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ARTICLE

How flexible is the orthographic processing of flankers? Effects for letter order and letter identification

Miguel Lázaro*, Lorena García and Víctor Illera

Department of Experimental Psychology, Cognitive Processes and Speech and Language Therapy, Universidad Complutense de Madrid, Madrid, Spain
*Corresponding author. Email: Miguel.lazaro@ucm.es

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Abstract

This study explored the flexibility of the orthographic processing at parafoveal level by manipulating the relationship between flankers and targets in two lexical decision tasks. In the first, we presented the following flankers: (1) the same words as targets (farola farola farola); (2) targets with transposed non-adjacent letters (falora farola falora); (3) the targets with one different letter (fapola farola fapola); and (4) unrelated pseudowords as control stimuli (pilata farola pilata). The results show significant facilitatory effects for all three experimental conditions in comparison to the Unrelated one, as well as differences between the Transposed and One Different Letter when compared to the Identity condition. In the second experiment, the procedure was the same but with the following modifications: the transposed non-adjacent letters were vowels instead of consonants (forala farola forala), and we also presented a condition in which both vowels and consonants were transposed (folara farola folara). The results of the response latencies showed that all the experimental conditions generated facilitatory effects in comparison to the Unrelated condition, with no differences between them, although the analyses of the error rates additionally showed significant differences between the Identity and the Transposed and Vowel and Consonant Transposed conditions. These two experiments are interpreted in terms of a highly flexible orthographic processing of flankers at parafoveal level, both in relation to letter ordering and letter identification.

Keywords: flankers; orthographic processing; transposed letter

1. Introduction

A relatively large number of studies have explored orthographic processing by focusing on the transposed letter effect (TL hereafter). This effect refers to the facilitation produced by presenting a masked prime in which two letters in the target are transposed, as in "jugde → judge" (e.g., Forster et al., 1987; Perea & Lupker, 2003; Schoonbaert & Grainger, 2004). This finding has been reported not only in adults, but also in children (e.g., Acha & Perea, 2008; Castles et al., 2007; Gómez et al., 2021; Lété & Fayol, 2013). The TL effect has been interpreted as showing a more flexible coding system for letter ordering than for letter identification, as the results also show that the facilitation is reduced when one letter in the prime is replaced (as in jutge → judge). The term flexible is used here, and throughout this manuscript, to mean that a letter that appears in any position leads to the activation of words containing this letter in different positions.

A number of experimental tasks have been used to provide evidence on the transposed letter effect (i.e., Johnson et al., 2007, for a sentence reading task; Muñoz et al., 2012 or Schubert et al., 2017, for a same-different task; Perea & Estévez, 2008, for a naming task; Perea et al., 2012, for an associative priming task), although greater emphasis has been placed on the use of the masked priming lexical decision task (e.g. Duñabeitia et al., 2009; Kahraman & Kirciki, 2021; Schoonbaert & Grainger, 2004). The fact that the evidence concerning the TL effect is not circumscribed to just one experimental task is highly positive. This is so because every different task involves specific cognitive demands on readers. Therefore, by considering all results in the context of the different tasks performed, researchers can better interpret and integrate the data collected. The flanker task is, in this sense, an interesting option for two key reasons: i) it allows for the assessment of parallel processing of targets and flankers – unlike priming studies where processing of primes and targets is sequential, and ii) it allows for the study of the parafoveal processing of flankers – unlike tasks in which stimuli are always presented in the fovea. Despite the flanker task having hitherto received little attention, there is solid evidence showing its pertinence for the field of visual word recognition. For example, Dare and Shillcock (2013) used this task to carry out a study in which participants were presented with words and pseudowords flanked by related letter pairs (such as in *ro rock ck*) or unrelated pairs (such as in *an rock ch*), with the aim of exploring parallel processing in word recognition. Their results showed facilitation for the related condition with respect to the unrelated condition (see also Dare & Shillcock, 2005). This was also true in the related reverse condition, as in *ck rock ro*. The overall results were interpreted following the assumption that flankers were processed in the parafovea, while targets were fixed and processed in the fovea. In the parafovea, letters presented are processed, with this activation benefiting recognition of the target when it shares the letters with the flankers (related condition). When the letters of the flankers do not match those of the targets, no benefit is observed (unrelated condition). Therefore, shared orthographic activation of flankers and targets explains the benefit at word recognition level. This occurs across both the foveal and parafoveal visual fields, within the duration of just one fixation (Dare, 2010).

The data reported by Dare and Shillcock (2013) were replicated in French by Grainger et al. (2014)). These authors also observed a benefit for the related condition in comparison to the unrelated one, but further observed that the benefit was reduced when the position of letters within flankers was reversed (CK ROCK RO vs. KC ROCK OR). This evidence indicates a key role for the order in which the flanker letters appear. The results reported by Dare and Shillcock (2013) and Grainger et al. (2014) were later extended in a study by Grainger et al. (2020), who studied morphological effects through the flanker task. They presented adult readers with flankers and targets with a transparent relationship (lune lunaire lune), with a pseudo-morphological relationship (foule foulard foule), and with a mere orthographic

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relationship (pot potasse pot). The authors observed that the semantically transparent condition facilitated responses in comparison to pseudo-morphological and form-related conditions, with no differences between the two latter experimental conditions. The authors interpreted that when targets and flankers are presented in different spatial locations, in contrast to what occurs in masked priming experiments, there is no possibility for lexical competition, and, therefore, the semantic transparent condition benefits more than the pseudo-morphological condition. However, more importantly for the present study, the results of Grainger et al. (2020) evidenced that, despite the long chain of characters presented to readers at one time (about 20 characters, considering both flankers, targets and spaces between stimuli), the readers were able to process and activate stems as morphological units. The study, thus, indirectly supported great acuity of parafoveal processing if only one fixation is supposed to occur in the flanker task (Dare, 2010).

Contradicting the results of the previous study, Lázaro et al. (2022) carried out a replication experiment in Spanish, reporting different results. Indeed, they observed the same facilitatory effects for all three experimental conditions (transparent, pseudo-morphological, and form related conditions) in comparison to the unrelated one, with no statistical differences between them (Experiment 1). These data supported orthographic processing of flankers but not morphological processing. These results were interpreted by assuming that the targets are processed in the fovea, while the flankers are processed through parafoveal processing. As parafoveal processing is known to be less accurate than foveal processing (e.g., Rayner et al., 1998), these authors construed that the ability of parafoveal processing is not sufficiently acute to recognize and activate stems, but only letters from these stems. Therefore, facilitatory effects of experimental conditions emerged from the activation of shared letters in flankers and targets, irrespective of their morphological status. The results of this study led the authors to propose further evaluation of parafoveal processing of flankers. Consequently, the present study was designed and carried out to further explore this issue.

2. Experiment 1

In this first experiment, we explore parafoveal processing of flankers by focusing on the manipulation of both letter order and letter identification. To do so, we transpose non-adjacent letters and replace letters from the flankers with respect to the targets. Our rationale is that if flankers are processed in parafovea, and acuity is limited in comparison to foveal processing, then the same facilitation should appear for the identity and the transposed conditions. This result has been observed in masked priming lexical decision tasks (Forster et al., 1987), although the most common finding in the literature is that the TL effect with non-adjacent letters is less powerful than the identical condition (see Rayner et al., 2006, for a study concerning the costs of reading words with transposed letters). We predict that when a letter is replaced (one letter different condition), the findings will also differ from the results observed in masked priming experiments. In these experiments, this condition generates a reduced benefit in comparison to the transposed. However, we understand that the less accurate orthographic processing at parafoveal level will also imply more flexibility at orthographic identification level and, therefore, we expect the same facilitation for the Identity and the One Letter Different conditions. All in all, we do not expect to replicate previous studies within the paradigm of masked priming but,

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rather, to obtain similar facilitatory effects for the Identity, the Transposed TL, and the One Letter Different conditions.

3. Method

3.1. Participants

Fifty-four undergraduate students from the Complutense University of Madrid participated in the study (42 women, mean age 22.1 – range 20–29 years old). All were native Spanish-language speakers and had normal or corrected-to-normal vision.

3.2. Stimuli

Four counterbalanced lists of 120 words were prepared. All the words were nouns with the exception of 4 adjectives. In each list, 30 words were flanked by the same words (farola farola farola – streetlamp), 30 were flanked by pseudowords containing a transposed letter (falora farola falora), 30 were flanked by pseudowords in which one letter from the targets was different (fapola farola fapola) and a further 30 words were flanked by unrelated pseudowords (pilata farola pilata) (see Appendix A for the stimuli employed). Just one list was presented to the participants, such that no stimulus was repeated. The mean frequency of the words was 1.24 per million (*SD* 1.04), the mean letter length was (6.20, *SD* 0.57) and the mean number of neighbors was 0.39 (*SD* 0.63). The characteristics of the word targets were obtained following the Espal database (Duchon et al., 2013). A set of 120 pseudowords was created to set up the flanker-lexical decision task. Half of the pseudowords were flanked by identical pseudowords and the other half by unrelated pseudowords.

3.3. Procedure

Participants were tested in a quiet room with subdued lighting. The experiment was programmed using the DMDX software package (Forster & Forster, 2003). Centrally positioned vertical fixation bars, separated from one another by a visual angle of 0.60°, were shown throughout each trial. At 500 ms after the start of every trial, a target stimulus with flankers (separated from the target by one character space) was shown between the fixation bars for 150 ms, after which the participants had a maximum of 2,000 ms to respond. Responses were given by means of a right- or a left-handed button press to indicate “word” or “nonword,” respectively. The display returned to the beginning state, and the next trial then started. The stimuli were presented in a random order.

3.4. Data analysis

Only word targets were considered in the analyses. Errors (26.62% of the data) were eliminated for the analysis of the response latencies. There were 4,755 observations for the response time analysis. These observations are sufficient to assure a good statistical power considering the experimental design implemented (Brysbaert, 2019).

We fit linear-mixed effects models with regular maximum-likelihood estimation, as implemented in lme4 package (version 1.1–30, Bates et al., 2015) in an R statistical computing environment (R Core Team) with log response latencies as a dependent variable to meet the assumption of normality of the residuals. The model included two fixed effects with four levels each: list (4 lists, sum-coded with list 1 as reference [“2” = c(−1/2, 1/2, 0, 0), “3” = c(−1/2, 0, 1/2, 0), “4” = c(−1/2, 0, 0, 1/2)], and flanker type (4 levels, dummy-coded with Unrelated as reference: identity [0, 1, 0, 0], one letter different [0, 0, 1, 0]), transposed letter [0, 0, 0, 1], and two random effects: subjects and items. As a warning message appeared indicating a singular fit when the maximal random-effects model was fitted (Barr et al., 2013), the random-effects structure of the model was simplified step by step until the warning message was no longer shown. The final model included only random intercepts for subjects and items. The emmeans package (version 1.8.0, Length, 2022) was used for pairwise comparisons of the experimental conditions, the results of which are presented below.

4. Results

The results of the response latencies showed clear differences between experimental conditions. The mean latencies were Identity 554 ms, Transposed 570 ms, One Letter Different 568 ms, and Unrelated 592 ms. The 38 ms difference between the Identity and the Unrelated was significant ($z = 4.98$, $p < 0.01$); as was the difference of 22 ms between the Transposed and the Unrelated ($z = 3.27$, $p < 0.01$) and the 24 ms difference between the One Letter Different and the Unrelated condition ($z = 2.53$, $p = 0.01$). Therefore, the three related flanker conditions facilitated the recognition of the targets with respect to the control. There were also significant differences between the Identity and One Letter Different conditions ($z = -2.44$, $p = 0.01$), with differences between the Identity and the Transposed conditions also approaching significance ($z = -1.72$, $p = 0.08$). The differences between One Letter Different and Transposition were not significant ($z = 0.73$, $p = 0.46$) (see Fig. 1).

The error data were analyzed with a logistic regression model that included only subject and item random intercepts. The differences in the error rates replicated those for the RTs: the three related flanker types facilitated the recognition of the targets in comparison to the unrelated condition: Unrelated versus Identity ($z = 8.03$, $p < 0.01$); Unrelated versus One Letter Different ($z = 2.53$, $p = 0.01$); Unrelated versus Transposition ($z = 3.93$, $p < 0.01$). The analyses also revealed a significant difference between Identity versus One Letter Different ($z = -5.53$, $p < 0.01$) and between the Identity versus Transposition conditions ($z = -4.17$, $p < 0.01$). However, the differences between the One Letter Different and Transposition conditions were not significant ($z = 1.39$, $p = 0.16$) (see Fig. 2).

5. Discussion

Consistent with the hypotheses of the experiment, the results of the response latencies showed that the Identity, the Transposition and the One Letter Different conditions produced facilitatory effects in comparison to the unrelated condition. However, the data also showed that the benefit generated by the Identity condition was significantly larger than that generated by the One Letter Different and Transposition

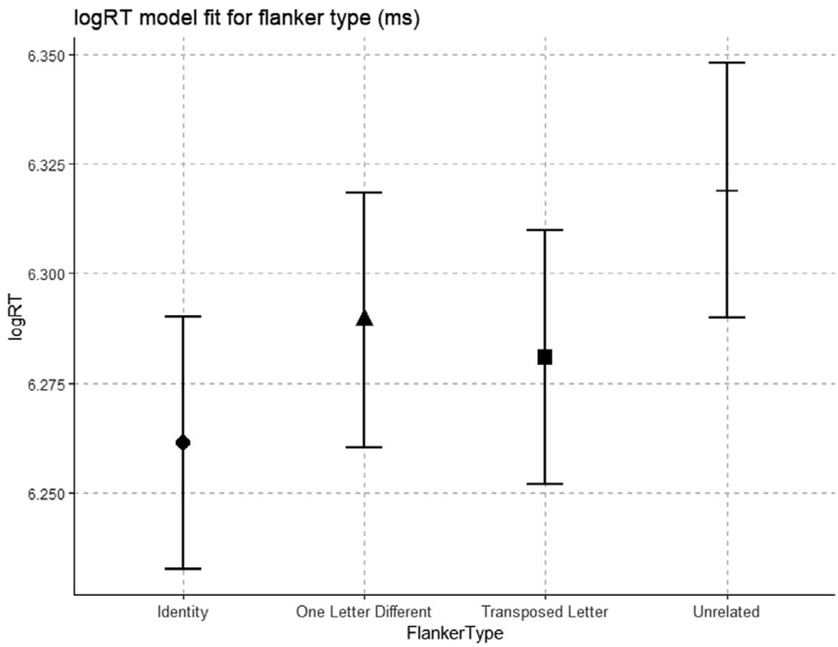

Fig. 1. Response latencies for Experiment 1. Error bars show standard errors.

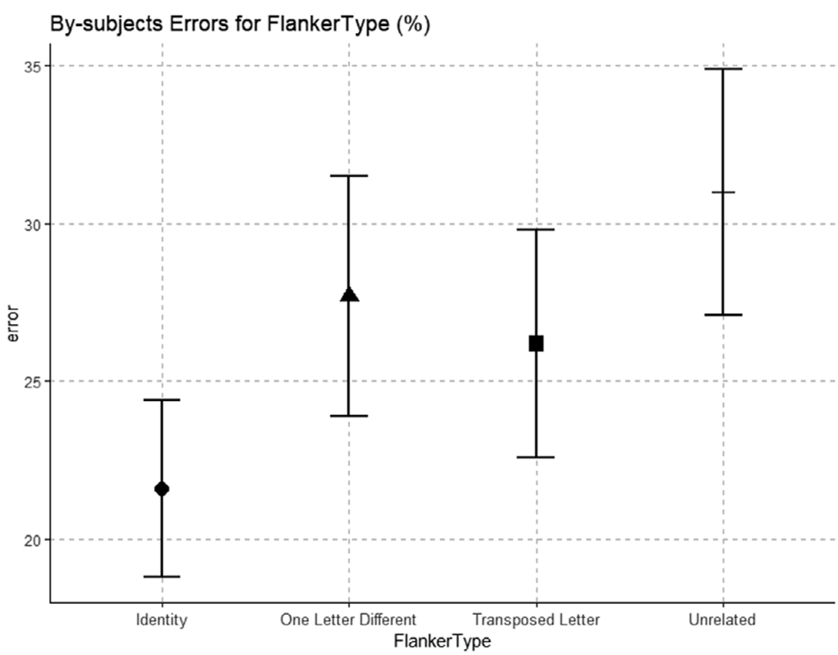

Fig. 2. Mean error rates for Experiment 1. Error bars show standard errors.

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conditions – in the latter case with a marginal significance. These differences were not expected. Concerning the error rates, the data fully replicated the results observed for the response latencies with just one difference, namely, that in the error analyses the comparison between the Identity and the Transposition conditions reached significance. Masked priming studies have repeatedly shown that transposed stimuli generate facilitation of a lesser magnitude than the Identity condition, but of a greater magnitude than when a letter from the target is replaced. Our results also showed a greater benefit for the Identity condition in comparison to the Transposition condition, but failed to show any difference between the Transposition and the One Letter Different conditions. The results of the masked priming experiments have been interpreted by proposing two different orthographic mechanisms; one related to the identification of letters and the other related to the letter ordering. In particular, it has been suggested that the identification process is highly accurate, as any replacement in a letter from the target decreases the facilitation. Letter ordering, however, has been considered more flexible, as transposition of non-adjacent letters generates greater facilitation than in the case of letter replacement. We understand that our results do not necessarily suggest the previous interpretation is inappropriate. Nevertheless, we believe that the same rationale can be applied to explain our results with just one consideration, that is, flankers, unlike primes, are processed parafoveally. As parafoveal processing is known to be less accurate than foveal processing (e.g., Legge et al., 2001; Legge & Mansfield, 1997; Rayner et al., 1980, 1998), if we consider that flankers are processed in the parafovea, it makes sense that the processing of letters in flankers is less accurate than the processing of these letters when presented in the fovea (as happens in the masked priming studies). Our results showing significant differences between the Transposition and the One Letter Different conditions with respect to the unrelated one suggest a flexible orthographic processing at parafoveal level in which the transposition of two internal letters or the replacement of one letter do not preclude benefits in target recognition. Moreover, the lack of differences between the One Letter Different and the Transposition conditions further suggests that the flexibility at parafoveal level is not larger with letter order than with letter identification, in contrast to what has been proposed for foveal processing (masked priming experiments). Lastly, the significant differences between the Identity and the Transposition and One Letter Different conditions are very much informative, as they clearly show that parafoveal processing is sufficiently precise to capture orthographic differences between targets and flankers. Therefore, our overall results show, on the one hand, that the parafoveal processing of letters is flexible in terms of both letter order and letter identification and, on the other, that the parafoveal processing of letters is highly precise. The interaction between flexibility and precision in parafoveal processing merits further investigation.

6. Experiment 2

In this second experiment, we further manipulated the orthographic relationship between flankers and targets by creating two new experimental conditions in addition to the Identity (farola farola farola) and Unrelated ones (pilata farola pilata). The first of the new experimental conditions consists of the transposition of vowels instead of consonants (forala farola forala). Previous evidence in masked priming experiments has shown that transposition of vowels does not generate facilitation or that this

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facilitation is lower than when transposing consonants (see Acha & Perea, 2010; Carreiras et al., 2007; Lupker et al., 2008; Perea & Lupker, 2004; but see also Colombo et al., 2020 and Schubert et al., 2017, for conflicting results), so it is of interest to see whether, in the flanker paradigm, this transposition still generates facilitation as we expect. The second condition exacerbates the manipulation of letter ordering as we transpose not only vowels but also consonants, creating pseudowords sharing letters with the targets but with less resemblance (folara farola folara). If this condition generates facilitation in comparison to the unrelated condition, we then have evidence to support highly flexible orthographic processing at parafoveal level.

7. Methods

7.1. Participants

Forty-five undergraduate students from the Complutense University of Madrid participated in the study (37 women, mean age 23.1 – range 21–31 years old). All were native Spanish-language speakers and had normal or corrected-to-normal vision.

7.2. Stimuli

The same target stimuli as in Experiment 1 were used, except for 20 items, which were omitted. These words were omitted as they had only one vowel, and were thus impossible to transpose (as occurs in words like *ozono* – ozone). We therefore had four counterbalanced lists of one hundred words. In each list, 25 words were flanked by identical words (farola farola farola), 25 were flanked by pseudowords containing a transposed vowel (forala farola forala), 25 were flanked by pseudowords in which vowels and consonants were transposed (folara farola folara) and a further 25 words were flanked by unrelated pseudowords (pilata farola pilata) (see Appendix B).

7.3. Procedure

The same procedure was followed as in Experiment 1.

7.4. Data analysis

Errors were eliminated (22.43%) from the analyses of the response latencies. As in the first experiment, the model included two fixed effects with four levels each: list (4 lists, sum coded), and flanker type (dummy-coded; Unrelated, Identity, Transposed, and Vowel and Consonant Transposition) and two random intercepts for subjects and items. There were 3,568 observations for the RT analysis.

7.5. Results

The results of the response latencies showed the following mean raw latencies: Identity 519 ms, Transposition 519 ms, Vowel and Consonant Transposed 509 ms, and Unrelated 541 ms. As in the first experiment, significant differences between the three related conditions with respect to the unrelated one were found. In particular,

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we found differences between the Unrelated and Identity conditions (z = 3.84, $p < 0.01$); between the Unrelated and Transposition conditions (z = 3.56, $p < 0.01$) and between the Unrelated and Vowel and Consonant Transposed conditions (z = 4.15, $p < 0.01$). No significant differences were found between the three related flanker conditions: Identity versus Transposition (z = −.24, p = 0.80), Identity versus Vowel and Consonant Transposition (z = 0.35, p = 0.73) and Transposition versus Vowel and Consonant Transposition (z = 0.60, p = 0.55) (see Fig. 3).

In the error analysis, the results also show significant differences between the three related conditions with respect to the unrelated one: Unrelated versus Identity (z = 5.98, $p < 0.01$); Unrelated versus Transposition (z = 2.94, $p < 0.01$); Unrelated versus Vowel and Consonant Transposed (z = 2.12, p = 0.03). Furthermore, the results also revealed a significant difference between the Identity and Transposition conditions (z = −3.80, $p < 0.01$) and between the Identity and Vowel and Consonant Transposition conditions (z = −3.86, $p < 0.01$). Differences between the Vowel and Consonant Transposition and Transposition conditions were not significant (z = −0.83, p = 0.41) (see Fig. 4).

8. Discussion

The results of this second experiment showed a significant facilitatory effect for all three related conditions with respect to the unrelated one, with no differences between them in the case of the response latencies, but with significant differences in the error analyses between the Identity and the Vowel and Consonant Transposed and Transposition conditions. The results of the response times were

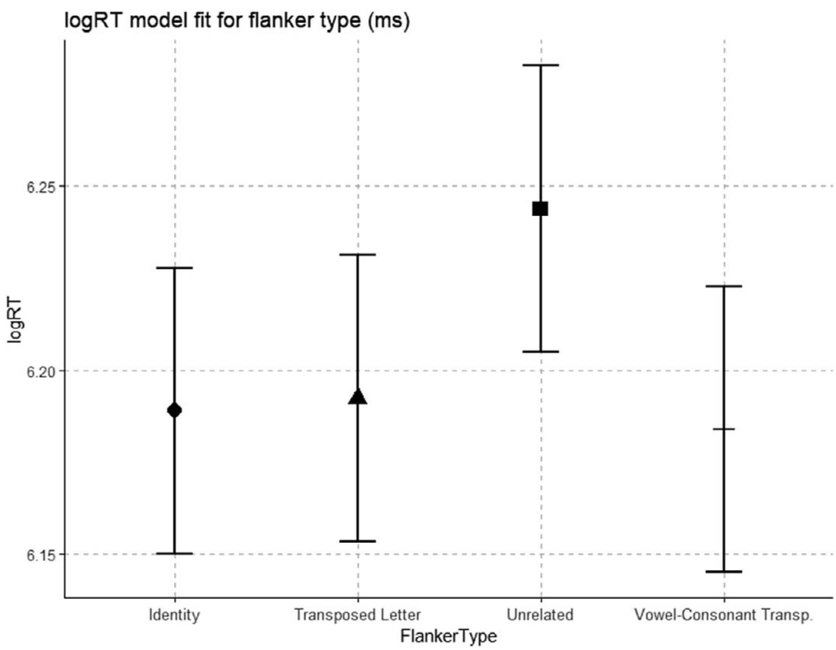

Fig. 3. Response latencies for Experiment 2. Error bars show standard errors.

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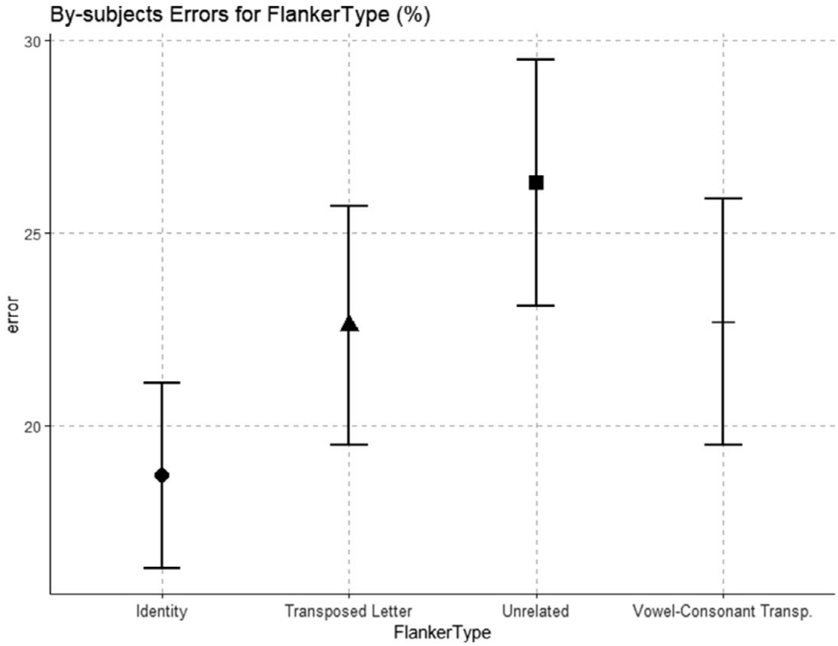

Fig. 4. Mean error rates for Experiment 2. Error bars show standard errors.

unexpected as previous studies have shown that vowel transposition generates less facilitation that consonant transposition (Lupker et al., 2008; Perea & Lupker, 2004; in line with Colombo et al., 2020). Regardless of the inconsistent results in the literature in this regard (see Schubert et al., 2017), in light of the first experiment, the most reasonably expected result was that the TL condition would generate less benefit than the Identity condition. The fact that the benefit in this second experiment was the same in these conditions suggests that the orthographic processing at parafoveal level does not code vowel transpositions, that is, changes in the order of vowels at parafoveal level do not alter target recognition at foveal level in the least. The problem with this interpretation is that the Vowel and Consonant Transposed condition also generated the same facilitation as the Identity condition, but incorporated not only a vowel, but also a consonant transposition. In the first experiment, we showed that transpositions of consonants at parafoveal level are detected in such a way that the Transposition condition generated less benefit than the Identity one. The similar facilitation for the Identity and Vowel and Consonant Transposition condition was therefore unexpected and challenging to explain. In our view, the evidence concerning the response times must be considered together with the data on the errors. The analyses of the error rates showed less benefit for the Transposition and Vowel and Consonant Transposition with respect to the Identity condition, which fits better with the results of the first experiment and permits a more parsimonious explanation of the results. Indeed, the facilitation observed for the Vowel and Consonant Transposition, despite the reduced resemblance between flankers and targets, suggests highly flexible processing in letter ordering at parafoveal level; the mere concurrence of the same letters in flankers and targets is sufficient to generate facilitation because of the shared activation of letters units.

9. General discussion

In this study, we explored the orthographic processing of flankers by transposing non-adjacent consonants (falora farola falora) and replacing letters (fapola farola fapola) (Experiment 1) and transposing non-adjacent vowels (forala farola forala) and consonants and vowels (folara farola folara) (Experiment 2). These conditions were compared to an unrelated one (pilata farola pilata) and to an identity condition (farola farola farola). The results of Experiment 1 showed facilitation for all three related conditions with respect to the unrelated one (Andrews, 1996), suggesting flexible processing at parafoveal level in terms of both letter order and letter identification. The results of this first experiment also showed that the facilitatory effect generated by the Transposition and One Letter Different conditions was of the same magnitude. This finding differs from the data observed in masked priming studies where the effect generated by the transposed stimuli is typically larger than the effect generated by the One Letter Different ones (e.g., Perea & Lupker, 2003; Schoonbaert & Grainger, 2004). The results of masked priming studies have typically been explained by proposing that the letter position is encoded flexibly during word processing, while letter identification is more accurately processed (e.g., Perea & Estévez, 2008; Peressotti & Grainger, 1999; Rayner et al., 2006). Following this rationale, in our study, the lack of differences for the Transposed and One Letter Different conditions suggests that, in the case of parafoveal processing, letter order and letter identification are both processed with similar flexibility. Lastly, with respect to Experiment 1, the results showed a larger facilitatory effect for the Identity than for the Transposed and One Letter Different conditions. This finding suggests that the orthographic processing at parafoveal level is sufficiently precise to benefit more from the identical condition than from other conditions in which the order or the identity of the flankers do not perfectly match the targets. Therefore, this last finding advance on previous ones showing flexibility of the orthographic processing at parafoveal level, because it indicates that the system is not just flexible, but also highly precise.

The results of the second experiment showed facilitation for the three related conditions with respect to the unrelated one. This result clearly supports the view by which the parafoveal processing of letters is highly flexible regarding letter ordering. However, one difficulty in explaining the results of the second experiment is that the data of the response latencies revealed no differences in the magnitude of the benefit for the three related conditions, while the results for the error rates indicated greater benefit for the Identity condition than for the Transposition and Vowel and Consonant Transposed ones. In our view, the fact that the Vowel and Consonant Transposed generated similar facilitation to the Identity in the response latencies is challenging because we showed in the first experiment, with similar items, that consonant transposition reduced the magnitude of the benefit. We believe that the results for the error rates fit better with previous findings but, more importantly, are compatible with the results of the response latencies in one key aspect, namely, that the orthographic processing at parafoveal level is highly flexible regarding letter ordering.

It is worth nothing that the discussion of the results assumes that the flankers are processed in the parafovea. Two arguments support this assumption. The first is the visual acuity hypothesis proposed by Bertram and Hyönä (2003). These authors explored word recognition of long and short compounds with an eye tracking system, finding different effects in word recognition depending on the letter length of the compound's first constituent. They concluded that "the system seems to be tuned in such a way that it starts to analyze the string of letters that is under foveal inspection. If this string [the compound] is around 8 letters (or less) it starts to analyze the whole word, whereas if the letter string is longer, it will start to analyze the beginning of the word to acquire access to a meaningful substring" (p. 630). In other words, these authors argued that the letter length of the target to be recognized affects how it is processed (see Lázaro et al., 2020, for similar rationale). The reason for this is that the fovea was unable to fixate and extract information from the entire compounds because they had more letters than the fovea is able to capture within a single fixation. Bertram and Hyönä (2003) observed that differences in their compounds emerged as a length of 8 letters, and so these authors considered that the capacity of the fovea is limited to 8 characters. In our study, the targets had a mean of 6.2 letters, such that they could be fixated and processed at foveal level. However, flankers, together with targets and spaces between them, involved a mean length of 20 characters, clearly outside the span of the fovea. Another factor that supports the parafoveal processing of flankers is that participants were asked to respond to whether the target – not the flankers, were real words or not. Therefore, readers had no need to focus on flankers to correctly perform the task. We believe that participants focused on targets because this is precisely what is needed to appropriately perform the task (see Veldre et al., 2022; for similar results with and without eye tracking when assessing the role of the retinal eccentricity on word identification – experiments 1a and 1b). This is our belief even in the extreme case that the left flanker would have been neglected because of the right-hand bias of the foveal processing. In this unlikely case, the target, plus the right flanker, would still have been far beyond the span of the foveal processing (a mean of 13.4 letters considering the space between target and flanker), and, therefore, the right flanker would have been parafoveally processed.

The right-hand bias of the system i.e., the fact that the size of the optimal perceptual span within an eye fixation for parafoveal processing is larger to the right of the fixation than to the left (e.g., Ducrot & Grainger, 2007; Rayner et al., 2009) has already been explored in a flanker task. This was addressed by Snell and Grainger (2018), who carried out a flanker task in which readers were presented with several conditions, among which were the following: both flankers (rock rock rock), just the right flanker (_____ rock rock), and just the left flanker (rock rock ____). The authors observed that the leftward repetition flanker generated longer response latencies than the rightward repetition flanker condition. They thus concluded that the recognition process is facilitated by orthographic information on the right, while information on the left provides no benefit, and may even interfere with recognition. Based on the study by Snell et al. (2018), in which it was observed that the spatial orthographic integration effects are driven by attention, the authors concluded, in parallel to what occurs in normal reading sentences (see Rayner, 1998), that attention in a flanker task is biased toward the right (see Scaltritti et al., 2021; for conflicting results). For our study, we understand that the right bias of attention and parafoveal processing has no impact on the present results, even in the most extreme case, given that the length of targets and right flankers exceeds the span of the fovea.

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Another important issue to consider in explaining our results is that of the number of overlapped letters between targets and flankers. The first letters to the right of the visual field (especially the first three ones) have been shown to be particularly important for letter coding (Rayner et al., 1982; see also Johnson et al., 2007). In our experiment, the Identity condition shared these first three letters between flankers and targets, but the Transposition and the One Letter Different conditions (first experiment) shared two non-consecutive ones (e.g., abedul abedul abedul vs. adebul abedul adebul vs. apedul abedul apedul). This raises the question of whether the greater benefit observed for the Identity condition emerged from the one more overlapped letter among the three first ones. We do not believe this has played a significant role in the results despite the paper by Snell and Grainger (2018) showing a right bias in a flanker task. The evidence for Spanish in this very same task showed no additional benefit for the right flanker in comparison to the left one (Lázaro et al., 2022) and, moreover, the potential right-hand bias does not necessarily rule out the left flanker playing a role in word recognition. In the previous example (abedul abedul abedul vs. apedul abedul apedul), the last three letters of the left flanker are identical for the Identity and One Letter Different conditions. In sum, we do not believe that the one more overlapped letter in the Identity than in the other conditions can explain the results, although it is reasonable to propose further research on this highly specific issue.

All in all, we understand that the results of our study show highly flexible orthographic processing at parafoveal level, such that relatively extreme manipulations in the orthographic resemblance between flankers and targets does not prevent a facilitatory effect appearing. Evidently, even more extreme manipulations can be carried out to identify a limit in the orthographic resemblance needed to generate facilitation (e.g., by presenting the letters in a random order or by manipulating the proportion and location of shared letters). However, our data clearly show highly flexible orthographic processing at parafoveal level. This flexibility, however, needs to be considered in the light of the results showing a precise letter processing of flankers – the greatest orthographic effects for the Identity condition. Additional research needs to be conducted in order to further characterize the orthographic abilities at parafoveal level.

Data availability statement. Raw data as well as R code can be downloaded here: https://osf.io/gke6v/.

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Appendix A. Stimuli of the experiment 1

ENGLISH	ID	TL	OLD	UR	ENGLISH	ID	TL	OLD	UR
birch	abedul	adebul	apedul	roecor	wild boar	jabato	jatabo	jacato	sipope
spruce	abeto	atebo	ameto	yotur	syrup	jarabe	jabare	japabe	bloche
capacity	aforo	arofo	ayoro	errio	giraffe	jirafa	jifara	jidafa	unetra
adjacent	aledaña	adelaña	amedaña	fiampre	hump	joroba	jobora	joloba	chicre
icon	icono	inoco	idono	pasco	lentil	lenteja	lenjeta	lerteja	alcorja
dressing	aliño	añilo	alipo	rulia	libido	libido	lidibo	limido	cudeta
battlement	almena	alnema	altena	rispra	bunk	litera	lireta	lirera	artojo
alpaca	alpaca	alcapa	almaca	peyate	sea bass	lubina	luniba	lutina	birtia
poppy	amapola	apamola	adapola	fladelo	backpack	macuto	matuco	maputo	forcol
amazon	amazona	azamona	acazona	sorrija	hank	madeja	majeda	mameja	guinta
amphibian	anfibio	anbifio	ancibio	peduche	juggling	malabar	mabalar	macabar	redaliz
craving	antojo	anjoto	antono	forios	marmot	marmota	martoma	malmota	enchure
rush	apuro	arupo	anuro	tepla	gossip	maruja	majura	matuja	trelza
arpeggio	arpegio	argepio	armegio	mapopla	mane	melena	menela	memena	apraso
watchtower	atalaya	alataya	acalaya	escrofa	hake	merluza	merzula	mesluza	caducha
avaricious	avaro	aravo	ataro	vaica	skunk	mofeta	motefa	moceta	bejuga
avatar	avatar	atavar	azatar	grotor	mojito	mojito	motijo	mopito	trosbo
hostess	azafata	afazata	apafata	sochozo	toiletry bag	neceser	nesecer	nereser	pispilo
scale	baremo	bamero	batemo	pelcal	smell	olfato	oltafo	olcato	julgla
flare	bengala	benlaga	besgala	notriza	olive grove	olivar	ovilar	ofivar	bapido
bermuda	bermuda	berduma	belmuda	sampara	opaque	opaco	ocapo	obaco	acial
sea bream	besugo	beguso	bedugo	viasda	nettle	ortiga	orgita	orpiga	gresfa
bobbin	bobina	boniba	bonina	adilto	caterpillar	oruga	ogura	oyuga	fotia
pot	botijo	bojito	bolijo	ecucto	pomace	orujo	ojuro	odujo	beyel
brew	brebaje	brejabe	blebaje	escasmo	ozone	ozono	onozo	ocono	aruno
armchair	butaca	bucata	bubaca	pircel	pagan	pagano	panago	padano	morriz
squid	calamar	camalar	canamar	atergia	palate	paladar	padalar	pasadar	arraito
penny	centavo	cenvato	certavo	ecirato	pamela	pamela	palema	pabela	acunte
beret	chapela	chalepa	chafela	pleseya	papyrus	papiro	paripo	paliro	apemia
luck	chiripa	chipira	chipipa	lintote	clown	payaso	pasayo	pacaso	jajuar
norway lobster	cigala	cilaga	cisala	badeta	pajamas	pijama	pimaja	pirama	asasco
zygote	cigoto	citogo	cinoto	asisco	piranha	piraña	piñara	pimaña	sulura

(*Continued*)

(*Continued*)

ENGLISH	ID	TL	OLD	UR	ENGLISH	ID	TL	OLD	UR
guinea pig	cobaya	coyaba	cozaya	ocezno	compliment	piropo	piporo	pitopo	acerno
blanket	cobija	cojiba	colija	espote	ointment	pomada	podama	pojada	puecho
eye drops	colirio	corilio	coririo	bucuelo	grapefruit	pomelo	polemo	povelo	bubido
sea bass	corvina	corniva	corpina	marrafo	pupil	pupila	pulipa	putila	avioma
dean	decana	denaca	dejana	cetras	sprout	retoño	reñoto	reroño	gluden
delicacy	delicia	decilia	desicia	esrigma	roulette	ruleta	rutela	rugeta	cualzo
headband	diadema	diameda	diajema	platebo	safari	safari	sarafi	sadari	peltis
emirate	emirato	emitaro	emicato	carpasa	salami	salami	samali	satami	pleuca
container	envase	ensave	enlase	nopivo	saliva	saliva	savila	sapiva	trolpa
erudite	erudito	erutida	erunita	esdanco	whistle	silbato	siltabo	sirbato	reterta
broom	escoba	esboca	estoba	trucra	siren	sirena	sinera	sitena	larcas
stove	estufa	esfuta	esdufa	afenal	armpit	sobaco	socabo	socaco	hotaza
fabada	fabada	fadaba	facada	lapaña	suffocation	sofoco	socofo	sodoco	parita
street lamp	farola	falora	fapola	pilata	lapel	solapa	sopala	sopapa	flegos
favela	favela	faleva	fafela	peruña	submissive	sumisa	susima	sulisa	chazco
doormat	felpudo	feldupo	feltudo	chasola	platform	tarima	tamira	tatima	rantio
fillet	filete	fitele	fipete	pelcha	cart	tartana	tarnata	tastana	adetona
phoneme	fonema	fomena	forema	pezino	dowel	tarugo	taguro	tafugo	acubia
mop	fregona	frenoga	flegona	gartafa	scissors	tijera	tireja	tirera	cofote
chamois	gamuza	gazuma	gasuza	melaje	jar	tinaja	tijana	tisaja	hutaño
doormat	garito	gatiro	galito	ercata	tutor	tutora	turota	tudora	bañiza
geranium	geranio	genario	gemanio	pacurdo	suitcase	valija	vajila	vanija	herdes
gorilla	gorila	golira	golila	jorpal	pot	vasija	vajisa	vafija	esnora
maroon	granate	gratane	glanate	melique	vegan	vegano	venago	vepano	socier
hammock	hamaca	hacama	hafaca	diezno	vinyl	vinilo	vilino	viyilo	toacla
heretic	hereje	hejere	hedeje	jofial	vignette	viñeta	viteña	viseta	camiar
hormone	hormona	hornoma	holmona	brintis	sapphire	zafiro	zarifo	zaliro	crirol
adjacent	aledaño	adelaño	atelaño	lonteva	young woman	zagala	zalaga	zamala	disdal

Appendix B. Stimuli of the experiment 2

ENGLISH	ID	VT	V + C + T	UR	ENGLISH	ID	VT	V + C + T	UR
birch	abedul	abudel	adulbe	roecor	piranha	piraña	pariña	pañira	sulura
spruce	abeto	abote	atebo	yotur	compliment	piropo	poripo	popiro	acerno
dressing	aliño	aloñi	añiol	rulia	ointment	pomada	pamoda	padoma	puecho
battlement	almena	almane	anamel	rispra	grapefruit	pomelo	pemolo	pelomo	bubido
rush	apuro	aporu	aupro	tepla	pupil	pupila	pipula	pilupa	avioma
miser	avaro	avora	aovar	vaica	sprout	retoño	roteño	roñeto	gluden
scale	baremo	beramo	bomera	pelcal	roulette	ruleta	reluta	retula	cualzo
sea bream	besugo	busego	bugose	viasda	safari	safari	sifara	sifara	peltis
bobbin	bobina	bibona	bibano	adilto	salami	salami	silama	simala	pleuca
botijo	botijo	bitojo	bijoto	ecucto	saliva	saliva	silava	sivala	trolpa
armchair	butaca	batuca	bacuta	pircel	mermaid	sirena	serina	senira	larcas
norway lobster	cigala	cagilla	caliga	badeta	armpit	sobaco	saboco	sacobo	hotaza
zygote	cigoto	cogito	cotogi	asisco	lapel	solapa	salopa	sapola	flegos
guinea pig	cobaya	caboya	cayaba	ocezno	submissive	sumisa	simusa	sisuma	chazco
blanket	cobija	ciboja	cajibo	espote	dais	tarima	tirama	timara	rantio
dean	decana	dacena	daneca	cetras	scissors	tijera	tejira	terija	cofote
container	envase	envesa	esvena	nopivo	tutor	tutora	totura	toruta	bañiza
broom	escoba	escabo	esboca	trucra	suitcase	valija	vilaja	vijala	herdes
stove	estufa	esfatu	efsatu	afenal	pot	vasija	visaja	vijasa	esnora
streetlight	farola	forala	folara	pilata	vegan	vegano	vageno	vanego	socier
slum	favela	fevala	felava	peruña	vinyl	vinilo	vonilo	volino	toacla
steak	filete	felite	fetile	pelcha	sapphire	zafiro	zifaro	zirafo	crirol
phoneme	fonema	fenoma	femona	pezino	adjacent	aledaña	aladeña	adaleña	fiampre
chamois	gamuza	gumaza	guzama	melaje	poppy	amapola	amopala	apomala	fladelo
bar	garito	girato	gitaro	ercata	amazon	amazona	amozana	azomana	sorrija
gorilla	gorila	girola	gilora	jorpal	arpeggio	arpegio	arpigeo	argipeo	mapopla
jabato	jabato	jobata	jotaba	sipope	flare	bengala	bangela	banlega	notriza
syrup	jarabe	jeraba	jebara	bloche	bermuda	bermuda	burmeda	burdema	sampara
giraffe	jirafa	jarifa	jafira	unetra	concoction	brebaje	brabeje	brajebe	escasmo
hump	joroba	jarabo	jabaro	chicre	penny	centavo	cantevo	canveto	ecirato
libido	libido	lobidi	lodibi	cudeta	fluke	chiripa	charipi	chapiri	lintote

(*Continued*)

(*Continued*)

ENGLISH	ID	VT	V + C + T	UR	ENGLISH	ID	VT	V + C + T	UR
bunk	litera	letira	lerita	artojo	eye drops	colirio	cilorio	cirilio	bucuelo
sea bass	lubina	libuna	linuba	birtia	delight	delicia	dilecia	dicelia	esrigma
macuto	macuto	mucato	mutaco	forcol	headband	diadema	diedama	diemada	platebo
hank	madeja	medaja	mejada	guinta	doormat	felpudo	fulpedo	fuldepo	chasola
lobster	maruja	muraja	mujara	trelza	mop	fregona	frogena	fronega	gartafa
mane	melena	malena	manela	apraso	geranium	geranio	garenio	ganerio	pacurdo
mofetta	mofetta	mefota	mefota	bejuga	maroon	granate	grenata	gretana	melique
mojito	mojito	mijoto	mitojo	trosbo	hormone	hormona	harmono	harnomo	brintis
olfato	olfato	olfota	oltofa	julgla	lentil	lenteja	lanteje	lanjeta	alcorja
olive grove	olivar	olavir	ovalir	bapido	marmot	marmota	mormata	mortama	enchure
opaque	opaco	opoca	ocopa	acial	hake	merluza	murleza	murzula	caducha
nettle	ortiga	ortagi	orgati	gresfa	whistle	silbato	salbito	saltibo	reterta
caterpillar	oruga	oragu	ogaru	fotia	neighboring	aledaño	aladeño	adelaño	lonteva
nettle	orujo	oroju	ojuro	beyel	Braid	chapela	chepala	chelapa	pleseya
heathen	pagano	pogana	ponaga	morriz	croaker	corvina	circona	cirnova	marrafo
pamela	pamela	pemala	pelama	acunte	scholar	erudita	eriduta	erituda	esdanco
papyrus	papiro	piparo	pirapo	apemia	emirate	emirato	emarito	ematiro	carpasa
clown	payaso	poyaso	posayo	jajuar	vignette	viñeta	veñita	vetiña	camiar
pajamas	pijama	pajima	pamija	asasco	Jar	tinaja	tanija	tajina	hutaño