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On the processing of canonical word order during eye fixations in reading: Do readers process transposed word previews?

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Abstract

Whether readers always identify words in the order they are printed is subject to considerable debate. In the present study, we used the gaze-contingent boundary paradigm (Rayner, 1975) to manipulate the preview for a two-word target region (e.g. *white walls* in *My neighbor painted the white walls black*). Readers received an identical (*white walls*), transposed (*walls white*), or unrelated preview (*vodka clubs*). We found that there was a clear cost of having a transposed preview compared to an identical preview, indicating that readers cannot or do not identify words out of order. However, on some measures, the transposed preview condition did lead to faster processing than the unrelated preview condition, suggesting that readers may be able to obtain some useful information from a transposed preview. Implications of the results for models of eye movement control in reading are discussed.

Keywords

Eye movements; reading; parafoveal processing; preview benefit; word order

A number of models have appeared during the past 15 years to account for the control of eye movements during reading. These models have been quite influential and have stimulated a great deal of research (for reviews see Rayner, 1998, 2009a, 2009b; Reichle, Rayner, & Pollatsek, 2003). While the models differ on a number of dimensions, most of them are able to fairly adequately account for important benchmark data regarding eye movements during reading. Thus, they are able to account for word frequency, predictability, and length effects, as well as preview benefit effects wherein a valid preview of a word prior to fixating it yields shorter fixation times on the word in comparison to an invalid preview. The two most influential models, the E-Z Reader model (Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle, Pollatsek, & Rayner, 2006, 2012; Reichle, Warren, & McConnell, 2009) and the SWIFT model (Engbert, Longtin, & Kliegl, 2002; Engbert, Nuthmann, Richter, & Kliegl, 2005; Schad & Engbert, 2012), share a number of similar features, but differ in two primary ways. First, E-Z Reader is a direct control model in the sense that on-going lexical processing drives the movements of the eyes across text. In SWIFT in contrast, lexical processing drives the eyes indirectly, by frequently delaying an autonomous timer that otherwise triggers saccades at random intervals. Second, in E-Z Reader words are lexically processed serially (i.e., one word at a time) while in SWIFT lexical processing occurs in parallel, so that multiple words can be processed at any given time. Due to this latter fundamental difference between the two models, E-Z Reader is generally classified as a serial attention shift (SAS) model, and SWIFT as what was originally called a guidance by attentional gradient (GAG) model, but more recently a processing gradient (PG) model. A

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critical consequence of this secondary difference is that E-Z Reader does not allow words to be identified out of the order in which they are printed, while SWIFT does (see the Discussion section).

In many languages (and especially in English), the word order in a sentence carries crucial information about the sentence's syntax and meaning. For example, the sentence *The home run was very exciting* does not mean the same thing as *The run home was very exciting*. Likewise, the sentence *This morning the rain fall was very light* does not mean exactly the same thing as when the word order is switched for two of the words as in *This morning the fall rain was very light*. Despite this, whether readers always identify words in the order they are printed has been somewhat debated recently. Specifically, Kennedy and Pynte (2008), proponents of a PG view of processing, claimed that readers can identify words out of order and maintain word order through a separate process, while Reichle, Liversedge, Pollatsek, and Rayner (2009), and Rayner, Pollatsek, Liversedge, and Reichle (2009), proponents of an SAS type of view, argued that readers always identify words in canonical order.

It has long been known that readers do not fixate each word in a sentence sequentially (Buswell, 1920; Kolers, 1976). Indeed, readers quite frequently skip over some words (especially short function words and highly predictable words, see Rayner, 2009a; Schotter, Angele, & Rayner, 2012 for reviews). And, sometimes (for example, when there is a sequence of very short words in succession) more than a single word will be skipped over. When a single word is skipped, it is often assumed within the context of SAS type models that the reader identified the word on the prior fixation. Alternatively, some skips may be due to readers making an “educated guess” about the next word (Brysbaert, Drieghe, & Vitu, 2005) or due to mislocated fixations or oculomotor error (Drieghe, Rayner, & Pollatsek, 2008). Skips are often followed by a regression to the skipped word, sometimes immediately, but sometimes not until a few words later and readers are much more likely to regress to a word that was skipped than one that was not skipped (Rayner, Juhasz, Ashby, & Clifton, 2003). Some of these situations in which readers regress to a skipped word may also stem from initially misperceiving it (Ehrlich & Rayner, 1981; Slattery, 2009), or maintaining uncertainty about its identity (Levy, Bicknell, Slattery, & Rayner, 2009). In these cases, later material in the text may either provide information that the word was misidentified or cause the reader's confidence about the word's identity to fall (Bicknell & Levy, 2010, 2011), resulting in a regression back to the misperceived word. Though there is no doubt that words are often fixated out of order in reading, readers do not experience “word salad” in reading and they seem to internally process words in the intended order (Kolers, 1976). But it is still unclear whether or not words are processed out of order via parallel processing or if an underlying serial processing mechanism is at work.

The first question, then, is whether transposition effects occur across two words (in English, letter strings separated by spaces). It is this issue for which E-Z Reader and SWIFT potentially differ in their predictions: If transposing a word pair does not cause readers any difficulties (i.e., if reading times for transposed and identical preview conditions are equivalent), that would be evidence in favor of parallel processing. On the other hand, if there are difficulties caused by transposition, this could be the result of the transposed words being processed in parallel, but their transposed order causing problems for the implied PG mechanism that keeps track of word order. Of course, SAS models would predict that words will always be processed in their canonical order and that processing can be disrupted by highly unusual word sequences. When readers skip a word, as noted above, within SAS models it is generally assumed that the word was processed on the prior fixation (thus preserving the correct word order). However, in those instances in which a word is initially skipped and then regressed to, some type of inner speech mechanism would preserve the correct word order (Rayner et al., 2009; Reichle, Liversedge et al., 2009).

A second question of interest is whether the presence of a transposed preview provides any type of benefit compared to a completely unrelated preview. There is some evidence that transposed morphemes within a word can provide some benefit. Yang (2013) reported a gaze-contingent boundary experiment (Rayner, 1975) in Chinese in which the character order of the preview for a two-character word was manipulated so that it could be either correct or transposed. Readers obtained the same amount of preview benefit from a transposed preview as from the correct preview, as long as the transposed characters (morphemes) plausibly fit into the sentence context. When the transposed characters did not fit in the sentence context, there was no preview benefit. Similarly, Angele and Rayner (2013) found that readers obtain preview benefit from a transposed preview in English, when the transposed units were constituents of a compound word (e.g., *cowboy*), although in this case the preview benefit was smaller than that obtained from the correct preview (presumably because the transposed preview, *boycow*, is not a word and would therefore not plausibly fit into the sentence). Taken together, these two results point to the possibility of a transposed preview benefit (pre-activation parafoveally), provided that the transposition is within a word, with plausibility playing a significant role. Contrary to these results, Drieghe, Pollatsek, Juhasz, and Rayner (2010) reported that preview benefit of the second half of a word is only obtained for monomorphemic words and constituents of compounds are processed serially. However, their study did not deal with morphemic transpositions. Importantly, in all of the experiments described in this paragraph, the target was a single word, which may lead to it being processed as a unitary whole. These experiments, therefore, do not provide evidence about whether similar benefits may also be found for word transpositions.

In the present study, we used the boundary paradigm (Rayner, 1975) to manipulate the preview for a two-word target region (e.g. *white walls* in *My neighbor painted the white walls black*). Readers received an identical (*white walls*), transposed (*walls white*), or unrelated preview (*vodka clubs*). If the transposed word preview provides the same amount of benefit as the identical preview, this would be evidence for parallel processing (Kennedy & Pynte, 2008) and suggest that readers could identify words out of order. On the other hand, if the identical condition is associated with shorter fixation times on the target region compared to the transposed condition, the results would be as predicted by a serial account of word identification that strictly maintains the canonical word order (although, as mentioned above, the results could also be accommodated by some parallel models; see the Discussion section below for more details). Additionally, the inclusion of the unrelated condition in our experiment enabled us to test whether the presence of a transposed word pair preview provided any preview benefit at all compared to the unrelated condition. If Yang's (2013) and Angele and Rayner's (2013) results generalize to word pairs, we should see shorter fixation times in the transposed preview condition compared to the unrelated preview condition. Alternatively, if readers do not obtain any useful information at all from a transposed preview, we should observe no difference between the transposed and the unrelated preview conditions.

Method

Subjects

Sixty University of California, San Diego students participated in this experiment for course credit. All were native speakers of English, had either normal or corrected to normal vision, and were naïve concerning the purpose of the experiment.

Apparatus

An SR Research Eyelink 1000 eyetracker was used to record subjects' eye movements with a sampling rate of 1000 Hz. Subjects read sentences displayed on an Iiyama Vision Master Pro 454 video monitor with a refresh rate of 150 Hz. Viewing was binocular, but only the right eye was recorded. Viewing distance was approximately 60 cm, with 3.8 letters equaling one degree of visual angle. A monospace font (Courier New) was used to ensure that all words of the same length had the same width on the screen.

Materials

One hundred and thirty-two experimental sentences were generated for the experiment. Each sentence contained a target region that consisted of two content words of the same length. Using the gaze-contingent boundary paradigm (Rayner, 1975), we manipulated the information available from the parafovea (i.e. the preview of the target region) while subjects were fixating to the left of the target region. For example, while subjects were fixating to the left of the target region *white walls* in the sentence *My neighbor painted the white walls black,* the parafoveal preview of the post-target word consisted of either (1) an identical preview of the target region (*white walls*), (2) a transposed preview of the target region (*walls white*), or (3) an unrelated word pair (*vodka clubs*). We created sentences for both possible orders of the target words (see Figure 1 for the full example), although each subject saw each pair of target words only once. Both the identical and the transposed preview were plausible up to the point at which they occurred within the sentence context while the unrelated preview was not, and word length of each of the preview words was always the same as the target region. Once subjects moved their eyes across the boundary located to the right of the pre-target word, the preview changed to the actual target region (*white walls*). For the most part, the two versions of the sentence did not dramatically change the meaning of the sentence as we were primarily interested in determining if transpositions per se would cause disruption in reading[1]. Furthermore, to ensure that the sentence as a whole was not unnatural it was necessary to have the end of the sentence (after the target region) differ between the identical and transposed conditions on two-thirds of the trials. Table 1 shows word frequency (from the Corpus of Contemporary American English, Davies, 2011), word length, and mean log bigram frequency (from the N-Watch software, Davis, 2005), and the Appendix lists all of the stimulus sentences.

Procedure

Readers started the experiment by completing a calibration and reading ten practice trials. Before each trial, a drift check was performed to ensure that the calibration was still accurate. If this was the case, subjects then started the trial by fixating a gaze target on the left side of the screen for 250 ms. If the drift check deviated too much from the previous calibration, the subject was re-calibrated. Another calibration was always performed before the start of the experimental trials.

During each of the experimental trials, the preview was replaced by the actual target region (e.g. *white walls*) once readers moved their eyes across the boundary. Our software was custom designed to perform display changes as rapidly as possible in order to ensure that they were not noticed by subjects. The median time to implement the display change was 8 ms. After the experiment, subjects were asked whether they had noticed anything unusual during the experiment. If subjects confirmed that they had seen a display change, they were asked to give an estimate of the number of changes they had seen. This was done because

[1]As a result, many of the transposed words also had some type of semantic relationship. However, semantic preview benefit has generally not been observed for readers of English (Rayner, Balota, & Pollatsek, 1986; see Schotter et al. for a review).

detecting a display change can have an effect on fixation times (Slattery, Angele, & Rayner, 2011; White, Rayner, & Liversedge, 2005). Most subjects were either entirely unaware of the changes or only reported seeing a few changes. All late occurring display changes were excluded from the data analyses (see below). Approximately 33% of the sentences were followed by a two-alternative forced choice comprehension question, which subjects answered by pressing the button corresponding to the correct answer on a button box.

Results

We computed a number of standard fixation time measures (Rayner, 1998, 2009a) on the entire target region as well as the first target word (Target 1), the second target word (Target 2), and the words preceding and following the target region (pre- and post-target, respectively). Specifically, we computed two early processing time measures, namely *first fixation duration* (FFD; mean duration of the first fixation on a word) and *gaze duration* (GD; the sum of the durations of all fixations on a word before leaving it), both calculated only for words that were not initially skipped, as is standard. We also calculated two later processing measures, *go-past time* (Go-past; all the fixations on the word and any regressive fixations before moving to the right) and *total viewing time* (TVT; the sum of the durations of all fixations on a word). Finally, we analyzed *the probability of a word being fixated, the probability of making a regression out* of a word together with the complementary measure, *the probability of making a regression into* a word. The *probability of regressions out* can be taken to reflect the difficulty subjects have with integrating the current word into the sentence context. The *probability of regressions in* can inform us as to where these regressions go, that is, what information subjects seek when they encounter processing difficulties.

We excluded all trials during which the display change completed more than 10 ms into the subsequent fixation[2]. Furthermore, if a fixation was shorter than 80 ms and located within one character space (11 pixels) of another fixation, it was merged into that fixation. Otherwise, it was deleted. For each eye movement measure that we analyzed, values that deviated from a subject's mean by more than two standard deviations were deleted as well (around 5% of the data). All subjects answered at least 85% of the comprehension questions correctly.

We report inferential statistics based on (generalized) linear mixed-effects models (LMM) with subjects and items as crossed random effects (Baayen, Davidson, & Bates, 2008). We fit the LMMs using the lmer function from the lme4 package (Bates, Maechler, & Dai, 2009) within the R Environment for Statistical Computing (R Development Core Team, 2011). For each factor, we report regression coefficients (b), standard errors, and t-values. We do not report p-values, since it is not clear how to determine the degrees of freedom for linear mixed-effects models, making it difficult to estimate p-values. However, since our analyses contain a large number of observations, subjects, and items and only a few fixed and random effects were estimated, we can assume that the distribution of the t-values estimated by the LMMs approximates the normal distribution. We will therefore use the two-tailed criterion $|t| \geq 1.96$ which corresponds to a significance test at the 5% α-level.

It was not always possible to generate sentence contexts that were completely unbiased (for example *the rare meat* might be more likely than *the meat rare* to follow a sentence starting

[2]Slattery et al. (2011) found that display changes which occurred more than 10 ms after the onset of a fixation can affect the duration of that fixation even when they are not consciously detected. In the present study, 19.64 % of the display changes completed more than 10 ms after fixation onset. In this case, we discarded the corresponding trial from the analysis. In order to ensure that the effects in the discarded data did not differ systematically from those observed in the rest of the data, we performed an additional analysis using a more lenient cutoff of 18 ms (9.2 % of data). The results of this analysis did not differ from the analysis with the 10 ms cutoff.

with *The chef cooked*) so we attempted to control for this by adding conditional word trigram predictability (conditional probability of the target region following the two preceding words) estimated from Kneser-Ney-smoothed trigram models estimated from an Americanized version of the British National Corpus as a second fixed effect. This conditional probability was a pure control variable in the analyses so we refrain from interpreting its associated coefficients.

As we were mostly interested in the differences between the transposed condition and each of the other two experimental preview conditions, we used two treatment contrasts the first of which compared the transposed condition to the unrelated condition and the second of which compared the transposed condition to the identical condition. As a result, the *t*-value for each contrast indicates if that comparison shows a significant difference between the two conditions, while the *b*-value reflects the magnitude of the difference, in ms. For the fixation probability and regression probability, logistic LMMs were used (Gelman & Hill, 2007) and the *b*-values give effect sizes in log-odds space (Agresti, 2002). The resulting *z* values can be interpreted exactly like *t* values. Finally, we included the interaction between conditional trigram probability and the two preview contrasts to determine whether predictability had an influence on the preview effect. In addition to these fixed effects, we used random intercepts for subjects and items, and random slopes for subjects and items for preview as well as random slopes for subjects only for conditional trigram predictability (which did not vary between items). More general models including random slopes for the interaction terms either did not converge or arrived at a singular convergence. For a few of the dependent variables, models including random slopes for conditional trigram probability did not converge either. In this case, we report models that only include random slopes for preview.

Another potential concern was that some of our sentences contained spaced compound words like *rain fall*, which are more commonly used as unspaced compounds (*rainfall*). To address this issue, we fit an additional set of LMMs including a predictor indicating whether a sentence contained a spaced compound that was more likely to occur as an unspaced compound word or not (according to internet searches). There were no significant interactions of this predictor with the other predictors described above on fixation time measures on the target region. Because of this, we only report the simpler LMMs containing the preview and conditional probability factors. We will now discuss the effects in detail.

Pre-target word

Table 2a shows the means for all dependent measures on the pre-target word, while Table 2b shows the LMM estimates for coefficients, standard errors, *t*-values for fixed effects, and variance estimates for random effects. Eye movement measures on the pre-target word were unaffected by the preview manipulation on the target region with four exceptions: (1) a significant difference between the unrelated and the transposed conditions in TVT (transposed: 261 ms, unrelated: 278 ms; $b = 20.52$, SE =9.32, $t = 2.2$) and (2) a significantly higher likelihood of making a regression into the pre-target word when the preview had been unrelated ($p = .23$) than when it had been transposed ($p = .18$; $b = .32$, SE =.14, $z = 2.31$). These results suggest that readers encountered more difficulties processing the target region when they had had an unrelated preview and were subsequently more likely to return to the pre-target word, whether in order to re-read the entire pre-target and target region or because of regressions that overshot the target region. Additionally, (3) we observed a significant interaction between preview and the conditional probability of the target word for go-past times. The interaction coefficients for both preview contrasts (transposed vs. unrelated: $b = -14.45$, SE = 6.43, $t = -2.25$; transposed vs. identical: $b = -15.18$, SE = 6.67, $t = -2.27$) suggest that the unrelated preview is associated with shorter go-past times (and, as a consequence, less disruption) when the target region is more predictable from the immediate context. There also was (4) a significant interaction between the transposed vs. identical preview contrast and conditional trigram probability ($b = -.22$, SE = .09, $z = -.253$), suggesting that the identical preview was associated with fewer regressions into the pre-target region when the target region was predictable from the immediate context.

Combined target region

We analyzed the target region as a whole and then split the region into the two target words. First, we present the analyses of the combined target region. Table 3a shows the means for all dependent measures on the combined target region, while Table 3b shows the LMM estimates for coefficients, standard errors, *t*-values for fixed effects and variance estimates for random effects. On the target region, we found strong effects of preview on all fixation time measures except for second pass time. First fixation duration (identical: 209 ms, transposed: 220 ms, $b = -12.56$, SE = 3.3, $t = -3.8$), gaze duration (identical: 392 ms; transposed: 418 ms, $b = -33.11$, SE = 8.57, $t = -3.86$), go-past time (identical: 513 ms, transposed: 570 ms, $b = -54.86$, SE = 14.49, $t = -3.79$), and total viewing time (identical: 537 ms, transposed: 618 ms, $b = -63.13$, SE = 13.92, $t = -4.54$) were all significantly shorter following the identical preview than the transposed preview. In addition, subjects were less likely to make regressions into the target region in the identical condition than in the transposed condition (identical: $p = .25$, transposed: $p = .28$; $b = -.34$, SE = .14, $z = -2.49$). There was no difference between the transposed and unrelated conditions in any dependent measures except for go-past time and the probability of making a regression out of the target region. In go-past time, we observed a significant difference between the transposed condition (570 ms) and the unrelated condition (615 ms, $b = 53.99$; SE = 17.26; $t = 3.13$). Additionally, the probability of making a regression out of the target region was higher in the unrelated condition ($p = .238$) than in the transposed condition ($p = .172$; $b = .39$, SE = .16, $z = 2.4$). This suggests that, while the target region is clearly easiest to process in the identical condition, the transposed condition does seem to provide some additional information compared to the unrelated condition. A similar effect was observed by Angele and Rayner (2013) on unspaced compound words.

First Target Word

Analyzing the target words separately enabled us to examine in more detail where exactly processing difficulties occur. Table 4a shows the means for all dependent measures on the first target word, while Table 4b shows the LMM estimates for coefficients, standard errors, *t*-values for fixed effects and variance estimates for random effects. The pattern of effects on the first target word was quite similar to that found on the combined target region: there was a significant preview benefit between the transposed and the identical conditions in all the dependent variables except for go-past time, where it was marginal (FFD: identical: 207, ms, transposed: 219 ms, $b = -12.50$, SE = 3.59, $t = -3.48$; GD: identical: 226 ms, transposed: 240 ms; $b = -14.36$, SE = 4.89, $t = -2.93$; go-past: identical: 286 ms, transposed: 309 ms, $b = -17.53$, SE = 9.2, $t = -1.91$ (marginal); TVT: identical: 297 ms, transposed = 335 ms, $b = -38.7$, SE = 8.65, $t = -4.48$). There was no difference between the transposed and the unrelated conditions except in go-past time (transposed: 309 ms, unrelated: 330 ms, $b = 25.18$, SE = 10.3, $t = 2.45$). Finally, readers were significantly more likely to make a regression into the first target word when the preview had been transposed ($p = .29$) than when it had been identical ($p = .19$, $b = -.73$, SE = .15, $z = -4.77$). This suggests that readers are likely to return to the beginning of the target region when a non-identical preview led to processing difficulties, perhaps relating to ambiguity about word order.

Second Target Word

Table 5a shows the means for all dependent measures on the second target word, while Table 5b shows the LMM estimates for coefficients, standard errors, *t*-values for fixed effects and variance estimates for random effects. As in the combined target region, go-past time and total viewing time were shorter in the identical than the transposed condition (go-past: identical: 306 ms, transposed: 331 ms, $b = -27.73$, SE = 10.73, $t = -2.4$, TVT: identical: 309 ms, transposed: 335 ms, $b = -27.44$, SE = 8.98, $t = -3.06$), but the effects did not reach significance in FFD and GD. However, there was a significant difference in gaze duration between the transposed (248 ms) and the unrelated condition (238 ms, $b = -10.31$, SE = 5.21, $t = -1.98$). Interestingly, this effect was in the opposite direction of those observed on the combined target region and the first target word. The second target word was also fixated more often when its preview had been transposed ($p = .85$) than when it has been identical ($p = .81$, $b = -.28$, SE = .15, $t = -2.75$). Additionally, readers made more regressions out of the second target word when the preview had been transposed than when it had been identical (identical: $p = .18$, transposed: $p = .13$, $b = -.47$, SE = .15, $z = -3.1$).

Post-target word

Table 6a shows the means for all dependent measures on the post-target word, while Table 6b shows the LMM estimates for coefficients, standard errors, t-values for fixed effects and variance estimates for random effects. There were no effects of preview on any of the dependent measures, with two exceptions: (1) a higher likelihood of making a regression out of the post-target word when the target preview had been transposed ($p = .14$) than when it had been identical ($p = .11$, $b = -.31$, SE = .15, $z = -2.13$) and (2) significant interactions between preview and the conditional probability of the target region on the probability of fixating the target region ($b = .63$, SE = .18, $z = 3.57$) and of making a regression into the post-target region ($b = .2$, SE = .09, $z = 2.16$). This interaction indicates that the difference in terms of fixations and regressions into the post-target region between the identical and the transposed conditions was larger for more predictable words than for less predictable words. A similar effect was observed on go-past time ($b = 15.29$, SE = 7.52, $t = 2.03$), with the difference in go-past times between the identical and the transposed condition being larger for more predictable words than for less predictable words. Both this and the effect on regressions out are clearly spillover effects of the difficulty of processing the target region caused by a non-identical preview.

Post-hoc analysis: The consequences of skipping the pre-target word

Due to the constraint that the two preview words be the same length as target words, the pre-target word had to be an article or another high-frequency function word in many of our sentences (see Appendix for a list of all experimental sentences). As a consequence, readers were quite likely to skip the pre-target word, and did so on slightly less than 50% of the trials (see Table 2a). Since skipping the pre-target word is likely to have reduced the amount of preview benefit a reader could obtain, it is possible that trials in which the pre-target word was fixated and those in which it was skipped differ systematically in terms of preview effects. In order to investigate this, we performed an additional set of LMMs on fixation time and probability measures on the target region. These LMMs included, apart from all the predictors described above, a fixed effect which indicated whether the pre-target word had been skipped as well as the interactions of that predictor with the preview contrasts and conditional probability (including the three-way-interaction). Table 7 shows condition means as a function of whether the pre-target word was fixated or skipped. In terms of random effects, the models contained the same effects as most of the models described above, that is, random intercepts for subjects and items as well as random slopes for preview for subjects and items and random slopes for conditional trigram probability for subjects only[3]. In the following, we will only report significant interactions between pre-target fixation status and preview. On the combined target region, the skipping status of the pre-target word significantly influenced the size of the difference between the transposed and the unrelated condition in FFD ($b = -6.75$, SE = 2.9, $t = -.2.29$) and GD ($b = -18.36$, SE = 8.53, $t = -2.15$). In order to investigate these differences further, we performed separate analyses for those cases in which the pre-target word was skipped and those in which it was fixated. On the combined target region, we found no significant preview effects on FFD in either analysis, however, there was a significant difference between the transposed (419 ms) and the unrelated preview condition (452 ms) on GD when the pre-target had been fixated (b = 27.73, SE = 13.072, t = 2.12), but not when the pre-target had been skipped (t < .5). On the first target word, the interaction between the transposed vs. unrelated contrast and pre-target fixation status reached significance in GD (b = −9.98, SE = 4.37, t = −2.28), but not in FFD. In follow-up analyses, the same pattern as for the combined target region was observed on GD on the first target word, with the difference between the transposed (238 ms) and the unrelated condition (254 ms) reaching significance when the pre-target word had been fixated (b = 16.1, SE = 8.0, t = 2.02), but not when it had been skipped (t < .5). Finally, there was a three-way interaction between the identical vs. transposed contrast, the fixation status of the pre-target word, and the conditional probability of the target region in FFD on the second target word (b = 5.26, SE = 2.13, t = 2.47), with the interaction between skipping status and the difference between the identical and transposed preview conditions stronger for high-probability words. Because this interaction involves skipping status of the pre-target word and fixation duration on the second target word this is likely a consequence of non-independence between the likelihood of skipping one word and another, nearby word (rather than a reflection of ongoing cognitive processing). Relatedly, because conditional probability (which is related to the predictability of a word) is also highly related to skipping (more predictable words are more likely to be skipped) this three-way interaction is probably a consequence of the eye movement behavior but not theoretically relevant.

In the later measures of go-past time and TVT on the combined target region, the fixation status of the pre-target word also interacted with the contrast between the identical and the transposed preview conditions (go-past: b = 26.8, SE = 12.7, t = 2.35; TVT: b = 42.42, SE = 10.96, t = 3.87). Just as for GD, separate analyses showed that preview effects were present when the pre-target word had been fixated, but were absent when the pre-target word had been skipped. In general, it appears that the benefit gained from having an identical preview of the target region was reduced when the pre-target word had been skipped. This is hardly unexpected as readers skipping the pre-target received less preview information about the target region (due to a further viewing distance and intervening word to be processed) than those who fixated the pre-target. A similar effect reached significance in the analysis of the probability of making a regression into the target region: readers were more likely to make a regression back into the target region in the identical condition compared to the transposed condition when they had skipped the pre-target word (b = .31, SE = .11, z = 2.79). In TVT on the second target word, there was a significant interaction between the identical vs. unrelated preview contrast and the pre-target fixation status, which can be interpreted as described above (b = 17.41, SE = 7.53, t = 2.31).

Finally, on the post-target word, we observed a significant spillover interaction effect between fixation status of the pre-target word and the identical vs. transposed contrast in go-past time (b = 28.56, SE = 11.39, t = 2.51). In separate analyses, the difference between the identical and transposed condition was significant when the pre-target word had been fixated, but not when it had been skipped. A similar effect was present on the probability of making regressions out of the post-target word (b = .433, SE = .15, t = 2.9). These effects,

[3]The latter random effect had to be omitted from the model for TVT on the first target word, as this model did not converge if it was included. Furthermore, the models for regressions into the second target word and the combined target region as well as those for fixation probability of the combined target region and the post-target word only converged when both random slopes for conditional trigram probability for subjects and random slopes for preview for items were removed from the model. It should be noted that the coefficients and t-values for the interaction terms are potentially anticonservative, since the models do not contain random slopes for the interaction. The more appropriate models including the random interaction slopes failed to converge for any of the dependent variables.

together with the interaction effect on regressions into the target region, suggest that readers tended to make more regressions from the post-target word to the target region when they had skipped the pre-target word in the identical condition. The cause of this behavior is not clear at this point. No other interactions with the pre-target fixation status reached significance.

In summary, this post-hoc analysis showed some interesting differences in the effect of our preview manipulation when the pre-target word had been skipped, which generally showed evidence that preview effects were larger when the pre-target word was fixated. Importantly, however, when the pre-target word had not been skipped, the pattern of effects was very similar to that observed in the main analysis.

Discussion

In the present experiment, there are two main findings. First, we found a robust effect of preview on fixation time, with identical previews resulting in faster processing once the target was fixated relative to transposed previews and unrelated previews[4]. As a consequence, our data demonstrate that word order is very important for identifying words during reading and there is a cost to processing words out of the order intended in the sentence. The results fit rather nicely with the predictions from E-Z Reader in that when word *n+1* (*walls*) and word *n+2* (*white*) in the transposed preview change to the correct word order (*white walls*), the reader should experience disruption in that he or she pre-processed the parafoveal word *walls* only to find that the fixated word following the saccade to the first target word is *white*. While our results with respect to early processing are quite consistent with E-Z Reader, they are not really damaging to SWIFT in that the model, while in principle a parallel model, can become a serial processing type of mechanism depending upon the exact circumstances (Engbert et al., 2005). Moreover, in SWIFT the dynamic field of activations inherent in the model seems to indicate that each word has its own location-specific activation slot with a maximum activation level relative to its word difficulty. After transposing the target words, new words would presumably have to be encoded at the specific word slots and processing might have to restart (see Kliegl & Engbert, 2003). In another PG type of model, Glenmore (Reilly & Radach, 2006), a letter unit vector explicitly codes the order of all letters within the current perceptual span. The individual letter units accumulate visual information about the identity of the corresponding letters and feed this information to the word level, where words become more and more activated until they reach saturation. Critically, letters and words must maintain their relative position from fixation to fixation no matter what the current level of activation is in each unit. Thus, in the context of Glenmore, the reason for the similar early measure preview effects in the unrelated and transposed conditions would be that in both cases the individual units in the letter input vector get completely new visual input. They cannot take advantage of the fact that the same sequence was available somewhere else in the perceptual span during the prior fixation.

While SWIFT and Glenmore can account for the data from the present experiment, they are quite problematic for the more extreme view of parallel processing espoused by Kennedy and Pynte (2008). Kennedy and Pynte argued that processing words in order is not typical and that parallel processing mechanisms are ubiquitous in reading. Their arguments rely on a corpus analysis in which they examined the frequency with which word sequences were not fixated in canonical order. They found that this occurred quite frequently in their corpus

[4]The null-hypothesis significance testing methods used in our analysis do not allow us to conclude that our results show that there was no difference between transposed and unrelated previews, as this would amount to arguing for the null hypothesis in the absence of statistical support against it.

(with many words skipped, sometimes without a regression to the skipped word). They found that out-of-order fixations seemed to have little effect on immediate processing times of words and only limited evidence of longer lasting effects. Thus, they argued that their results were very problematic for SAS models like E-Z Reader and more consistent with PG models like SWIFT. But, they also argued that their results were problematic for SWIFT given the current implementation of the model. Our view is that the current experiment provides a more direct test of canonical word order processing than does their study.

The second main finding of this study is that we found faster processing of the target relative to the unrelated condition when the preview had been transposed both in gaze duration on the combined target region and the first target word, in the case that the pre-target word had been fixated, and in go-past time on and regressions out of the target region regardless of the fixation status of the pre-target word. These data seem to demonstrate that the presence of the transposed words in the parafovea has some effect on processing. There are at least two possible explanations for this. First, the apparent preview benefit of having the correct words in the wrong order in the transposed condition might actually be a preview cost of having an unrelated word preview in the unrelated condition. Indeed, the unrelated words in the unrelated condition are of slightly lower frequency than the actual target words and likely also less predictable from (or plausible in) the sentence context. However, both the actual Words 1 and 2 and the unrelated previews were still quite common on average (both mean frequencies greater than 100 per million), so that at least the influence of frequency might be quite limited. Second, parafoveal information that readers obtain about the second word in the pair (the first word in the preview) may assist with some later process. For example, readers who received unrelated previews are likely to assume they have landed in the wrong location, and make a regression to return to a familiar part of the text, but readers who received a transposed preview may merely think that they initially missed a word. This account, with readers being able to use information about the upcoming words in some way even if they are transposed, fits in quite well with Yang's (2013) and Angele and Rayner's (2013) results concerning compound words, with at least some benefit resulting from the transposed preview of a compound word compared to an unrelated preview. Based on these results, one might speculate that readers obtain some orthographic or feature level information from the entire perceptual span (that is, pre-attentively), while lexical processing necessitates moving one's attention to a word.

Regardless of whether the above speculations are correct, the data reported here are clearly not compatible with an account that allows words to be identified without any regard to order (an extreme version of parallel processing as per Kennedy & Pynte, 2008). If that were the case, we should have found no difference in fixation times on the target region between the identical and the transposed preview conditions. The fact that we did find a significant difference between the transposed and the unrelated conditions on some measures on the target region does not imply that words in the target region can be processed out of order. Instead, these results merely suggest that readers can obtain some useful information from either of the words in the target region. This does not have to be high-level information, and in fact it is quite likely that the information that readers use is either orthographic or even of a lower level (e.g. readers might be using word initial letters, word shape, and word length to determine whether a saccade was successful in moving the gaze to a target word or not).

In summary, while the results from the present study can be accounted for in the context of PG models like SWIFT and Glenmore that might allow for the possibility that readers identify words out of order, they are naturally predicted by SAS models like E-Z Reader without any additional assumptions. But, the fact that there was an advantage for the transposed condition over the unrelated condition in some measures (gaze duration contingent on fixation the pre-target word, go-past time, and regressions out of the target region) suggests that a transposed word preview yields some, likely low level, information that readers can use.

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Appendix

List of pairs of stimuli for each order of the target words (bolded). Transposed previews were produced by switching the order of the target words. Unrelated previews are in parentheses.

1 a. This morning the **fall rain** was very light.	(nose lift)
1 b. This morning the **rain fall** was very light.	(lift nose)
2 a. We parked by the **road side** to view the scenery.	(onto west)
2 b. We parked by the **side road** to view the scenery.	(west onto)
3 a. The little girl’s **shoe lace** became untied.	(dean alas)
3 b. The little girl’s **lace shoe** became dirty.	(alas dean)
4 a. She drank her **tea hot** from the kettle.	(led die)
4 b. She drank her **hot tea** straight from the kettle.	(die led)
5 a. I saw the **boat sail** on its own.	(mock feed)
5 b. I saw the **sail boat** move on its own.	(feed mock)
6 a. You can hear the **snakes rattle** their tails.	(middle critic)
6 b. You can hear the **rattle snakes** outside in the bushes.	(critic middle)
7 a. My neighbor painted the **white walls** black.	(vodka clubs)
7 b. My neighbor painted the **walls white** today.	(clubs vodka)
8 a. Because it had snowed all morning the **walk back** to town was very difficult.	(find soft)
8 b. Because it had snowed all morning the **back walk** was covered with snow.	(soft find)
9 a. The girl who walked by had a **thin twig** in her hands.	(lacy flow)
9 b. The girl who walked by had a **twig thin** figure.	(flow lacy)
10 a. I saw the **crew boat** on the lake.	(feed ours)
10 b. I saw the **boat crew** on deck.	(ours feed)
11 a. There was a **cave dark** as the night.	(fish mess)
11 b. There was a **dark cave** near my house.	(mess fish)
12 a. He had a **bone pale** complexion and scary eyes.	(jobs kiss)
12 b. He had a **pale bone** pendant hanging from his neck.	(kiss jobs)
13 a. He watched as the **shut door** opened by itself.	(five idol)
13 b. He watched as the **door shut** on its own.	(idol five)
14 a. Their son likes to **jump high** when he is happy.	(kept gang)
14 b. Their son likes to **high jump** for the track team.	(gang kept)
15 a. The chef cooked the **meat rare** for the couple.	(moon wood)
15 b. The chef cooked the **rare meat** for a little longer.	(wood moon)
16 a. She grew her **hair long** over the winter.	(keep free)
16 b. She grew her **long hair** out even more.	(free keep)
17 a. He made the table’s **dull wood** shinier using wax.	(meat lift)
17 b. He made the table’s **wood dull** with so much use.	(lift meat)
18 a. There is a **thin wire** inside the instrument.	(uses flow)
18 b. There is a **wire thin** cord holding everything together.	(flow uses)
19 a. The soldier checked the **tank fuel** earlier in the week.	(bird ford)
19 b. The soldier checked the **fuel tank** of his vehicle.	(ford bird)
20 a. You have to keep your **coat warm** by the fire.	(mine evil)

20 b. You have to keep your **warm coat** on when it's snowing.	(evil mine)
21 a. She opened her notebook to a **full page** of notes.	(guys bath)
21 b. She opened her notebook to a **page full** of notes.	(bath guys)
22 a. We all got some **food free** from the event today.	(hair dark)
22 b. We all got some **free food** from the event today.	(dark hair)
23 a. He waited for the **year long** experiment to be over.	(keep give)
23 b. He waited for the **long year** to finally end.	(give keep)
24 a. She made up for the **time lost** by studying extra the next day.	(dark down)
24 b. She made up for the **lost time** by spending an extra day studying.	(down dark)
25 a. The powerful air conditioning made the **room cold** enough for John.	(oath ever)
25 b. The powerful air conditioning made the **cold room** even colder.	(ever oath)
26 a. Why are the **wild dogs** barking so much?	(tape soft)
26 b. Why are the **dogs wild** and uncontrollable?	(soft tape)
27 a. The teacher called my **last name** to give me my test back.	(miss took)
27 b. The teacher called my **name last** when checking attendance.	(took miss)
28 a. Why are the **lights bright** in the house at this hour?	(knight tights)
28 b. Why are the **bright lights** on if no one is home?	(tights knight)
29 a. On the beach I felt the **sand warm** on my feet.	(mine cool)
29 b. On the beach I felt the **warm sand** on my feet.	(cool mine)
30 a. I liked the **lake blue** colored crayon.	(thin kids)
30 b. I liked the **blue lake** in the mountains.	(kids thin)
31 a. This gold will make the **king rich** when we give it to him.	(wait drop)
31 b. This gold will make the **rich king** even richer.	(drop wait)
32 a. He had to make a **move fast** to win the game.	(lead area)
32 b. He had to make a **fast move** to win the game.	(area lead)
33 a. We saw his **carrot orange** hair from across the field.	(essays rinsed)
33 b. We saw his **orange carrot** fall from his pocket.	(rinsed essays)
34 a. You have to keep your **sharp knife** in a safe place.	(finds clung)
34 b. You have to keep your **knife sharp** at all times.	(clung finds)
35 a. Why are the **leaky pipes** still being used?	(paper daily)
35 b. Why are the **pipes leaky** when we've just bought them?	(daily paper)
36 a. Until what time was the **room open** last night?	(ajar ever)
36 b. Until what time was the **open room** full of people last night?	(ever ajar)
37 a. This other answer is **also true** according to the book.	(form idea)
37 b. This other answer is **true also** according to the book.	(idea form)
38 a. He hid his **secret family** from his wife for years.	(levity normal)
38 b. He hid his **family secret** for years before finally telling someone.	(normal levity)
39 a. Did the family **just move** to the neighborhood?	(area good)
39 b. Did the family **move just** this past year?	(good area)
40 a. We went to the **resort island** over the summer.	(actual varied)
40 b. We went to the **island resort** over the summer.	(varied actual)
41 a. The new wallpaper is **marked easily** by your hands.	(swanky credit)
41 b. The new wallpaper is **easily marked** by your hands.	(credit swanky)

42 a. The large fire was **caused partly** by carelessness.	(grotty normal)
42 b. The large fire was **partly caused** by carelessness.	(normal grotty)
43 a. Next Friday they are having a **party night** for just the girls.	(wight gouty)
43 b. Next Friday they are having a **night party** on a yacht.	(gouty wight)
44 a. Your friend Lucy **seemed really** bored in class today.	(smutty moment)
44 b. Your friend Lucy **really seemed** bored in class today.	(moment smutty)
45 a. Did the **object thrown** from the boat hit anyone?	(flower rhymed)
45 b. Did the **thrown object** hit anyone?	(rhymed flower)
46 a. This lemonade has too much **sugar added** into it.	(offal ropes)
46 b. This lemonade has too much **added sugar** in it.	(ropes offal)
47 a. It's time to drive to the **next town** on the schedule.	(hear used)
47 b. It's time to drive to the **town next** on the schedule.	(used hear)
48 a. The bus driver **spoke often** of his previous job.	(allow spats)
48 b. The bus driver **often spoke** of his previous job.	(spats allow)
49 a. The rocks were **easily pushed** off the road.	(jackal swanky)
49 b. The rocks were **pushed easily** off the road.	(swanky jackal)
50 a. We finally found the **lost keys** in the couch.	(tape dark)
50 b. We finally found the **keys lost** in the couch.	(dark tape)
51 a. Make sure he has **orders signed** by the captain.	(repeat silver)
51 b. Make sure he has **signed orders** from the captain.	(silver repeat)
52 a. She picked the **rose pink** dress to wear to the dance.	(yard news)
52 b. She picked the **pink rose** to wear to the dance.	(news yard)
53 a. These cars were **chosen mainly** for their speed.	(nearly advice)
53 b. These cars were **mainly chosen** for their speed.	(advice nearly)
54 a. Luckily, we landed on **nearby ground** instead of the water.	(permit nearly)
54 b. Luckily, we landed on **ground nearby** the lake.	(nearly permit)
55 a. The family drove down the **road west** of town.	(sick said)*
55 b. The family drove down the **west road** this morning.	(said sick)*
56 a. He had always **talked openly** about his life.	(sporty lethal)
56 b. He had always **openly talked** about his life.	(lethal sporty)
57 a. Last weekend he watched the **live game** on television.	(poor turn)
57 b. Last weekend he watched the **game live** on television.	(turn poor)
58 a. The sled driver let his **lead dogs** guide him through the snowstorm.	(tape foot)
58 b. The sled driver let his **dogs lead** him through the snowstorm.	(foot tape)
59 a. Is it possible to recover the **lost data** from the crash?	(kids dark)
59 b. Is it possible to recover the **data lost** during the crash?	(dark kids)
60 a. I forgot my **full case** of CDs at home.	(seen bath)
60 b. I forgot my **case full** of CDs at home.	(bath seen)
61 a. She dropped the **pen ink** all over her paper.	(cab jam)
61 b. She dropped the **ink pen** onto the floor.	(jam cab)
62 a. Today we had **fruit fresh** from the market.	(tired beach)
62 b. Today we had **fresh fruit** from the market.	(beach tired)
63 a. I visited the **grave stone** again this morning.	(clean panic)

63 b. I visited the **stone grave** again this morning.	(panic clean)
64 a. I bought the **cheap books** online last week.	(trade stony)
64 b. I bought the **books cheap** online last week.	(stony trade)
65 a. He made his **debt huge** by gambling all the time at the casino.	(boys bull)
65 b. He made his **huge debt** disappear by winning big at the casino.	(bull boys)
66 a. We watched as the **bent pole** finally broke.	(guts fuel)
66 b. We watched as the **pole bent** under the fallen tree.	(fuel guts)

*For Item 55, the identical preview was displayed instead of the unrelated preview due to a programming error. Analyses performed excluding Item 55 showed the same pattern of results as analyses including it.

Sentence frame	Preview condition	Example
1	Identical	My neighbor painted the white walls black.
1	Transposed	My neighbor painted the walls white black.
1	Unrelated	My neighbor painted the clubs vodka black.
2	Identical	My neighbor painted the walls white today.
2	Transposed	My neighbor painted the white walls today.
2	Unrelated	My neighbor painted the vodka clubs today.

Figure 1.
Example sentence frames and preview conditions for the word pair “white walls.” Each subject only saw one sentence frame per word pair. After readers fixated to the right of the invisible boundary (dashed line), the display changed to the correct preview condition corresponding to the sentence frame.

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Table 1

Properties of the target region

Measure	Mean (SD)
Word 1 and 2 frequency (in occurrences/million)	182.88 (259.9)
Word 1 and 2 mean log bigram frequency	2.99 (0.44)
Word 1 and 2 unrelated preview frequency	117.90 (172.2)
Word 1 and 2 unrelated preview mean log bigram frequency	2.85 (0.43)
Word 1 and 2 length	4.53 (0.86)
Acceptability within the sentence context (on a scale from 1 – unacceptable to 7 – perfectly acceptable)	4.88 (0.74)

Note that each word in a pair was presented (to different subjects) as both Word 1 and Word 2, so that the frequency counts for Word 1 and Word 2 are the same.

Frequency estimates are derived from the Corpus of Contemporary American English (Davies, 2011). This corpus has a total of 450 million words.

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Table 2a

Condition means on the pre-target word.

	Fixation time measures				Probabilities		
	First fixation duration	**Gaze duration**	**Go-past time**	**Total viewing time**	**Fixation probability**	**Probability of regressions in**	**Probability of regressions out**
Identical	200 (58.8)	212 (74.8)	261 (153)	257 (131)	0.521 (0.5)	0.172 (0.378)	0.0709 (0.257)
Transposed	200 (59.7)	213 (76.6)	269 (158)	261 (141)	0.526 (0.5)	0.18 (0.384)	0.082 (0.275)
Unrelated	196 (56.6)	205 (69.4)	257 (153)	278 (151)	0.553 (0.497)	0.232 (0.423)	0.0899 (0.286)

Standard deviations are in parentheses.

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Table 2b

LMM analyses on the pre-target word. Each column represents a model.

		First fixation duration			Gaze duration*			Go-past time*			Total viewing time			Fixation probability			Probability of regressions in			Probability of regressions out		
		b	SE	*t*	*b*	SE	*t*	*b*	SE	*t*	*b*	SE	*t*	*b*	SE	*z*	*b*	SE	*z*	*b*	SE	*z*
	(Intercept)	198.29	4.02	**49.38**	208.94	5.36	**38.95**	263.13	9.93	**26.49**	254.71	9.03	**28.21**	0.16	0.15	1.10	−1.74	0.15	**−11.97**	−2.90	0.20	**−14.76**
Preview	Transposed vs. Unrelated	−2.00	3.59	−0.56	−5.86	4.68	−1.25	−3.50	10.03	−0.35	20.52	9.32	**2.20**	0.13	0.11	1.23	0.32	0.14	**2.31**	0.31	0.20	1.54
	Transposed vs. Identical	1.17	4.02	0.29	1.01	5.31	0.19	−5.31	10.45	−0.51	−2.09	8.78	−0.24	−0.03	0.11	−0.24	−0.07	0.13	−0.55	−0.03	0.21	−0.12
Conditional trigram probability	Word 1 and Word 2	4.16	1.73	**2.41**	3.78	2.33	1.62	9.17	4.49	**2.04**	4.30	4.07	1.06	−0.02	0.06	−0.30	0.07	0.07	0.99	0.12	0.09	1.30
Interactions	Transposed vs. Unrelated × Conditional probability	−3.00	2.40	−1.25	−4.19	3.05	−1.38	−14.45	6.43	**−2.25**	−4.77	5.50	−0.87	−0.06	0.07	−0.85	−0.12	0.09	−1.33	−0.10	0.12	−0.85
	Transposed vs. Identical × Conditional probability	−3.16	2.57	−1.23	−3.20	3.32	−0.96	−15.18	6.67	**−2.27**	−4.88	5.49	−0.89	−0.13	0.07	−1.88	−0.22	0.09	**−2.53**	−0.16	0.12	−1.31
Random effects: Item	(Intercept)	36.14	6.01	NA	224.35	14.98	NA	396.09	19.90	NA	907.16	30.12	NA	0.76	0.87	NA	0.30	0.54	NA	0.14	0.37	NA
	Preview: Transposed vs. Unrelated	40.49	6.36	NA	82.77	9.10	NA	936.58	30.60	NA	928.40	30.47	NA	0.00	0.01	NA	0.24	0.49	NA	0.00	0.07	NA
	Preview: Transposed vs. Identical	210.67	14.51	NA	445.87	21.12	NA	1634.00	40.42	NA	954.93	30.90	NA	0.00	0.01	NA	0.06	0.25	NA	0.03	0.18	NA
Random effects: Subject	(Intercept)	557.63	23.61	NA	898.74	29.98	NA	3070.20	55.41	NA	2218.84	47.10	NA	0.27	0.52	NA	0.49	0.70	NA	1.03	1.02	NA
	Preview: Transposed vs. Unrelated	11.67	3.42	NA	74.06	8.61	NA	225.81	15.03	NA	783.63	27.99	NA	0.07	0.26	NA	0.01	0.10	NA	0.41	0.64	NA
	Preview: Transposed vs. Identical	18.71	4.33	NA	60.17	7.76	NA	0.84	0.92	NA	204.99	14.32	NA	0.08	0.28	NA	0.00	0.02	NA	0.43	0.65	NA
	Conditional trigram probability	0.84	0.92	NA	*	*	*	*	*	*	7.29	2.70	NA	0.00	0.05	NA	0.00	0.02	NA	0.03	0.18	NA
Residual	Error	2874.60	53.62	NA	4604.56	67.86	NA	19390.00	139.25	NA	16533.89	128.58	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

b: Regression coefficient, SE: standard error, *t* or *z*: test statistic (*b*/SE). Cells with |*t*| or |*z*| >= 1.96 are marked in bold.

*denotes dependent variables for which the model including a random slope for conditional trigram probability by subjects did not converge or reached a singular convergence. For these dependent variables we report a restricted model without that random slope.

Asterisks (*) mark cases in which models without random slopes for conditional trigram probability for subjects were used, as the more general models did not converge.

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Table 3a

Condition means on the combined target region

	Fixation time measures				Probabilities		
	First fixation duration	**Gaze duration**	**Go-past time**	**Total viewing time**	**Fixation probability**	**Probability of regressions in**	**Probability of regressions out**
Identical	209 (57.9)	392 (188)	513 (281)	537 (251)	0.985 (0.123)	0.245 (0.431)	0.168 (0.374)
Transposed	220 (66.1)	418 (207)	570 (318)	595 (277)	0.987 (0.112)	0.278 (0.448)	0.172 (0.378)
Unrelated	220 (69.5)	433 (204)	615 (313)	618 (270)	0.989 (0.104)	0.284 (0.451)	0.238 (0.426)

Standard deviations are in parentheses.

Table 3b

LMM analyses on the combined target region. Each column represents a model.

		First fixation duration			Gaze duration			Go-past time			Total viewing time			Fixation probability			Probability of regressions in*			Probability of regressions out		
		b	**SE**	***t***	***b***	**SE**	***t***	***b***	**SE**	***t***	***b***	**SE**	***t***	***b***	**SE**	***z***	***b***	**SE**	***z***	***b***	**SE**	***z***
	(Intercept)	221.24	4.25	**52.03**	421.03	14.45	**29.14**	569.28	22.24	**25.60**	600.66	21.38	**28.09**	6.32	0.59	**10.80**	−1.09	0.12	**−8.76**	−1.80	0.14	**−12.44**
Preview	Transposed vs. Unrelated	−0.48	3.66	−0.13	9.95	9.39	1.06	53.99	17.26	**3.13**	25.31	14.27	1.77	11.00	3.77	**2.92**	0.03	0.11	0.27	0.39	0.16	**2.40**
	Transposed vs. Identical	−12.56	3.30	**−3.80**	−33.11	8.57	**−3.86**	−54.86	14.49	**−3.79**	−63.13	13.92	**−4.54**	0.49	0.87	0.56	−0.34	0.14	**−2.49**	−0.09	0.13	−0.65
Conditional trigram probability	Word 1 and Word 2	0.75	1.65	0.45	−9.76	4.56	**−2.14**	−16.17	7.16	**−2.26**	−22.54	6.61	**−3.41**	−0.26	0.36	−0.74	−0.05	0.05	−0.99	0.03	0.07	0.48
Interactions	Transposed vs. Unrelated × Conditional probability	1.31	2.10	0.62	5.55	5.84	0.95	−4.24	9.73	−0.44	−2.42	8.09	−0.30	0.03	1.33	0.02	−0.14	0.07	−1.93	−0.08	0.09	−0.85
	Transposed vs. Identical × Conditional probability	−2.51	1.97	−1.28	−0.12	5.56	−0.02	−7.20	8.77	−0.82	−4.16	7.57	−0.55	−0.32	0.49	−0.65	−0.07	0.08	−0.86	−0.14	0.09	−1.60
Random effects: Item	(Intercept)	158.01	12.57	NA	1114.25	33.38	NA	6581.72	81.13	NA	4991.31	70.65	NA	1.93	1.39	NA	0.02	0.16	NA	0.27	0.52	NA
	Preview: Transposed vs. Unrelated	185.91	13.63	NA	596.38	24.42	NA	6552.34	80.95	NA	2553.14	50.53	NA	68.61	8.28	NA	0.02	0.13	NA	0.40	0.63	NA
	Preview: Transposed vs. Identical	75.54	8.69	NA	37.34	6.11	NA	1936.75	44.01	NA	1545.54	39.31	NA	5.44	2.33	NA	0.11	0.33	NA	0.01	0.10	NA
Random effects: Subject	(Intercept)	693.29	26.33	NA	9397.27	96.94	NA	18821.21	137.19	NA	19229.29	138.67	NA	2.72	1.65	NA	0.55	0.74	NA	0.49	0.70	NA
	Preview: Transposed vs. Unrelated	139.16	11.80	NA	489.11	22.12	NA	2182.00	46.71	NA	2538.56	50.38	NA	80.02	8.95	NA	0.01	0.10	NA	0.24	0.49	NA
	Preview: Transposed vs. Identical	100.67	10.03	NA	261.11	16.16	NA	1374.14	37.07	NA	3120.36	55.86	NA	3.03	1.74	NA	0.24	0.49	NA	0.01	0.12	NA
	Conditional trigram probability	24.17	4.92	NA	150.68	12.28	NA	57.35	7.57	NA	311.95	17.66	NA	0.47	0.69	NA	*	*	*	0.01	0.11	NA
Residual	Error	3459.08	58.81	NA	29411.04	171.50	NA	70350.74	265.24	NA	49525.28	222.54	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

b: Regression coefficient, SE: standard error, *t* or *z*: test statistic (*b*/SE). Cells with $|t|$ or $|z| >= 1.96$ are marked in bold.

Asterisks (*) mark cases in which models without random slopes for conditional trigram probability for subjects were used, as the more general models did not converge.

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Table 4a

Condition means on the first target word

	Fixation time measures				Probabilities		
	First fixation duration	**Gaze duration**	**Go-past time**	**Total viewing time**	**Fixation probability**	**Probability of regressions in**	**Probability of regressions out**
Identical	207 (55.5)	226 (77.9)	286 (155)	297 (151)	0.815 (0.389)	0.192 (0.394)	0.128 (0.334)
Transposed	219 (66)	240 (87.8)	309 (178)	335 (164)	0.809 (0.394)	0.287 (0.453)	0.125 (0.331)
Unrelated	218 (65.4)	247 (93)	330 (187)	342 (163)	0.836 (0.371)	0.31 (0.463)	0.158 (0.365)

Standard deviations are in parentheses.

Table 4b

LMM analyses on the first target word. Each column represents a model.

		First fixation duration			Gaze duration			Go-past time			Total viewing time			Fixation probability			Probability of regressions in			Probability of regressions out		
		b	**SE**	***t***	***b***	**SE**	***t***	***b***	**SE**	***t***	***b***	**SE**	***t***	***b***	**SE**	***z***	***b***	**SE**	***z***	***b***	**SE**	***z***
	(Intercept)	219.59	4.47	**49.18**	239.29	5.72	**41.87**	305.88	10.86	**28.16**	333.19	11.44	**29.13**	1.85	0.19	**9.98**	−1.04	0.13	**−8.14**	−2.25	0.15	**−14.73**
Preview	Transposed vs. Unrelated	−1.34	4.26	−0.31	6.02	5.16	1.17	25.18	10.30	**2.45**	12.72	9.39	1.35	0.15	0.13	1.15	0.15	0.11	1.38	0.19	0.17	1.11
	Transposed vs. Identical	−12.50	3.59	**−3.48**	−14.36	4.89	**−2.93**	−17.53	9.20	−1.91	−38.70	8.65	**−4.48**	−0.18	0.15	−1.22	−0.73	0.15	**−4.77**	−0.06	0.15	−0.39
Conditional trigram probability	Word 1 and Word 2	−0.02	1.74	−0.01	−0.28	2.32	−0.12	−6.74	4.68	−1.44	−3.50	3.91	−0.90	−0.10	0.07	−1.57	−0.11	0.05	−1.95	−0.10	0.08	−1.28
Interactions	Transposed vs. Unrelated × Conditional probability	2.91	2.30	1.27	2.93	3.02	0.97	4.59	5.86	0.78	−2.29	5.18	−0.44	0.05	0.09	0.60	−0.05	0.07	−0.72	0.07	0.10	0.72
	Transposed vs. Identical × Conditional probability	−2.31	2.13	−1.09	−1.49	2.87	−0.52	−2.83	5.43	−0.52	−0.33	4.93	−0.07	−0.04	0.09	−0.46	−0.03	0.08	−0.35	−0.03	0.10	−0.29
Random effects: Item	(Intercept)	208.93	14.45	NA	317.71	17.82	NA	824.25	28.71	NA	1282.47	35.81	NA	0.17	0.41	NA	0.11	0.34	NA	0.22	0.46	NA
	Preview: Transposed vs. Unrelated	310.79	17.63	NA	233.14	15.27	NA	973.01	31.19	NA	919.95	30.33	NA	0.00	0.05	NA	0.00	0.03	NA	0.28	0.53	NA
	Preview: Transposed vs. Identical	150.51	12.27	NA	104.84	10.24	NA	92.40	9.61	NA	418.19	20.45	NA	0.11	0.33	NA	0.01	0.08	NA	0.04	0.19	NA
Random effects: Subject	(Intercept)	717.20	26.78	NA	1105.98	33.26	NA	4261.22	65.28	NA	5060.67	71.14	NA	1.34	1.16	NA	0.52	0.72	NA	0.51	0.72	NA
	Preview: Transposed vs. Unrelated	236.43	15.38	NA	274.90	16.58	NA	1349.80	36.74	NA	1284.98	35.85	NA	0.00	0.03	NA	0.01	0.11	NA	0.13	0.36	NA
	Preview: Transposed vs. Identical	84.53	9.19	NA	251.34	15.85	NA	881.31	29.69	NA	968.67	31.12	NA	0.20	0.44	NA	0.51	0.71	NA	0.03	0.17	NA
	Conditional trigram probability	18.26	4.27	NA	22.82	4.78	NA	281.25	16.77	NA	4.45	2.11	NA	0.01	0.09	NA	0.01	0.08	NA	0.05	0.21	NA
Residual	Error	3192.34	56.50	NA	6317.03	79.48	NA	23974.40	154.84	NA	20264.40	142.35	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

b: Regression coefficient, SE: standard error, *t* or *z*: test statistic (*b*/SE). Cells with |*t*| or |*z*| >= 1.96 are marked in bold.

Asterisks (*) mark cases in which models without random slopes for conditional trigram probability for subjects were used, as the more general models did not converge.

Table 5a

Condition means on the second target word

	Fixation time measures				Probabilities		
	First fixation duration	**Gaze duration**	**Go-past time**	**Total viewing time**	**Fixation probability**	**Probability of regressions in**	**Probability of regressions out**
Identical	219 (62.8)	241 (86.5)	306 (172)	309 (153)	0.814 (0.39)	0.191 (0.393)	0.13 (0.336)
Transposed	221 (67.7)	248 (93.1)	331 (192)	335 (170)	0.848 (0.36)	0.197 (0.398)	0.178 (0.382)
Unrelated	217 (64)	238 (82.8)	324 (183)	326 (150)	0.868 (0.338)	0.18 (0.384)	0.209 (0.407)

Standard deviations are in parentheses.

Table 5b

LMM analyses on the second target word. Each column represents a model.

		First fixation duration			Gaze duration			Go-past time			Total viewing time*			Fixation probability			Probability of regressions in			Probability of regressions out*		
		b	SE	*t*	*b*	SE	*t*	*b*	SE	*t*	*b*	SE	*t*	*b*	SE	*z*	*b*	SE	*z*	*b*	SE	*z*
	(Intercept)	220.31	4.22	**52.24**	246.96	5.98	**41.31**	330.34	12.07	**27.38**	334.88	10.75	**31.16**	2.09	0.16	**12.77**	−1.57	0.12	**−12.75**	−1.65	0.12	**−14.25**
Preview	Transposed vs. Unrelated	−4.42	3.66	−1.21	−10.31	5.21	**−1.98**	−5.24	10.57	−0.50	−7.98	7.89	−1.01	0.17	0.15	1.12	−0.09	0.12	−0.75	0.21	0.12	1.71
	Transposed vs. Identical	−2.53	3.61	−0.70	−8.85	5.78	−1.53	−25.73	10.73	**−2.40**	−27.44	8.98	**−3.06**	−0.28	0.16	−1.81	−0.28	0.15	−1.85	−0.47	0.15	**−3.10**
Conditional trigram probability	Word 1 and Word 2	−2.05	1.62	−1.26	0.35	2.36	0.15	−6.51	4.93	−1.32	−11.64	4.03	**−2.89**	−0.21	0.08	**−2.75**	−0.14	0.06	**−2.43**	−0.12	0.06	**−2.04**
Interactions	Transposed vs. Unrelated × Conditional probability	0.64	2.21	0.29	−4.89	2.95	−1.66	−1.35	6.40	−0.21	−0.73	5.10	−0.14	0.07	0.10	0.74	0.00	0.08	0.06	0.08	0.08	1.01
	Transposed vs. Identical × Conditional probability	0.11	2.17	0.05	−3.88	2.99	−1.30	−2.79	6.41	−0.44	−2.49	5.18	−0.48	−0.02	0.09	−0.27	0.02	0.09	0.23	0.00	0.09	0.01
Random effects: Item	(Intercept)	52.88	7.27	NA	265.38	16.29	NA	1480.05	38.47	NA	1506.39	38.81	NA	0.37	0.61	NA	0.04	0.20	NA	0.04	0.21	NA
	Preview: Transposed vs. Unrelated	110.50	10.51	NA	149.91	12.24	NA	1155.22	33.99	NA	279.59	16.72	NA	0.06	0.24	NA	0.01	0.10	NA	0.00	0.04	NA
	Preview: Transposed vs. Identical	49.80	7.06	NA	177.52	13.32	NA	1380.96	37.16	NA	535.10	23.13	NA	0.07	0.27	NA	0.13	0.36	NA	0.08	0.28	NA
Random effects: Subject	(Intercept)	717.21	26.78	NA	1333.43	36.52	NA	4928.92	70.21	NA	3887.34	62.35	NA	0.63	0.79	NA	0.42	0.65	NA	0.29	0.54	NA
	Preview: Transposed vs. Unrelated	113.63	10.66	NA	401.58	20.04	NA	826.02	28.74	NA	250.78	15.84	NA	0.09	0.31	NA	0.01	0.08	NA	0.01	0.08	NA
	Preview: Transposed vs. Identical	131.37	11.46	NA	714.85	26.74	NA	828.74	28.79	NA	1050.19	32.41	NA	0.25	0.50	NA	0.25	0.50	NA	0.21	0.45	NA
	Conditional trigram probability	13.69	3.70	NA	35.49	5.96	NA	110.68	10.52	NA	*	*	*	0.02	0.14	NA	0.00	0.03	NA	*	*	*
Residual	Error	3590.33	59.92	NA	6498.91	80.62	NA	28559.44	169.00	NA	21072.23	145.16	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

b: Regression coefficient, SE: standard error, *t* or *z*: test statistic (*b*/SE). Cells with |*t*| or |*z*| >= 1.96 are marked in bold.

Asterisks (*) mark cases in which models without random slopes for conditional trigram probability for subjects were used, as the more general models did not converge.

Table 6a

Condition means on the post-target word

	Fixation time measures				Probabilities		
	First fixation duration	Gaze duration	Go-past time	Total viewing time	Fixation probability	Probability of regressions in	Probability of regressions out
Identical	214 (64.3)	239 (87.3)	328 (191)	316 (169)	0.604 (0.489)	0.185 (0.389)	0.111 (0.315)
Transposed	215 (65.6)	241 (89.6)	335 (194)	311 (157)	0.61 (0.488)	0.16 (0.367)	0.136 (0.343)
Unrelated	217 (63.6)	237 (87)	319 (176)	297 (140)	0.627 (0.484)	0.143 (0.35)	0.127 (0.333)

Table 6b

LMM analyses on the post-target word. Each column represents a model.

		First fixation duration*			Gaze duration			Go-past time*			Total viewing time*			Fixation probability*			Probability of regressions in			Probability of regressions out		
		b	**SE**	***t***	***b***	**SE**	***t***	***b***	**SE**	***t***	***B***	**SE**	***t***	***b***	**SE**	***z***	***b***	**SE**	***z***	***b***	**SE**	***z***
	(Intercept)	213.86	3.73	**57.36**	213.86	5.64	**42.47**	335.23	12.37	**27.10**	308.78	9.29	**33.25**	0.63	0.18	**3.58**	−1.96	0.16	**−12.33**	−1.97	0.12	**−16.26**
Preview	Transposed vs. Unrelated	2.33	3.88	0.60	2.33	5.22	−0.86	−18.86	13.46	−1.40	−13.91	8.87	−1.57	0.11	0.11	1.04	−0.29	0.16	−1.82	−0.26	0.15	−1.74
	Transposed vs. Identical	0.37	4.00	0.09	0.37	5.24	−0.17	−6.82	13.82	−0.49	2.62	10.29	0.25	−0.08	0.11	−0.67	0.29	0.15	1.85	−0.31	0.15	**−2.13**
Conditional trigram probability	Word 1 and Word 2	−1.06	1.91	−0.55	−1.06	2.72	−0.38	−6.65	5.74	−1.16	−8.10	4.21	−1.92	0.01	0.06	0.13	−0.17	0.07	**−2.41**	−0.03	0.07	−0.45
Interactions	Transposed vs. Unrelated × Conditional probability	1.98	2.60	0.76	1.98	3.52	0.39	1.85	7.66	0.24	2.86	5.59	0.51	0.00	0.07	−0.01	0.07	0.10	0.70	−0.05	0.10	−0.48
	Transposed vs. Identical × Conditional probability	−2.46	2.56	−0.96	−2.46	3.46	0.32	15.29	7.52	**2.03**	2.90	5.80	0.50	0.63	0.18	**3.57**	0.20	0.09	**2.16**	0.10	0.10	1.09
Random effects: Item	(Intercept)	150.27	12.26	NA	150.27	18.23	NA	1210.35	34.79	NA	765.92	27.68	NA	0.10	0.11	0.97	0.37	0.61	NA	0.14	0.37	NA
	Preview: Transposed vs. Unrelated	43.82	6.62	NA	43.82	2.32	NA	15.87	3.98	NA	24.43	4.94	NA	−0.08	0.11	−0.68	0.24	0.49	NA	0.04	0.20	NA
	Preview: Transposed vs. Identical	89.61	9.47	NA	89.61	4.27	NA	81.75	9.04	NA	818.86	28.62	NA	0.01	0.06	0.21	0.41	0.64	NA	0.00 0.00	NA	
Random effects: Subject	(Intercept)	252.88	15.90	NA	252.88	27.70	NA	4056.39	63.69	NA	2402.09	49.01	NA	0.00	0.07	0.02	0.60	0.77	NA	0.19 0.43	NA	
	Preview: Transposed vs. Unrelated	4.51	2.12	NA	4.51	6.21	NA	3281.75	57.29	NA	628.48	25.07	NA	−0.02	0.07	−0.28	0.07	0.27	NA	0.06 0.25	NA	
	Preview: Transposed vs. Identical	0.15	0.39	NA	0.15	2.99	NA	3727.73	61.06	NA	1460.28	38.21	NA	1.14	1.07	NA	0.04	0.20	NA	0.03 0.18	NA	
	Conditional trigram probability	*	*	*	20.31	4.51	NA	*	*	*	*	*	*	*	*	*	0.01	0.10	NA	0.00 0.05	NA	
Residual	Error	3718.94	60.98	NA	6824.79	82.61	NA	31082.00	176.30	NA	20693.00	143.85	NA	NA	NA	NA	NA	NA	NA	NA NA	NA	

b: Regression coefficient, SE: standard error, *t* or *z*: test statistic (*b*/SE). Cells with |*t*| or |*z*| >= 1.96 are marked in bold.

Asterisks (*) mark cases in which models without random slopes for conditional trigram probability for subjects were used, as the more general models did not converge.

Table 7

Means on the combined target region conditional on fixating the pre-target word

		Fixation time measures					Probabilities	
Pre-target fixated on first pass	**Preview**	**First fixation duration**	**Gaze duration**	**Go-past time**	**Total viewing time**	**Fixation probability**	**Probability of regressions out**	**Probability of regressions in**
	Identical	211 (55.7)	394 (180)	477 (279)	499 (241)	0.981 (0.136)	0.105 (0.306)	0.197 (0.398)
Yes	**Transposed**	219 (67.2)	419 (211)	557 (340)	605 (301)	0.988 (0.109)	0.14 (0.347)	0.292 (0.455)
	Unrelated	224 (70.6)	452 (201)	613 (316)	633 (281)	0.986 (0.117)	0.194 (0.396)	0.274 (0.446)
	Identical	206 (60.3)	390 (196)	552 (279)	578 (256)	0.989 (0.106)	0.237 (0.426)	0.298 (0.458)
No	**Transposed**	221 (65)	418 (202)	585 (291)	584 (246)	0.987 (0.115)	0.208 (0.407)	0.262 (0.44)
	Unrelated	215 (67.9)	410 (205)	618 (311)	601 (256)	0.993 (0.0855)	0.292 (0.455)	0.297 (0.457)

Standard deviations are in parentheses.