Appendix.

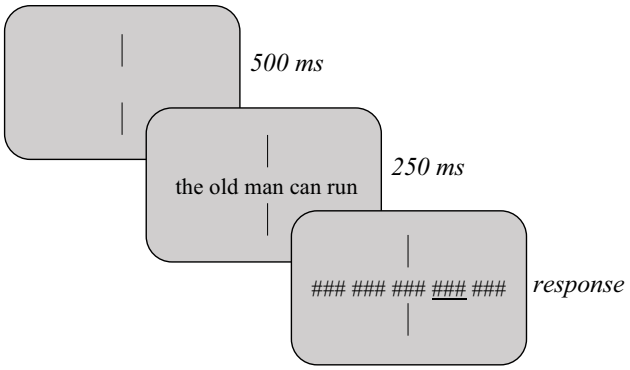

Fig. 1 Illustration of the sequence of events in the post-cued partial report Rapid Parallel Visual Presentation (RPVP) procedure

Procedure

All participants provided their informed consent before the online experiment started. The presentation of the stimuli was controlled by LabVanced (Finger et al., 2017). A unique random trial order was generated for each participant. Each trial began with two vertical fixation bars presented for 500 ms at the screen centre. Next, a sequence of five words was presented for 250 ms. We increased stimulus duration compared with the 200-ms presentation duration used in our previous studies (Declerck et al., 2020; Snell & Grainger, 2017; Wen et al., 2019) given that here we tested five-word sequences as opposed to the four-word sequences tested in our prior work. Then, a sequence of hash marks

was presented at all prior letter locations, together with an underline at the target location as the post-cue (see Fig. 1). Participants were instructed to focus their eyes on the space between the fixation bars and to report the target at the post-cued location. They could take as long as needed to type in their response. The inter-trial interval was set at 500 ms. Prior to the experiment, six practice trials were used to familiarise the participants with the procedure.

Data analysis

A response was coded as correct only if it was an exact match of the target. Using the lme4 (Bates et al., 2015) and lmerTest (Kuznetsova et al., 2017) packages in R (R Core Team, 2021), the accuracy data were analysed with a logistic mixed-effects model (Jaeger, 2008) using sum contrasts. Participants and items were included as random effects (Baayen et al., 2008), and by-participant and by-item random slopes were also included (Barr et al., 2013). The main effects (Context/Position) were obtained from the Type II Wald χ^2 test using the car package (Fox & Weisberg, 2019). Pairwise comparisons were conducted using Tukey's adjustment to control the familywise error rate.

Results

Condition means are shown in Fig. 2. Average identification accuracy in the grammatical, transposed-word, and control conditions was 62.2%, 58.8%, and 55.3% respectively. The analysis using mixed-effects modelling revealed a main effect of Context, χ^2 (2) = 47.9058, $p < .001$. Planned pairwise comparisons showed that identification accuracy rates for words presented in the grammatical condition were higher than in the control condition ($\beta = 0.424$, SE = 0.0619, z = 6.845, $p < .0001$), a standard sentence superiority effect. Crucially, accuracy was also significantly higher in the grammatical condition compared with the transposed-word condition ($\beta = 0.216$, SE = 0.0537, z = 4.019, $p = .0002$), and significantly higher in the transposed-word condition compared with the control condition ($\beta = 0.208$, SE = 0.0591, z = 3.516, $p = .0013$). Although Position did influence identification accuracy (χ^2 (1) = 24.6982, $p < .001$), with higher accuracy for words in position 2 (66.9%) than in position 4 (50.3%), it did not interact with Context (χ^2 (2) < 2, $p > .50$).

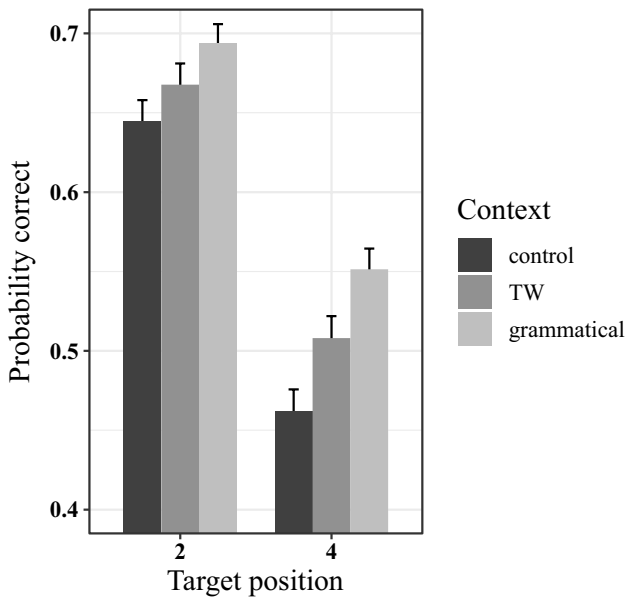

Fig. 2 Mean identification accuracy rates with 95% confidence intervals (Cousineau, 2005) at the two target positions in the control, transposed-word (TW) and grammatical context conditions

Discussion

The present study aimed to investigate whether a transposed-word effect could be obtained in a word-in-sequence identification experiment using the RPVP technique combined with post-cued identification. That is, contrary to all prior observations of transposed-word effects, in the present study participants only had to identify one word. Finding a transposed-word effect in the present study would therefore provide evidence that such effects are at least partly driven by the transposed-word sequences activating the corresponding correct sentence structure, which then constrains on-going word identification processes. To investigate this, we compared identification accuracy of a target word in five-word sequences that could be (1) a grammatically correct sentence (e.g., *The boy can run fast*), (2) a transposed-word sequence (e.g., *The can boy run fast*), or (3) an ungrammatical control sequence (e.g., *The can get run fast*), with the same target word at the same position (here the word *run*) tested in the three conditions. Target words could appear at either position 2 or 4 and were never part of the transposed-word manipulation.

Our first main finding is that post-cued word identification accuracy was higher in transposed-word sequences than in control sequences, which demonstrates for the first time a transposed-word effect in word-in-sequence identification. This finding fits with the general hypothesis that transposed-word sequences provide bottom-up support for the corresponding grammatical base sentence from which they are derived, and the sentence-level representation of the base sentence then constrains processing of the target word in the transposed-word sequence. Both parallel and serial accounts of word sequence processing appeal to sentence-level constraints as a key mechanism in driving transposed-word effects.

The second main finding of the present study was the higher word identification accuracy in correct sentences compared with transposed-word sequences, another novel finding that could not be attested with the grammatical decision task given that different responses ("yes" vs. "no") are associated with the grammatical decisions made to these two types of sequence. We predicted this pattern on the basis of our cascaded-interactive account of the sentence superiority effect (Declerck et al., 2020; Snell & Grainger, 2017; Wen et al., 2019). That is, given the positional mismatch between words in the correct sentence representation and the transposed-word sequence, we predicted that bottom-up support for sentence-level representations would be reduced in transposed-word sequences compared with true sentences, resulting in less feedback and less accurate word identification. We would further argue that the difference observed between transposed-word sequences and correct sentences is evidence against a "re-ordering" account, according to which a transposed-word sequence is mistakenly processed as a correct sequence (Huang & Staub, 2021a, 2021b).[2]

Concerning the main effect of target position, our results are in line with prior research that has consistently reported highest identification accuracy at position 2 within 4-word sequences (e.g., 58.2% for position 1, 79.2% for position 2, 61.3% for position 3 and 62.2% for position 4 in Wen et al., 2019), hence strongly suggesting that participants were not performing a left-to-right serial processing of words in the sequence, otherwise highest accuracy should have been obtained at position 1. We nevertheless acknowledge that the higher performance at position 2 compared with position 4 in the present study, and compared with position 3 in prior studies, merits further examination in future research.

One further means to test the cascaded-interactive account proposed here would be to manipulate the location of the target word relative to the transposed words (i.e., the target is one of the transposed words or not). In the present study, the target word was never one of the transposed words. We predict that when the target is one of the transposed-words (e.g., the target "glass" in the sequence "he throws glass the there"), then positional noise in the feedback process should diminish the difference between transposed-word sequences and the ungrammatical controls (i.e., a smaller transposed-word effect). In addition, future research could also examine whether transposed-word effects can be observed with syntactically valid but semantically odd sentences (e.g., *Angry water flies quietly*) in the same-different matching task (see Massol et al., 2021, for a demonstration of a sentence superiority effect with semantically anomalous sentences). The existence of transposed-word effects in this case would speak against the post-lexical integration account proposed by Huang and Staub (2021a, 2021b) since semantic anomalies should diminish the role played by sentence-level constraints in re-ordering transposed words.

Finally, the present study also provides a further demonstration of the utility of the RPVP paradigm as a tool to investigate reading comprehension. The brief simultaneous presentation of horizontally aligned words is intended to capture the kind of processing that might occur across multiple words during a single fixation in natural reading. We nevertheless acknowledge that in the absence of eye-movement recordings, we cannot be absolutely sure that our participants were indeed fixating the central fixation point as per instructions, and not moving their eyes during stimulus presentation. It will be therefore important for future studies to combine eye-movement recordings with the RPVP paradigm in order to monitor participants' eye fixation location and eye movements. Furthermore, we admit that the present study did not control for viewing angle since the display size (the size of stimuli and screens) varied across participants and participants' viewing distance was also unknown. Although the lack of control over the display size and viewing distance is a longstanding limitation for web-based experiments (Angele et al., 2022; Grootswagers, 2020), means to address such limitations have only recently been investigated (Brascamp, 2021; Li et al., 2020). It is therefore recommended that future online studies using the RPVP paradigm adopt recently developed methods to better estimate viewing angle, given that changes in viewing angle might impact on the serial versus parallel processing of word sequences. We note, nevertheless, that everyday reading is characterized by variations in text size and viewing distance, and so such variations in the present study might actually be a better reflection of reading out of the lab. Regardless of such variations, the present study replicated a reliable lab-based result: the sentence superiority effect (Declerck et al., 2020; Snell & Grainger, 2017; Wen et al., 2019). Thus, we reason that variations in viewing angle likely did not impact our main findings (see Angele et al., 2022, for a similar reasoning for masked-priming effects in online vs. in-lab experiments).

To conclude, the present study found a transposed-word effect expressed as a higher word identification accuracy in transposed-word sequences compared with control sequences. We also observed that word identification accuracy was greater in correct sentences compared with transposed-word sequences. We suggest that the word identification advantage in transposed-word sequences is driven by facilitatory feedback to on-going word identification processes from partially activated sentence-level representations within the framework of a cascaded-interactive theory of word identification and sentence comprehension.

[2] However, once again in all fairness to serial processing theorists, this pattern could arise if the "re-ordering" only occurs on certain trials.

Appendix

Stimuli tested in the present experiment, with the three types of context for each target word.

Grammatical	Transposed word	Control	Target
The desert was dimly visible	The was desert dimly visible	The was throws dimly visible	dimly
He throws the glass there	He the throws glass there	He the desert glass there	glass
The things are even worse	The are things even worse	The are missed even worse	even
We missed the train again	We the missed train again	We the things train again	train
He climbs the hill weekly	He the climbs hill weekly	He the street hill weekly	hill
The street was simply empty	The was street simply empty	The was climbs simply empty	simply
You change the office too	You the change office too	You the people office too	office
Did people play tennis here	Did play people tennis here	Did play change tennis here	tennis
The villas were built nearby	The were villas built nearby	The were pretty built nearby	built
The pretty lady laughs loud	The lady pretty laughs loud	The lady villas laughs loud	laughs
Peter seldom wears rubber gloves	Peter wears seldom rubber gloves	Peter wears advice rubber gloves	rubber
Whose advice was taken finally	Whose was advice taken finally	Whose was seldom taken finally	taken
Your voices are heard now	Your are voices heard now	Your are bought heard now	heard
You bought what looked fancy	You what bought looked fancy	You what voices looked fancy	looked
She doubts who shows up	She who doubts shows up	She who church shows up	shows
The church was ruined twice	The was church ruined twice	The was doubts ruined twice	ruined
We wonder why she quits	We why wonder she quits	We why babies she quits	she
Why babies cry seems obvious	Why cry babies seems obvious	Why cry wonder seems obvious	seems
He asked when you arrived	He when asked you arrived	He when uncle you arrived	you
Your uncle was indeed tall	Your was uncle indeed tall	Your was asked indeed tall	indeed
My lunch smells very good	My smells lunch very good	My smells study very good	very
They study how fish swim	They how study fish swim	They how lunch fish swim	fish
The steak tastes really bitter	The tastes steak really bitter	The tastes would really bitter	really
Who would win became clear	Who win would became clear	Who win steak became clear	became
The whole team just agreed	The team whole just agreed	The team likes just agreed	just
She likes very sweet candies	She very likes sweet candies	She very whole sweet candies	sweet
This small monkey sat here	This monkey small sat here	This monkey movie sat here	sat
The movie lasted two hours	The lasted movie two hours	The lasted small two hours	two
Harry might start late tonight	Harry start might late tonight	Harry start woman late tonight	late
The woman only blames herself	The only woman blames herself	The only might blames herself	blames
Jack could avoid being mean	Jack avoid could being mean	Jack avoid young being mean	being
Some young girls prefer tea	Some girls young prefer tea	Some girls could prefer tea	prefer
How smart the police are	How the smart police are	How the bunny police are	police
The bunny bites soft toys	The bites bunny soft toys	The bites smart soft toys	soft
Lily often snores like him	Lily snores often like him	Lily snores cards like him	like
Sending cards cheers them up	Sending cheers cards them up	Sending cheers often them up	them
They want more green apples	They more want green apples	They more home green apples	green
Her home was rather clean	Her was home rather clean	Her was want rather clean	rather
These pens sell well abroad	These sell pens well abroad	These sell have well abroad	well
We have made eight skirts	We made have eight skirts	We made pens eight skirts	eight
His feet are both dirty	His are feet both dirty	His are keep both dirty	both
They keep the pigs outside	They the keep pigs outside	They the feet pigs outside	pigs
She used the cup once	She the used cup once	She the soup cup once	cup
The soup was almost warm	The was soup almost warm	The was used almost warm	almost
The gift was from them	The was gift from them	The was does from them	from
How does your friend look	How your does friend look	How your gift friend look	friend
The poor guy still suffers	The guy poor still suffers	The guy dogs still suffers	still
Do dogs love going outside	Do love dogs going outside	Do love poor going outside	going
Can boys carry large boxes	Can carry boys large boxes	Can carry wild large boxes	large
The wild animal scares me	The animal wild scares me	The animal boys scares me	scares
When will her flight arrive	When her will flight arrive	When her hard flight arrive	flight

Grammatical	Transposed word	Control	Target
How they spoke amazed us	How spoke they amazed us	How spoke were amazed us	amazed
Who can wait all day	Who wait can all day	Who wait sky all day	all
The sky was quite red	The was sky quite red	The was can quite red	quite
We got home early today	We home got early today	We home him early today	early
Tell him the happy story	Tell the him happy story	Tell the got happy story	happy
The big sharks attack humans	The sharks big attack humans	The sharks she attack humans	attack
Does she never answer questions	Does never she answer questions	Does never big answer questions	answer
We were having dinner there	We having were dinner there	We having they dinner there	dinner
How hard the tailor works	How the hard tailor works	How the will tailor works	tailor
Here are some cheap hats	Here some are cheap hats	Here some she cheap hats	cheap
Normally she cooks meals alone	Normally cooks she meals alone	Normally cooks are meals alone	meals
What was his final score	What his was final score	What his the final score	final
Cut the pie right now	Cut pie the right now	Cut pie was right now	right
Has the artist slept yet	Has artist the slept yet	Has artist you slept yet	slept
What you watch sounds boring	What watch you sounds boring	What watch the sounds boring	sounds
When she died was unknown	When died she was unknown	When died the was unknown	was
Have the twins ever called	Have twins the ever called	Have twins she ever called	ever
Hold the cute teddy up	Hold cute the teddy up	Hold cute may teddy up	teddy
Alice may fly there tomorrow	Alice fly may there tomorrow	Alice fly the there tomorrow	there
Several busy nurses left today	Several nurses busy left today	Several nurses kids left today	left
Must kids drink milk daily	Must drink kids milk daily	Must drink busy milk daily	milk
There lies our old king	There lies old our king	There lies old was king	lies
The city has its cathedral	The city its has cathedral	The city its one cathedral	city
The birds lay eggs yearly	The birds eggs lay yearly	The birds eggs the yearly	birds
He began one week ago	He began week one ago	He began week has ago	began
His boss was hurt yesterday	His boss hurt was yesterday	His boss hurt the yesterday	boss
The lion was shot dead	The lion shot was dead	The lion shot our dead	lion
The rent was paid monthly	The rent paid was monthly	The rent paid she monthly	rent
There goes the full bus	There goes full the bus	There goes full was bus	goes
The wine has sold out	The wine sold has out	The wine sold the out	wine
Stop eating out every day	Stop eating every out day	Stop eating every has day	eating
Here comes the heavy rain	Here comes heavy the rain	Here comes heavy lay rain	comes
John hopes you visit him	John hopes visit you him	John hopes visit the him	hopes
Such fears are among us	Such fears among are us	Such fears among the us	fears
Which side you stand matters	Which side stand you matters	Which side stand the matters	side
How thin the walls are	How thin walls the are	How thin walls has are	thin
Sara wishes she earned more	Sara wishes earned she more	Sara wishes earned was more	wishes
Our tree has turned yellow	Our tree turned has yellow	Our tree turned out yellow	tree
How lazy the writer is	How lazy writer the is	How lazy writer you is	lazy
Why did the farmer smile	Why did farmer the smile	Why did farmer are smile	did
Please put the jacket here	Please put jacket the here	Please put jacket you here	put
Eric should pass the ball	Eric should the pass ball	Eric should the food ball	should
Bring enough food back please	Bring enough back food please	Bring enough back pass please	enough
There exists many free books	There exists free many books	There exists free were books	exists
Joyce thinks they feel guilty	Joyce thinks feel they guilty	Joyce thinks feel were guilty	thinks
The couple next door skated	The couple door next skated	The couple door rang skated	couple
The shoes cost nine hundred	The shoes nine cost hundred	The shoes nine here hundred	shoes
The phone rang last night	The phone last rang night	The phone last next night	phone
Get some rest when necessary	Get some when rest necessary	Get some when seen necessary	some
You also have blue curtains	You also blue have curtains	You also blue more curtains	also
He has seen that ring	He has that seen ring	He has that rest ring	has
There were more fresh pears	There were fresh more pears	There were fresh have pears	were
It stays here since then	It stays since here then	It stays since cost then	stays
Her sons were badly served	Her sons badly were served	Her sons badly many served	sons

Grammatical	Transposed word	Control	Target
Dancing with cats looks funny	Dancing with looks cats funny	Dancing with looks were funny	with
The war then broke out	The war broke then out	The war broke went out	war
Our pets were buried there	Our pets buried were there	Our pets buried they there	pets
The bags were filled before	The bags filled were before	The bags filled cats before	bags
Sometimes they went hiking together	Sometimes they hiking went together	Sometimes they hiking then together	they
They have fixed ten bikes	They have ten fixed bikes	They have ten along bikes	have
Follow others along the road	Follow others the along road	Follow others the fixed road	others
David hardly feels any pain	David hardly any feels pain	David hardly any water pain	hardly
Drinking hot water can help	Drinking hot can water help	Drinking hot can feels help	hot
The flower grows fast lately	The flower fast grows lately	The flower fast money lately	flower
How little money they own	How little they money own	How little they grows own	little
Reading novels gives him joy	Reading novels him gives joy	Reading novels him their joy	novels
Alex hears their boat sank	Alex hears boat their sank	Alex hears boat gives sank	hears
The noises annoy the crew	The noises the annoy crew	The noises the could crew	noises
Any plan could worry them	Any plan worry could them	Any plan worry annoy them	plan
The tutor lives far away	The tutor far lives away	The tutor far price away	tutor
The house price drops recently	The house drops price recently	The house drops lives recently	house
The class share the reward	The class the share reward	The class the ducks reward	class
Luckily the ducks walked back	Luckily the walked ducks back	Luckily the walked share back	the
They are moving too quick	They are too moving quick	They are too smokes quick	are
The actor smokes over there	The actor over smokes there	The actor over moving there	actor
Hopefully our guests get ready	Hopefully our get guests ready	Hopefully our get cannot ready	our
The doctor cannot jump high	The doctor jump cannot high	The doctor jump guests high	doctor
That white rabbit runs away	That white runs rabbit away	That white runs finish away	white
Lucy must finish around noon	Lucy must around finish noon	Lucy must around rabbit noon	must
Emma knows people hate her	Emma knows hate people her	Emma knows hate raises her	knows
His aunt raises three kids	His aunt three raises kids	His aunt three people kids	aunt
Sadly his wallet went missing	Sadly his went wallet missing	Sadly his went drives missing	his
Jane rarely drives those cars	Jane rarely those drives cars	Jane rarely those wallet cars	rarely
Which day suits you better	Which day you suits better	Which day you dress better	day
Wash your dress before bed	Wash your before dress bed	Wash your before suits bed	your
Mary always writes lovely poems	Mary always lovely writes poems	Mary always lovely bridge poems	always
The new bridge fell down	The new fell bridge down	The new fell writes down	new
My store opens this month	My store this opens month	My store this party month	store
The formal party ended early	The formal ended party early	The formal ended opens early	formal
The chef talks about it	The chef about talks it	The chef about sugar it	chef
Add extra sugar and stir	Add extra and sugar stir	Add extra and talks stir	extra
The words were said rudely	The words said were rudely	The words said some rudely	words
You need some juicy oranges	You need juicy some oranges	You need juicy were oranges	need

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Declarations

Conflicts of interest The authors report no conflicts of interest.

References

Angele, B., Baciero, A., Gómez, P., & Perea, M. (2022). Does online masked priming pass the test? The effects of prime exposure duration on masked identity priming. *Behavior Research Methods*. https://doi.org/10.3758/s13428-021-01742-y

Asano, M., & Yokosawa, K. (2011). Rapid extraction of gist from visual text and its influence on word recognition. *The Journal of General Psychology, 138*(2), 127–154. https://doi.org/10.1080/00221309.2010.542510

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

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language, 68*(3), 255–278. https://doi.org/10.1016/j.jml.2012.11.001

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67*, 1–48. https://doi.org/10.18637/jss.v067.i01

Brascamp, J. W. (2021). Controlling the spatial dimensions of visual stimuli in online experiments. *Journal of Vision, 21*(8), 19. https://doi.org/10.1167/jov.21.8.19

Christianson, K. (2016). When language comprehension goes wrong for the right reasons: Good-enough, underspecified, or shallow language processing. *Quarterly Journal of Experimental Psychology, 69*(5), 817–828. https://doi.org/10.1080/17470218.2015.1134603

Cousineau, D. (2005). Confidence intervals in within-subject designs: A simpler solution to Loftus and Masson's method. *Tutorials in Quantitative Methods for Psychology, 1*(1), 42–45. https://doi.org/10.20982/tqmp.01.1.p042

Declerck, M., Wen, Y., Snell, J., Meade, G., & Grainger, J. (2020). Unified syntax in the bilingual mind. *Psychonomic Bulletin & Review, 27*(1), 149–154. https://doi.org/10.3758/s13423-019-01666-x

Ferreira, F., & Lowder, M. W. (2016). Prediction, information structure, and good-enough language processing. In *The psychology of learning and motivation.* (Vol. 65, pp. 217–247). Elsevier Academic Press. https://doi.org/10.1016/bs.plm.2016.04.002

Finger, H., Goeke, C., Diekamp, D., Standvoß, K., & König, P. (2017). *LabVanced: A unified JavaScript framework for online studies*. International Conference on Computational Social Science (Cologne).

Fox, J., & Weisberg, S. (2019). *An R Companion to Applied Regression*. Sage Publications.

Gómez, P., Ratcliff, R., & Perea, M. (2008). The overlap model: A model of letter position coding. *Psychological Review, 115*(3), 577–600. https://doi.org/10.1037/a0012667

Grootswagers, T. (2020). A primer on running human behavioural experiments online. *Behavior Research Methods, 52*(6), 2283–2286. https://doi.org/10.3758/s13428-020-01395-3

Huang, K.-J., & Staub, A. (2021a). Using eye tracking to investigate failure to notice word transpositions in reading. *Cognition, 216*, 104846. https://doi.org/10.1016/j.cognition.2021.104846

Huang, K.-J., & Staub, A. (2021b). Why do readers fail to notice word transpositions, omissions, and repetitions? A review of recent evidence and theory. *Lang & Ling Compass, 15*(7), e12434. https://doi.org/10.1111/lnc3.12434

Jaeger, T. F. (2008). Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of Memory and Language, 59*(4), 434–446. https://doi.org/10.1016/j.jml.2007.11.007.

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest package: Tests in linear mixed effects models. *Journal of Statistical Software, 82*(13). https://doi.org/10.18637/jss.v082.i13

Li, Q., Joo, S. J., Yeatman, J. D., & Reinecke, K. (2020). Controlling for participants' viewing distance in large-scale, psychophysical online experiments using a virtual chinrest. *Scientific Reports, 10*(1), 904. https://doi.org/10.1038/s41598-019-57204-1

Liu, Z., Li, Y., Paterson, K. B., & Wang, J. (2020). A transposed-word effect in Chinese reading. *Attention, Perception, & Psychophysics, 82*(8), 3788–3794. https://doi.org/10.3758/s13414-020-02114-y

Liu, Z., Li, Y., & Wang, J. (2021). Context but not reading speed modulates transposed-word effects in Chinese reading. *Acta Psychologica, 215*, 103272. https://doi.org/10.1016/j.actpsy.2021.103272

Liu, Z., Li, Y., Cutter, M. G., Paterson, K. B., & Wang, J. (2022). A transposed-word effect across space and time: Evidence from Chinese. *Cognition, 218*, 104922. https://doi.org/10.1016/j.cognition.2021.104922

Massol, S., Mirault, J., & Grainger, J. (2021). The contribution of semantics to the sentence superiority effect. *Scientific Reports, 11*, 20148. https://doi.org/10.1038/s41598-021-99565-6

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: I. An account of basic findings. *Psychological Review, 88*(5), 375–407. https://doi.org/10.1037/0033-295X.88.5.375

Mirault, J., Snell, J., & Grainger, J. (2018). You that read wrong again! A transposed-word effect in grammaticality judgments. *Psychological Science, 29*(12), 1922–1929. https://doi.org/10.1177/0956797618806296

Mirault, J., Guerre-Genton, A., Dufau, S., & Grainger, J. (2020). Using virtual reality to study reading: An eye-tracking investigation of transposed-word effects. *Methods in Psychology, 3*, 100029. https://doi.org/10.1016/j.metip.2020.100029

Mirault, J., Vandendaele, A., Pegado, F., & Grainger, J. (2022). *Transposed-word effects when reading serially*. Manuscript submitted for publication.

Palan, S., & Schitter, C. (2018). Prolific.ac—A subject pool for online experiments. *Journal of Behavioral and Experimental Finance, 17*, 22–27. https://doi.org/10.1016/j.jbef.2017.12.004

Pegado, F., & Grainger, J. (2019). Dissociating lexical and sublexical contributions to transposed-word effects. *Acta Psychologica, 201*, 102943. https://doi.org/10.1016/j.actpsy.2019.102943

Pegado, F., & Grainger, J. (2020). A transposed-word effect in same-different judgments to sequences of words. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 46*(7), 1364–1371. https://doi.org/10.1037/xlm0000776

Pegado, F., & Grainger, J. (2021). On the noisy spatiotopic encoding of word positions during reading: Evidence from the change-detection task. *Psychonomic Bulletin & Review, 28*(1), 189–196. https://doi.org/10.3758/s13423-020-01819-3

Pegado, F., Wen, Y., Mirault, J., Dufau, S., & Grainger, J. (2021). An ERP investigation of transposed-word effects in same-different matching. *Neuropsychologia, 153*, 107753. https://doi.org/10.1016/j.neuropsychologia.2021.107753

R Core Team. (2021). *R: a language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.R-project.org

Snell, J., & Grainger, J. (2017). The sentence superiority effect revisited. *Cognition, 168*, 217–221. https://doi.org/10.1016/j.cognition.2017.07.003

Snell, J., & Grainger, J. (2019). Word position coding in reading is noisy. *Psychonomic Bulletin & Review, 26*(2), 609–615. https://doi.org/10.3758/s13423-019-01574-0

Snell, J., Meeter, M., & Grainger, J. (2017). Evidence for simultaneous syntactic processing of multiple words during reading. *PLoS One, 12*(3), e0173720. https://doi.org/10.1371/journal.pone.0173720

Snell, J., van Leipsig, S., Grainger, J., & Meeter, M. (2018). OB1-reader: A model of word recognition and eye movements in text reading. *Psychological Review, 125*(6), 969–984. https://doi.org/10.1037/rev0000119

van Heuven, W. J. B., Mandera, P., Keuleers, E., & Brysbaert, M. (2014). SUBTLEX-UK: A new and improved word frequency database for British English. *The Quarterly Journal of Experimental Psychology, 67*(6), 1176–1190. https://doi.org/10.1080/17470218.2013.850521

Wen, Y., Snell, J., & Grainger, J. (2019). Parallel, cascaded, interactive processing of words during sentence reading. *Cognition, 189*, 221–226. https://doi.org/10.1016/j.cognition.2019.04.013

Wen, Y., Mirault, J., & Grainger, J. (2021a). Fast syntax in the brain: Electrophysiological evidence from the rapid parallel visual presentation paradigm (RPVP). *Journal of Experimental Psychology: Learning, Memory, and Cognition, 47*(1), 99–112. https://doi.org/10.1037/xlm0000811

Wen, Y., Mirault, J., & Grainger, J. (2021b). The transposed-word effect revisited: The role of syntax in word position coding. *Language, Cognition and Neuroscience, 36*(5), 668–673. https://doi.org/10.1080/23273798.2021.1880608

Open practices statement The stimuli are listed in the Appendix. The data are available on the Open Science Framework (https://osf.io/m2gd3/).