Assessing the influence of letter position in reading normal and transposed texts using a letter detection task

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RUNNING HEAD: Letter position effect in reading

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Abstract

During word recognition, some letters appear to play a more important role than others. Although some studies have suggested that the first and last letters of a word have a privileged status, there is no consensus with regards to the importance of the different letter positions when reading connected text. In the current experiments, we used a simple letter search task to examine the impact of letter position on word identification in connected text using a classic paper and pencil procedure (Experiment 1) and an eye movement monitoring procedure (Experiment 2). In Experiments 3 and 4, a condition with transposed letters was included. Our results show that the first letter of a word is detected more easily than the other letters, and transposing letters in a word revealed the importance of the final letter. It is concluded that both the initial and final letters play a special role in word identification during reading, but that the underlying processes might differ.

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Keywords: reading, missing-letter effect, letter position, eye movements

Assessing the Influence of Letter Position in Reading Connected Texts Using a Letter Detection Task

As the basic element of written words in alphabetic languages, the processing of letters has always had a special status in the study of word recognition. A number of studies have shown that the words exterior letters play an important role in word recognition (e.g., Humphreys, Evett, & Quilan, 1990; Jordan, Patching, & Milner, 2000; Mason, 1975; McCusker, Gough, & Bias, 1981; Stevens & Grainger, 2003). However, these studies used paradigms in which words are presented in isolation. As Jordan, Thomas, and Patching (2003) pointed out: "whereas evidence of a privileged status for exterior letter pairs in processing single (foveal) word displays is plentiful […] this evidence has not been matched in studies in which words are presented in bodies of text" (p.900). Although there is evidence that both the first and the last letters of the word play a more important role than interior letters when reading connected text (e.g., Jordan, Thomas, Patching, & Scott-Brown, 2003) other studies have shown that only the first letter is critical (e.g., Briihl & Inhoff, 1995). The objective of the present series is to examine the importance of the words' exterior letters during reading by using a letter detection task.

To investigate the contribution of individual letter positions in word processing during reading, Briihl and Inhoff (1995) used an eye contingent paradigm and manipulated the availability of letters in the target word when readers were fixating the previous word. They found a preview benefit – that is, fixation duration on the target word decreased – when the first letters of the target word were available in the parafovea compared to a condition where all letters were replaced by Xs. The availability of the two exterior letters of the word did not lead to a larger preview benefit than presenting only the first two letters, suggesting that the last letter does not enjoy a particular status when reading continuous text. Other eye contingent studies of connected text reading have also concluded that the peripheral availability of a word's first letters was more beneficial than the availability of ending letters—suggesting a more important role for initial letters (Inhoff, 1989; Rayner, McConkie, & Zola, 1980; Rayner, Well, Pollatsek, & Bertera, 1982).

In 2003, Jordan, Thomas, Patching and Scott-Brown measured eye movements while participants were reading continuous text. The critical manipulation was the degradation of a few letters in the text through digital filtering. The results indicated that degrading exterior letters (first and last) slowed reading speed more than degrading interior letters or degrading only the first two letters; hence, the findings suggest that a words' last letter may be more important than was suggested by Briihl and Inhoff (1995). The importance of the last letters of a word was also demonstrated in studies using the transposed letters paradigm (e.g., see Johnson, Perea, & Rayner, 2007; Rayner, White, Johnson, & Liversedge, 2006; White, Johnson, Liversedge, & Rayner, 2008). For example, in a study by White et al., participants were asked to read continuous text where target words had two adjacent letters transposed. They showed that fixation duration on the critical words was longer when the beginning letters were transposed (*oculd* instead of *could*) than when the ending letters were transposed (*coudl*) and that end transpositions were associated to longer fixation duration than interior transpositions (*cuold)*. The two sets of studies described so far provide diverging evidence with regards to the importance of a word's ending letters. In order to shed light on this debate, we assessed the importance of letter positions using a different procedure than that employed in previous studies namely, a letter detection task.

Letter Position Effects in the Letter Detection Task

A number of studies have investigated the importance of letter position using single words displays. Evidence that the exterior letters of words have a privileged status was obtained using a wide variety of tasks such as letter recognition paradigms (e.g., Jordan, 1990; Jordan et al., 2000), word recognition paradigms (Humphreys et al., 1990; McCusker et al., 1981) and lexical decision tasks (Humphreys et al., 1990). One task that has been widely used is letter detection where participants are asked to indicate if a target letter is part of a word displayed on the screen (see Acha & Perea, 2010; Krueger, 1970; Mason, 1975; Pitchford, Ledgway, & Masterson, 2008). Such a task has enjoyed great popularity in the study of letter position effects. Indeed, in addition to providing converging evidence with other paradigms, it is believed to reflect key processes involved in word recognition and reading (e.g., see Acha & Perea, 2010; Pitchford et al., 2008).

Letter detection has also frequently been used to investigate the cognitive factors involved in letter and word identification in reading (Healy, 1994) and has served to examine the role of several factors, such as word frequency (e.g., Roy-Charland & Saint-Aubin, 2006), text repetition (e.g., Saint-Aubin, Roy-Charland, & Klein, 2007) and word function (Koriat & Greenberg, 1991). In the classical letter detection task introduced by Corcoran (1966), participants are asked to read a continuous text for comprehension while looking for a target letter. Typically, the results show that readers cannot detect all occurrences of the target letter and they are more likely to miss it when it is embedded in frequent function words (e.g., *the*) than in less frequent content words (e.g., *tie, toe*) (see, e.g., Moravcsik & Healy, 1995; Saint-Aubin & Poirier, 1997).

Despite its great popularity in studying reading processes and the importance of the different letter positions in single word displays, letter detection has been seldom used in order to investigate the letter position effect during reading. Indeed, only two studies assessed the importance of letter position using a letter detection task during reading (Assink & Knuijt, 2000;

Schneider & Healy, 1993), but this was a peripheral aim of those studies. As a consequence, these studies lack sufficient control to allow strong conclusions about the importance of the different letter positions during reading.

The letter detection task was used in the present study in order to examine the letter position effect. Participants were asked to read a text for comprehension while searching for a target letter. In Experiment 1, the classical paper and pencil procedure was used. In Experiment 2, the importance of parafoveal processing in the letter position effect was examined by measuring eye movements during the letter detection task. In Experiments 3 and 4, a transposed letters condition was included in order to investigate the discrepancy observed between different procedures.

Experiment 1

A paper and pencil procedure was used in Experiment 1 in order to examine the letter position effect in reading connected text (in French). The target letter was embedded equally frequently at each letter position in five-letter content words. Because there are not enough five-letter function words containing the letter *r* in French, function words of any length were included in the text solely in order to assess the presence of the classic missing-letter effect. Participants were presented with a text in a booklet and asked to circle the letter *r* each time they noticed it. They were instructed to read at their normal speed and to try to comprehend the text. The text was followed by a series of eight questions to ensure that participants read for comprehension.

Method

Participants. Sixty students from Université Laval, with French as their first language, volunteered to take part in the experiment in exchange of a small honorarium. All reported normal or corrected-to-normal vision.

Materials. A total of 20 critical French words containing the letter *r* were used in the experiment with four words for each letter position (see Table 1). The words for each letter position were equated on frequency, with a mean of 61 occurrences per million. Throughout the text, each word was repeated five times for a total of 100 critical words, in a French text containing 1,564 words. The critical words were used either as nouns or adjectives. Great care was taken to ensure that critical words were inserted in similar contexts throughout the text. For instance, in all conditions, 14 to 16 critical words followed a determinant and 4 to 6 critical words followed a noun or an adjective. In addition, in order to assess the presence of the classical missing-letter effect, 20 function words containing the letter *r* were also included in the text. The function words were prepositions and conjunctions that comprised between three and six letters and the target letter was either embedded in the last or penultimate position. The function words *car* [because], *contre* [against], *sur* [on], and *pour* [for] were used 1, 1, 6, and 12 times respectively. The target letter was also embedded in 87 non-critical words. The text was constructed with the restriction that there were at least four words without *r*s between two words containing the target letter, whether they were critical or not. No critical words were inserted in the first sentence of the text or at the beginning or end of a line (see Smith & Groat, 1979, for an empirical justification). Finally, no critical word began with a capital letter or was preceded or followed by a punctuation mark. The text was printed in times new roman 12 points and was two and a half pages long, with left and right margins of 2 cm and top and bottom margins of 1.5 cm.

In order to promote reading for comprehension, eight multiple choice comprehension questions were developed and were inserted at the end of the booklet. For each question, participants had to choose between four possible responses.

Procedure. Participants were tested individually. They were instructed to read the text for comprehension and to circle all occurrences of the target letter *r*. They were warned not to slow their reading speed and not to come back to circle a letter they had missed. They were also informed that their comprehension would be tested with eight multiple-choice questions.

Results

The comprehension score was 58.3% (SD = 21.2). The proportion of omissions was first analysed as a function of word syntactic role to verify the presence of the basic missing-letter effect. To this end, for each participant, the proportion of omissions was computed by pooling together the 100 occurrences of the critical content words, and by pooling together the 20 occurrences of function words. For all analyses, the .05 level of significance was adopted and the Greenhouse-Geisser correction was applied when the sphericity criterion was not met. A repeated-measures analysis of variance (ANOVA) indicated that the mean proportion of omissions was much larger for function words (M = .66, SD = .23) than for the critical content words (M = .15, SD = .10), $F(1, 59) = 463.22$, MSE = 0.01, $\eta^2_p = .89$.

The proportion of omissions among the critical content words was then assessed separately as a function of letter position. As shown in Figure 1, there are fewer omissions for the first letter position, and more omissions for the third letter position. A repeated-measures ANOVA showed that the main effect of letter position was significant, $F(4, 236) = 8.02$, MSE = 0.01, $\eta^2_p = .12$. Post hoc comparisons (Tukey, HSD) revealed that readers made significantly fewer omissions when the target letter was in the first position than in the third or fifth position and more omissions when the target letter was in the third than in the second or fourth position. No other contrasts were significant. To ensure that this pattern was not due to the relatively low comprehension scores, we removed the participants that had a comprehension score at chance level (25%) or below from the analysis (n = 56). The same pattern of results was observed.

‘Insert Figure 1 about here’

A surprising finding is that the proportion of omissions in fourth position was very low compared to other positions. One possibility is that the *r* in fourth position was detected more often because in half of these critical words, it followed another consonant. Indeed, the letter *r* in the critical word *cèdre* might be pronounced with more emphasis than in the word *polar* because it is preceded by a consonant. In order to test this idea, we analysed the proportion of omissions in position four for critical words where the letter *r* was preceded by a consonant (*cèdre* and *cadre*) and where the letter *r* was preceded by a vowel (*phare* and *genre*). The analysis indicated that the proportion of omissions was much lower when the target letter was preceded by a consonant (M = .13, SD = .16) than by a vowel (M = .23, SD = .13), $F(1, 59) = 24.99$, MSE = 0.01, $\eta^2_p = .30$.

A final analysis was carried out in order to ensure that the repetition of each critical word did not influence our pattern of results. Indeed, each critical word was repeated five times throughout the text. For each letter position, we therefore calculated the proportion of omissions for the first and last occurrences of the critical words in the text. A 5 (letter position; 1 to 5) x 2 (occurrence; first, last) repeated measures ANOVA confirmed that the effect of letter position was significant, $F(4, 236) = 4.32$, MSE = 0.03, $\eta^2_p = .07$. Neither the main effect of occurrence, nor the interaction between letter position and occurrence were significant (Fs < 1), suggesting that the proportion of omission was not influence by the repetition of the critical word. This result is in line with that of Saint-Aubin et al. (2007) showing that the pattern of omissions is unaffected by text repetition.

Discussion

The present experiment replicated the classical missing-letter effect, that is, the target letter was detected more often when it was embedded in content than in function words (e.g., Corcoran, 1966; Koriat & Greenberg, 1994; Moravcsik & Healy, 1995; Saint-Aubin & Poirier, 1997). Consistent with previous studies (Briihl & Inhoff, 1995), the results also indicated that when the target letter occupied the first position of the word, it was detected more often than when it occupied other positions. Importantly, when the target letter was in the last position, it was not detected more often than the interior positions.

A surprising finding is that the proportion of omissions was particularly low in fourth position. This finding might be due to the fact that the letter *r* in position four was sounder than in other positions because in half of the critical words, it followed a consonant. This is supported by the finding that when the letter *r* in fourth position followed a consonant, the proportion of omissions was much lower than when it followed a vowel. It is important to note that for letter positions 1, 3 and 5, the critical letter always followed a vowel and therefore, that this particularity cannot explain the advantage for the first letter over the final letter.

Although the latter finding is in line with Briihl and Inhoff's (1995) results, it is not consistent with studies in which text was degraded (e.g., Jordan, Thomas, Patching, & Scott-Brown, 2003) or letters were transposed (e.g., White et al., 2008). Inhoff, Radach, Eiter, and Skelly (2003) suggested that the advantage for the last letter occurred mostly when foveal processing is dominant. As in Jordan's et al. study, both foveal and parafoveal processing were available to readers in Experiment 1 and therefore, according to Inhoff et al.'s (2003) theory, we should have observed an advantage for the last letter. One possibility however, is that the importance of the last letter depends on the amount of parafoveal processing given to a word: a lower amount of parafoveal processing – leading to an increased reliance on foveal processing – could lead to an advantage for the last letter. Another possible reason for the discrepancy between our results and that of other studies is that our measure was not sensitive enough. Indeed, we measured the proportion of omissions whereas other studies used time-related measures such as fixation duration (e.g., see White et al., 2008) or reading time (e.g., Jordan, Thomas, Patching, & Scott-Brown, 2003).

Experiment 2

In order to examine the role of parafoveal processing in producing the advantage for the words' last letter, eye movements were recorded while participants read the text presented on the computer screen. Participants were required to mouse-click each time they detected the target letter, which allowed measuring response latencies for detections. The proportion of omissions and response latencies at each letter position were analysed as a function of the distance between the critical word and the location of the closest fixation made prior to fixating the critical word (e.g., see Briihl & Inhoff, 1995). If the advantage for the last letter occurs when foveal processing is dominant, this advantage should be observed when the amount of parafoveal processing is lower, that is, when the pre-target fixation lands further to the left of the critical words.

Method

Participants. Thirty students from Université de Moncton volunteered to take part in the experiment. All reported normal or corrected-to-normal vision.

Apparatus and materials. The text was the same as that used in Experiment 1. The 1,564 words were split into 28 pages each containing between 3 and 4 lines of text so that each page began with a new sentence (no sentences were split to begin on one page and finish on the next page). In order to preserve the same arrangement as in Experiment 1, the first sentence on each page began at the top of the page, one space to the right of the last sentence's period, at the same horizontal location it would have if the two sentences were presented on the same screen. Eye movements were recorded with the SR Research Ltd EyeLink II system. The system's resolution and sampling rate are < 0.5 degree and 500 Hz. The eye movements were captured by two cameras mounted on a headband that allowed tracking of both eyes and head position for head-motion compensation. In this experiment, only the pupil of the participant's eye for which the most accurate calibration was achieved was tracked.

Procedure. The experimental session began with a calibration phase where participants were asked to fixate alternatively nine calibration dots. After calibration, the pages of text were presented one after the other. When participants were done reading one page, they were instructed to look at a small cross located at the right-bottom of the screen to indicate to the experimenter that the next page could be displayed. In order to ensure eye movement recording accuracy, before the presentation of each page, participants had to fixate a single calibration dot located in the top left corner of the page, vertically aligned with the first line of text.

As in Experiment 1, participants were instructed to read for comprehension. Simultaneously, they were told to press the left button of the mouse as fast as possible each time they encountered the letter *r*. After reading the 28 pages, they were asked to answer eight multiple-choice questions that were presented on paper.

Results

The comprehension score was 52.08% (*SD* = 19.99). Eye movements were analysed with the EyeLink Data Viewer program which displays the participants' eye movements superimposed on the text presented during the experiment. Over the 3600 observations (30 participants X 120 critical words), 0.28% were removed from the analysis due to large distortions in eye movement recording. Moreover, when making a line return, the eyes did not always land on the first word of the new line: on some occasions, the eyes landed on the critical word—which was never the first word of a line—or immediately to its right. Those cases represent 3.72% of all observations and were removed from the analyses. Also, several studies have shown that when the critical word is skipped during reading, the proportion of omissions increases (e.g., see Roy-Charland, Saint-Aubin, Klein, & Lawrence, 2007). A word was considered skipped when it was not fixated at all, that is to say, neither during the first pass, nor after a regression. In our experiment, the percentage of skips was not equivalent between the five letter positions: it was 11%, 11%, 9%, 4% and 7% for positions 1 to 5 respectively, a difference that was significant, $F(4, 116) = 8.80$, $MSE = 0.004$, $\eta^2_p = .23$. As typically found in eye monitoring studies, function words (26%) were also skipped significantly more often than the critical content words (8%), $F(1, 29) = 24.64$, $MSE = 0.02$, $\eta^2_p = .46$ (see, e.g., Carpenter & Just, 1983; Greenberg, Inhoff, & Weger, 2006; Saint-Aubin & Klein, 2001). In order to ensure that the differences observed are not due to the percentage of skips, the following analyses are based on fixated words only, whether fixation occurred through the first past, or after a regression. Moreover, the analyses on the proportion of omissions and on response latencies yielded the same pattern of results irrespective of whether they were performed on all subjects, or only on subjects that had a comprehension score above chance level (n = 25). Therefore, only the former analyses are reported

Proportion of omissions. A repeated-measures ANOVA showed that the mean proportion of omissions was again larger for function words ($M = .65$, $SD = .27$) than for the critical content words ($M = .20$, $SD = .15$), $F(1, 29) = 133.11$, $MSE = 0.02$, $\eta^2_p = .82$. The proportion of omissions among the critical content words was then assessed as a function of letter position. As shown in Figure 1, the pattern of omissions is very similar to that of Experiment 1: there were fewer omissions for Position 1, but not for Position 5. A repeated-measures ANOVA revealed that the main effect of letter position was significant, $F(4, 116) = 5.33$, $MSE = 0.01$, $\eta^2_p = .16$. Post hoc comparisons (Tukey, HSD) revealed that readers made significantly fewer omissions when the target letter was in first position than in the third or fifth position and fewer omissions when the target letter was in fourth than in the third or fifth position. No other contrasts were significant.

The proportion of omissions was then measured as a function of eccentricity. For each target, we calculated the number of characters (including spaces and punctuation) between the location of the closest fixation that preceded fixation on the critical word and the first letter of the critical word[1]. When no regression was made from the previous word, the location of the closest fixation was also the location of the last fixation prior to fixation on the critical word. For each participant, the proportion of omissions was assessed separately for pre-target fixations that were located fewer than four characters to the left of the critical word's first letter (near fixation; mean closest fixation distance = 2.3 characters, $SD = 0.1$) and for pre-target fixations that were located four characters or farther (far fixation; $M = 7.6$, $SD = 0.9$). These values were chosen as they allow equal sample size. As shown in Figure 2A, the proportion of omissions for all letter positions was higher for far than for near fixations, but the pattern of omissions across letter positions was the same in both cases. This was confirmed by a 2 (eccentricity; far fixation, near fixation) x 5 (letter position) repeated-measures ANOVA showing that the main effects of eccentricity, $F(1, 29) = 14.39$, $MSE = 0.01$, $\eta^2_p = .3$, and of letter position, $F(4, 116) = 5.12$, $MSE = 0.001$, $\eta^2_p = .15$, were significant, but not the interaction between eccentricity and letter position, $F < 1$.

‘Insert Figure 2 about here’

Response latency. The time required to respond after a target letter was detected was calculated from the time the eyes crossed the first letter of the critical word for the first time (e.g., see Roy-Charland et al., 2007). To be included in the analysis, the response had to be given before the eyes crossed the first letter of another word containing the target letter. Response latency for detected targets was first compared between critical function and content words. This analysis was based on 25 participants since, as it is often the case, 5 participants detected no function word (see, e.g., Roy-Charland et al., 2007; Roy-Charland, Saint-Aubin, Lawrence, & Klein, 2009). A repeated-measures ANOVA showed that response latency was longer for function words (M = 1009 ms, SD = 259 ms) than for the critical content words (M = 704 ms, SD = 118 ms), $F(1, 24) = 33.50$, $MSE = 35517.50$, $\eta^2_p = .58$. Response latency for the critical content words was then assessed separately for the five letter positions. Table 2 shows that response time was shorter for the first letter position than for the remaining letters. A repeated-measures ANOVA confirmed that the main effect of letter position was significant, $F(4, 116) = 5.99$, $MSE = 7592.31$, $\eta^2_p = .17$. Post hoc comparisons (Tukey, HSD) revealed that response latency was shorter for the first letter position than for the four other positions which did not differ one from the other.

‘Insert Table 2 about here’

Response latencies were then examined for far and near pre-target fixations. As for the pattern of omissions, Figure 2B shows that although far fixations led to longer response latencies, they did so for all letter positions. Two participants were removed from the analysis because they detected no target letter in one condition. A 2 (eccentricity; far fixation, near fixation) x 5 (letter position) repeated-measures ANOVA indicated that the main effects of eccentricity, $F(1, 27) =$

162.59, *MSE* = 14033.34, η^2_p = .86, and of letter position, $F(4, 108) = 7.61$, *MSE* = 14326.68, η^2_p = .22, were significant, but the interaction between eccentricity and letter position was not significant ($F < 1$).

Eye movement data. Although eccentricity did not modulate the effect of letter position on response latency and omissions, eccentricity increased response latency by 180 ms and the proportion of omissions by 5%. In order to understand the effect of eccentricity on our measures, we calculated gaze duration (the sum of all fixations on the critical word prior to a saccade to a following word), total fixation time (the sum of all fixations on the critical word), skipping rate (the percentage of critical words not fixated at all, neither during the first pass, nor after a regression), and the percentage of regressions on target words (the proportion of target words on which a fixation has been made after first pass reading) as a function of eccentricity (see Table 3). A repeated-measures ANOVA showed that gaze duration, $F(1, 29) = 112.42$, *MSE* = 1478.20, η^2_p = .80, and total fixation time on the critical words, $F(1, 29) = 184.10$, *MSE* = 1334.33, η^2_p = .86, were longer for far compared to near fixations. Although the skip rate of the critical words was higher for far fixations, $F(1, 29) = 49.45$, *MSE* = 70.96, η^2_p = .63, the percentage of regressions on the critical words did not differ between far and near fixations, $F < 1$.

‘Insert Table 3 about here’

Discussion

Experiment 2 replicated the missing-letter effect by showing that the proportion of omissions was smaller and response latency was shorter when the target letter was embedded in a content word than in a function word (e.g., see Roy-Charland et al., 2007). As in Experiment 1, we observed an advantage for the first letter position, but not for the last letter position. These results were corroborated by an analysis of response latencies indicating that the first letter, but not the last letter, was detected faster than the interior letters. When analysed as a function of eccentricity, the proportion of omissions and response latency for all letter positions decreased for near pre-target fixations compared with far pre-target fixations. An analysis of eye movement data showed that fixations on the critical words were longer for far pre-target fixations (~ 100 ms) and that skipping rate was higher for near fixations. The effect of eccentricity on response latencies might therefore be due to the fact that for near fixations, the target letter could be detected in parafovea.

Importantly, far pre-target fixations did not lead to an advantage for the last letter. Therefore, our results suggest that neither the sensitivity of our measure, nor the amount of parafoveal processing is responsible for the discrepancy between our results and those of other studies (e.g., White et al., 2008). In order to examine the source of the differences between our findings and those of previous studies, we combined the letter detection paradigm with a manipulation of transposed letters (e.g., see White et al., 2008).

Experiment 3

In Experiment 3, we used a classical paper-and-pencil letter detection procedure as in Experiment 1. A transposed letters condition was included for sake of comparability with previous studies. If the transposed letters procedure is responsible for uncovering the importance of the words' last letter, the advantage for the initial letter compared to the ending letter should be attenuated or abolished when transposed critical words are used. Moreover, in order to ensure that the effect observed in the two previous experiments is not due to the use of the target letter *r* or to the fact that the text was in French, two different texts were constructed in English: one in which participants had to search for the letter *t* and one in which they had to search for the letter *d*.

Method

Participants. Sixty-six students from City University London volunteered to take part in the experiment. All reported normal or corrected-to-normal vision.

Materials and Procedure. A total of 24 five-letter critical words containing the letter *d* were selected for the experiment, 8 with the target letter in first position, 8 with the target letter in third position and 8 with the target letter in fifth position. Another set of 24 five-letter critical words containing the letter *t* was selected, 8 for each of the letter positions 1, 3, and 5. The words for each letter position were equated on familiarity rating according to the MRC psycholinguistic database (ranging from 100 to 700; Coltheart, 1981) with a mean familiarity rating of 516. Each target word was presented once in the text. The critical words containing the letter *d* were included in a text that comprised 671 words. The text also included 71 non-critical words containing the letter *d*.

The critical words containing the letter *t* were included in a text that comprised 805 words. The text included 132 non-critical words containing the letter *t*. Each text ended with six multiple-choice questions to assess their comprehension. Each participant read both texts. Half of the participants began with the target letter *d* and half began with the target letter *t*. For each critical word, a transposed word was created by reversing the target letter with the previous or following letter. For middle transpositions, half of the transpositions were made by reversing the letters 2 and 3 (*fduge* instead of *fudge*) and half were made by reversing the letters 3 and 4 (*saitn* instead of *satin*). There were two versions of each text. In the first version, half of the critical words were transposed (four for each letter position) and the other half was presented normally. In the second version, the transposed words of the first version were presented normally whereas the other half was transposed. Each participant was exposed to one of the two versions for each target letter. The two versions were used equally often in first and second order. All texts also included 12 transposed filler words in which the target letter was never embedded. In the *d* text, the filler words were three function words containing three or four letters and nine content words containing between 4 and 9 letters in which the beginning, middle or ending letters were transposed. In the *t* text, the transposed filler words were three function words containing two, three and four letters and nine content words containing between 4 and 9 letters. The transposed filler words were the same in all versions of the text and the first transposed word in the text was always a filler word. Instructions warned participants that some words in the text might have transposed letters but to try to read at their normal speed without backtracking.

Results

***D* text**. The comprehension score was 86.11% (*SD* = 18.62%). A repeated-measures ANOVA showed that the mean proportion of omissions for non-transposed words was larger for function words (*M* = .91, *SD* = .15) than for the critical content words (*M* = .18, *SD* = .15), $F(1, 65) = 863.36$, $MSE = 0.02$, $\eta^2_p = .93$. As shown in Figure 3A, the proportion of omissions tended to increase as a function of letter position for normal words, but to be much flatter for the transposed words, with a slightly reverse U-shaped function. A 2 (transposition; transposed, normal) x 3 (letter position; beginning, middle, ending) repeated measures ANOVA showed that the proportion of omissions was higher for the normal critical words than for transposed critical words, $F(1, 65) = 21.43$, $MSE = 0.05$, $\eta^2_p = .25$. The effect of letter position was significant, $F(2, 130) = 8.72$, $MSE = 0.03$, $\eta^2_p = .12$, as well as the interaction between transposition and letter position, $F(2, 130) = 5.71$, $MSE = 0.02$, $\eta^2_p = .08$. Simple main effects analysis showed that there was a significant effect of letter position for normal critical words, $F(2, 130) = 9.47$, $MSE = 0.04$, $\eta^2_p = .13$, but not for transposed critical words, $F(2, 130) = 1.15$, $MSE = 0.01$, $\eta^2_p = .02$. Post hoc comparisons (Tukey, HSD) revealed that for normal critical words, there were significantly fewer omissions when the target letter was at the beginning than in the middle of the word, and that fewer omissions when the target letter was in the middle than at the end of the word.

'Insert Figure 3 about here'

***T* text**. The comprehension score was 91.14% (*SD* = 13.15%). A repeated-measures ANOVA showed that the mean proportion of omissions for non-transposed words was larger for function words (*M* = .56, *SD* = .24) than for the critical content words (*M* = .22, *SD* = .19), $F(1, 65) = 188.28$, $MSE = 0.02$, $\eta^2_p = .74$. The effect of letter positions in the normal and transposed conditions is presented in Figure 3B. A 2 (transposition; transposed, normal) x 3 (letter position; beginning, middle, ending) repeated measures ANOVA showed that the proportion of omissions was higher for the normal critical words than for transposed critical words, $F(1, 65) = 24.76$, $MSE = 0.05$, $\eta^2_p = .28$. The effect of letter position was significant, $F(2, 130) = 22.35$, $MSE = 0.03$, $\eta^2_p = .26$. The interaction between transposition and letter position was also significant, $F(2, 130) = 5.02$, $MSE = 0.04$, $\eta^2_p = .07$, suggesting that the effect of transposition increased as a function of letter position. Simple main effects analysis showed that there was a significant effect of letter position for normal critical words, $F(2, 130) = 17.72$, $MSE = 0.05$, $\eta^2_p = .21$, as well as for transposed critical words, $F(2, 130) = 4.89$, $MSE = 0.02$, $\eta^2_p = .07$. Post hoc comparisons (Tukey, HSD) revealed that for both normal and transposed critical words, there were significantly fewer omissions when the target letter was at the beginning than in the middle and ending of the word, and that there was no difference between the two latter conditions.

Discussion

The results first replicated the robust effect of misspellings on omission rate. As repeatedly shown, omission rate is lower for misspelled than for correctly spelled words (see, e.g., Healy & Drewnowski, 1983; Koriat & Greenberg, 1991; Proctor & Healy, 1985). In the missing-letter effect literature, this effect has traditionally been interpreted by assuming that letters are processed more extensively and for a longer amount of time when words are misspelled, which translates into a lower omission rate (Healy, 1994). Most importantly for the aim of the current study, the results of Experiments 1 and 2 were replicated since there were fewer omissions for the words' beginning letters, but not for the words' ending letters, confirming that this effect is not specific to a given target letter, text or language. In addition, the advantage for the initial letter compared to the final letter was much lower when the critical words were transposed, suggesting that the importance of the last letter is better captured by this particular manipulation. An examination of Figure 3 suggests that the advantage of the word's initial letter over the final letter was abolished only in the *d* text and not in the *t* text. One possibility is that the abolition of this effect in the *d* text is due to a floor effect. Indeed, it is possible that a higher level of omissions would still yield an advantage for the initial letter. However, we want to emphasize that even though an advantage for the initial letter may subsist in the *t* text, it is strikingly reduced compared to a control condition in both texts.

One hypothesis accounting for the interaction between transposition and letter position, might be that in words with transposed letters, the target letter is no longer presented in its original position. Consequently, the different pattern of omissions between the normal and transposed conditions may be due to the fact that the position in which the target letter was presented differed between the normal and transposed conditions. For example, for the ending letter position, the target letter was presented in Position 5 in the normal condition and in Position 4 in the transposed condition. The target letter might be easier to detect when presented in Position 4 than in Position 5.

Experiment 4

The text used in Experiment 4 was the same as that used in Experiment 1. This choice was made to assess the impact of transposition on text comprehension by comparing the mean comprehension score with that of Experiment 1 where there were no transpositions. Although not central to the current demonstration, similar levels of comprehension for normal texts and for texts with transpositions would further support the usefulness of the transposed letter paradigm for investigating letter processing in connected texts. The hypothesis that the interaction between transposition and letter position occurred because the target letter was transposed was tested by including a group where the transpositions involved other letters than the target letter.

Method

Participants. One hundred and twenty students (two groups of sixty participants) from Université de Moncton volunteered to take part in the experiment. All reported normal or corrected-to-normal vision. None had participated in the previous experiments.

Materials and Procedure. The text was the same as that used in Experiment 1. In order to equate the proportion of transposed words in the text to that of Experiment 3, only a subset of the critical words used in Experiment 1 were manipulated in the present experiment. More precisely, the 40 critical words with the target letter in second and fourth positions were not used. From the remaining 60 critical words containing the letter *r*, 54 were selected, 18 with the target letter in first position, 18 with the target letter in third position and 18 with the target letter in fifth position. There were three versions of the text, each containing a different subset of 18 transposed critical words (six for each letter position). In one group, (*r* transposed), the transposition always involved the target letter *r* and the adjacent letter (e.g., *urche* for the critical word *ruche*). For middle transpositions, each text included three transpositions made by reversing the letters 2 and

3 (e.g., *mrain* for the critical word *marin*) and three made by reversing the letters 3 and 4 (e.g., *mairn* for the critical word *marin*). In the other group, (*r* not transposed), the transposition involved two letters that were adjacent to the target letter r (e.g., *rcuhe* for the critical word *ruche*). For middle transpositions, each text included three transposed words made by reversing the letters 1 and 2 (e.g., *amrin* for the critical word *marin*) and three made by reversing the letters 4 and 5 (e.g., *marni* for the critical word *marin*). All texts also included 12 transposed filler words in which the target letter was never embedded (three function words containing two or three letters and nine content words containing between 5 and 12 letters) in which the beginning, middle or ending letters were transposed. The transposed filler words were the same in all versions of the text and the first transposed word in the text was always a filler word.

Results

The mean comprehension score was 56.98% (*SD* = 23.86%), which did not differ from that in Experiment 1 (*M* = 58.3%, *SD* = 21.2%), $F < 1$. A mixed ANOVA with letters transposed (target letter, non-target letters) as a between-subjects factor and word function (content, function) as a within subject factor showed that the mean proportion of omissions for non-transposed words was larger for function words (*M* = .55, *SD* = .24) than for the critical content words (*M* = .17, *SD* = .15), $F(1, 118) = 506.44$, $MSE = 0.02$, $\eta^2_p = .81$. Neither the effect of letters transposed, nor the interaction between letters transposed and word function were significant, $F < 1$.

As shown in Figure 4, the patterns of omissions are very similar to that of Experiment 3: The advantage for the initial letter in the normal condition appeared to be reduced in the transposed letter condition. A mixed ANOVA with letters transposed (target letter, non-target letters) as a between-subjects factor and transposition (transposed, normal) and letter position (beginning, middle, ending) as within subject factors was performed on the proportion of omissions. The analysis showed that the proportion of omissions was higher for the normal critical words, than for transposed critical words, *F*(1, 118) = 101.29, *MSE* = 0.02, η^2_p = .46. The effect of letter position was significant, *F*(2, 236) = 20.46, *MSE* = 0.02, η^2_p = .15, as well as the interaction between transposition and letter position, *F*(2, 236) = 6.33, *MSE* = 0.01, η^2_p = .05. The effect of letter transposed was not significant, *F* < 1. No other interactions were significant. Simple main effects analysis showed that there was a significant effect of letter position for normal critical words, *F*(2, 238) = 21.33, *MSE* = 0.01, η^2_p = .15, as well as for transposed critical words, *F*(2, 238) = 8.15, *MSE* = 0.01, η^2_p = .06. Post hoc comparisons (Tukey, HSD) revealed that for normal critical words, there were significantly fewer omissions when the target letter was at the beginning of the word than in the middle or ending, but that there was no difference between the middle and ending conditions. For the transposed critical words, there were significantly more omissions when the target letter was in the middle position than at the beginning or ending of the word, but there was no difference between the beginning and ending conditions.

‘Insert Figure 4 about here’

Additional analyses were performed in order to examine if the proportion of omissions in the group where the target letter *r* was transposed is determined by the position of the letter after it has been transposed, or its initial position in the unaltered word. Indeed, in this group, the beginning transpositions involve presenting the target letter 1 in Position 2, and the ending transpositions involve presenting the target letter 5 in Position 4. If, as we assumed so far, the letter’s initial position in the unaltered word is critical, the proportion of omissions should be the same whether the third letter is transposed in Position 2 (*mrain* instead of *marin*) or in Position 4 (*mairn* instead of *marin*). On the other hand, if the transposed position is critical, the proportion of omissions should be the same whether the transposed letter in position 2 was initially located in position 1 (*urche* instead of *ruche*) or in position 3 (*mrain* instead of *marin*), and it should be the same whether the transposed letter in position 4 was initially located in position 3 (*mairn* instead of *marin*) or in Position 5 (*futru* instead of *futur*). We therefore compared the beginning and ending transpositions (exterior transpositions) with the middle transpositions where the transposed target letter was presented in Position 2 and in Position 4. Figure 5 shows that the proportion of omissions is higher for interior transpositions than for exterior transpositions. However, the proportion of omissions is not modulated by whether the target letter is transposed in Position 2 or in Position 4. This was confirmed by a 2 (transposed position; 2, 4) x 2 (initial position; exterior, interior) repeated-measures ANOVA performed on the proportion of omissions in the transposed condition, showing that the main effect of transposed position was not significant, $F < 1$, but that the main effect of initial position was significant, $F(1, 59) = 11.63$, $MSE = 0.02$, $\eta^2_p = .17$. The interaction between initial position and transposed position was not significant, $F < 1$.

‘Insert Figure 5 about here’

Discussion

The results replicated those of Experiment 3 and showed that with unaltered words, there is a striking advantage for the initial letter compared to the middle or ending letters. This advantage was severely reduced when the critical words included transpositions, irrespective of whether the transpositions involved the target letter or not. Indeed, in words with transpositions, the ending letter was detected as often as the initial letter. Our results cannot be attributed to the fact that transpositions modulated text comprehension since the comprehension score was similar to that in Experiment 1 where there were no transpositions. Additional analyses confirmed that the effect of letter transpositions does not occur because, when transposed, the last letter is presented in fourth position, which is easier to detect.

Although the three-way interaction was not significant, inspection of Figure 4 suggests that when the target letter was transposed (panel A), there were fewer omissions in ending than in middle position. One possible explanation is that transposing the ending letter *r* affected the phonological coding of the word. As suggested in the discussion of Experiment 1, the target letter *r* might be easier to detect depending on the letter that precedes it. This suggests that phonological processing is critical for letter detection and might also be modulated by transpositions. Importantly however, even if the pattern of results in the transposed letter condition might seem inconsistent in the two latter experiments, the advantage for the beginning letter over the ending letter is always reduced with transposed words compared to normal words.

General Discussion

The objective of the present series of experiments was to examine the importance of word letter positions when reading connected texts. In Experiment 1, a classic paper and pencil procedure showed that the target letter was better detected when it occupied the first position in the word than an interior position, but this advantage was not observed for the last letter position (see Briihl & Inhoff, 1995). This pattern was replicated in Experiment 2 and corroborated by an analysis of response latencies showing that the first letter was detected faster than the other letters. An analysis of eye movements further indicated that the absence of advantage for the last letter is not modulated by the pre-target fixation eccentricity. Experiment 3 replicated these results in English with different target letters. Moreover, Experiments 3 and 4 showed that even though the word's last letter is not detected more easily than the remaining letters for unaltered words, including transpositions in words reduced or even abolished the advantage for the initial letter over the ending letter. This result was observed irrespective of whether the transpositions involved the target letter or not.

When the critical words were unaltered, the words' first letter was detected faster and more often than the other positions. The initial letter of a word might benefit from enhanced processing because it plays a central role in lexical access. Indeed, the words' first letter would be used to restrain the pool of possible lexical representations activated (e.g., see Lima & Inhoff, 1985). Its processing could start in parafovea, as suggested by several studies using eye contingent paradigms, showing that the availability of the words' beginning letters in periphery was more beneficial than the availability of the words' ending letters (Briilh, & Inhoff, 1995; Inhoff, 1989; Rayner et al., 1980, 1982). The processing of the words' first letter in parafovea then would help speed lexical access once words are in fovea.

The current results also showed that the advantage of the first letter over other letter positions does not vary as a function of the location of the closest fixation on the previous word. One possibility is that readers try to extract information from the forthcoming word as it becomes available in parafovea: As each letter becomes available to the reader, information starts to accumulate about it, until the word is identified in fovea. This idea is consistent with studies showing that the probability of identifying a letter declines as a function of its eccentricity (see e.g., Klein, Berry, Briand, D'Entremont, & Farmer, 1990): Since the word's first letter is the first to be available in parafovea, it would be analysed before any other letter. Consequently, the words' first letter would be detected faster once the word is in fovea and the probability of identifying it as a target would be higher. When the closest pre-target fixation is too far to allow processing of the target word as in Experiment 2 however, we still observe an advantage for the initial letter of the word. This finding is comparable with studies that have investigated letter recognition in words presented in isolation (e.g., see Kwantes & Mewhort, 1999; Mulatti, Peressotti, & Job, 2007). Indeed, such studies have suggested that letters are processed sequentially from left to right during visual word recognition, leading to an advantage for the initial letter of the word. Therefore, the same basic processes recruited during individual word recognition would also operate during reading, and be apparent when parafoveal processing is limited.

When the critical words included transpositions, we showed that the advantage for the beginning compared to the ending letter was much reduced, and even abolished in some conditions. This result is in line with studies using degraded texts (Jordan, Thomas, Patching, & Scott-Brown, 2003) or the transposed letters paradigm (Johnson et al., 2007; White et al., 2008). The discrepancy between normal and transposed words might suggest that both beginning and ending letters play an important role in reading, but at different levels. One possibility is that the recognition of the last letter is important in later stages of processing during reading whereas initial letters are processed early. This idea is consistent with the findings of White et al. (2008) showing that when the words' ending letters are transposed, global measures (e.g., reading time) but not local measures (e.g., initial fixation) are affected. White et al. suggested that a word's ending might be more important in later processing stages. For instance, Perea and Lupker (2003) showed that the word's ending might play an important role in activating the semantic information associated to a word. In the present experiments, the proportion of omissions and response latency for normal words might reflect early processes related to low level visual analysis. For instance, letter detection might benefit from the processing of the visual features of the initial letters that begin in parafovea (see Rayner, 1998). Interestingly, according to some models of word recognition, the processing of letter identity is dissociated from the processing of letter position (e.g., SERIOL, Whitney, 2001; Whitney & Lavidor, 2005; SOLAR, see Davis 2010), and therefore, it is not surprising that letter identification results in different letter position effects than disrupting letter order. This finding however, might be specific to European languages, since the order of letters is more critical in other languages such as Hebrew, where several words share the same letters, but differ mostly relatively to their order (e.g., see Frost, 2011).

Another possibility explaining the finding that the first letter but not the last letter of a word is detected more easily is that the words' first letter is more separable from the rest of the word compared with the last letter. The last letter could be part of a larger perceptual unit, possibly including the word's ending, which would make it difficult to detect individually (see Jordan, Thomas, Patching, & Scott-Brown, 2003). This might suggest that the last letter is difficult to separate from the other letters and that a manipulation that impacts the penultimate letters of a word affects the processing of the final letter. According to this idea, the initial and final letters of a word might be equally important, but the initial letter would be easier to detect because it can be processed individually. The idea that the first letter of a word is easier to detach from the rest of the word than the final letter nevertheless suggests that both letters contribute to word recognition via different processes. Finally, it is also possible that transposing letters in words slowed reading speed. The final letter might have been easier to detect in this condition because the words were processed more carefully. This idea is supported by the fact that transposing the target letter had the same effect on letter detection than transposing other letters in the words (see Experiment 4).

In conclusion, our results show that the initial letter is detected more easily than the other letters, and that transposing some letters stresses the importance of the final letter. The finding that the importance of the initial and final letters can be revealed using different procedures suggests that although they may be equally important, initial and final letters might contribute to word recognition during reading through different processes. For instance, the largest impact of the first letter could result from early processes that come into play while the word is in parafovea in order to speed lexical access, whereas final letters might be more important during later stages of word recognition.

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Author Note

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Footnote

[1]Briihl and Inhoff (1995) also considered eccentricity as a mediating factor for the letter position effect. Instead of the closest fixation location however, they considered the size of the saccade made toward the target word, that is, the location of the *last* fixation prior to fixation on the target word. Because such a measure does not take into account instances where participants made a fixation close to the critical word and made a regression before fixation on the critical word, we used the location of the closest pre-target fixation. An analysis of the data as a function of saccade size showed a similar pattern of results.

Table 1
Critical words used in all experiments. The number of occurrence per million (Experiments 1 and 2) and familiarity ratings (Experiment 3) are indicated in parentheses and the English translation for French words used in Experiments 1 and 2 is in brackets. Note however, that the translation is provided for information purpose only since the English translations have different frequencies.

Experiment (target letter)	Letter position 1	2	3	4	5
1 and 2 (r)	ruche (4) [beehive]	frêne (3) [ash]	baril (3) [cask]	cèdre (4) [cedar]	polar (1) [thriller]
	reine (34) [queen]	orage (35) [thunderstorm]	marin (33) [sailor]	phare (31) [beacon]	futur (12) [future]
	règle (50) [rule]	crise (50) [crisis]	corde (48) [rope]	cadre (43) [frame]	décor (46) [setting]
	reste (169) [rest]	droit (164) [right]	forme (177) [shape]	genre (156) [kind]	soeur (161) [sister]
3 (t)	trunk (485)		petal (466)		saint (463)
	trend (512)		satin (470)		craft (487)
	tiger (513)		witch (479)		alert (523)
	tales (529)		entry (492)		upset (536)
	thief (529)		patch (528)		roast (536)
	trade (537)		match (558)		point (538)
	topic (539)		metal (559)		court (549)
	train (548)		hotel (565)		paint (551)
3 (d)	dough (474)		fudge (477)		vivid (500)
	dummy (478)		badge (478)		rigid (503)
	donor (479)		widow (485)		guard (504)
	ditch (511)		hedge (487)		rapid (524)
	daisy (519)		medal (494)		blind (531)
	drama (534)		pedal (512)		weird (539)
	dusty (537)		judge (539)		beard (538)
	dream (553)		older (548)		board (546)

Table 2

Response latencies (ms) and standard deviation for function words and critical words as a function of letter position in Experiment 2.

	Letter position					Mean	
	1	2	3	4	5	Critical words	Function words
M	636	704	736	716	720	704	1009
SD	121	162	136	125	156	118	259

Table 3
Means and standard deviations for gaze duration, total fixation time, skip rate and the proportion of regressions as a function of eccentricity.

	Gaze duration (ms)		Total fixation (ms)		Skip rate (%)		Regressions (%)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Near	225	75	261	85	17	2	10	8
Far	330	60	389	79	13	2	9	7

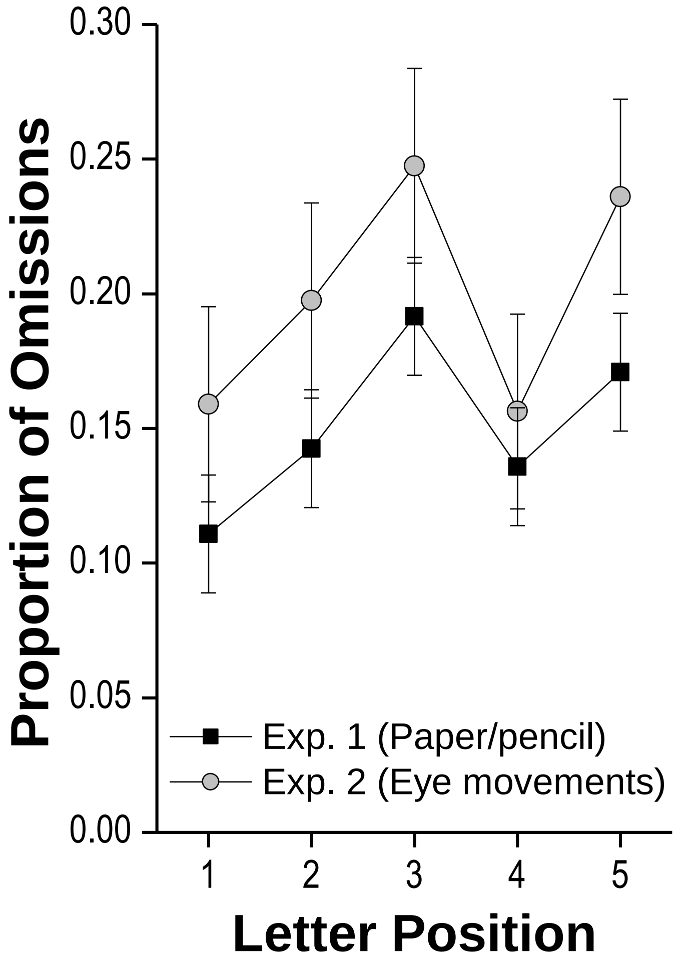

Figure 1. Proportion of omissions as a function of letter position in Experiments 1 and 2. Error bars represent 95% confidence intervals.

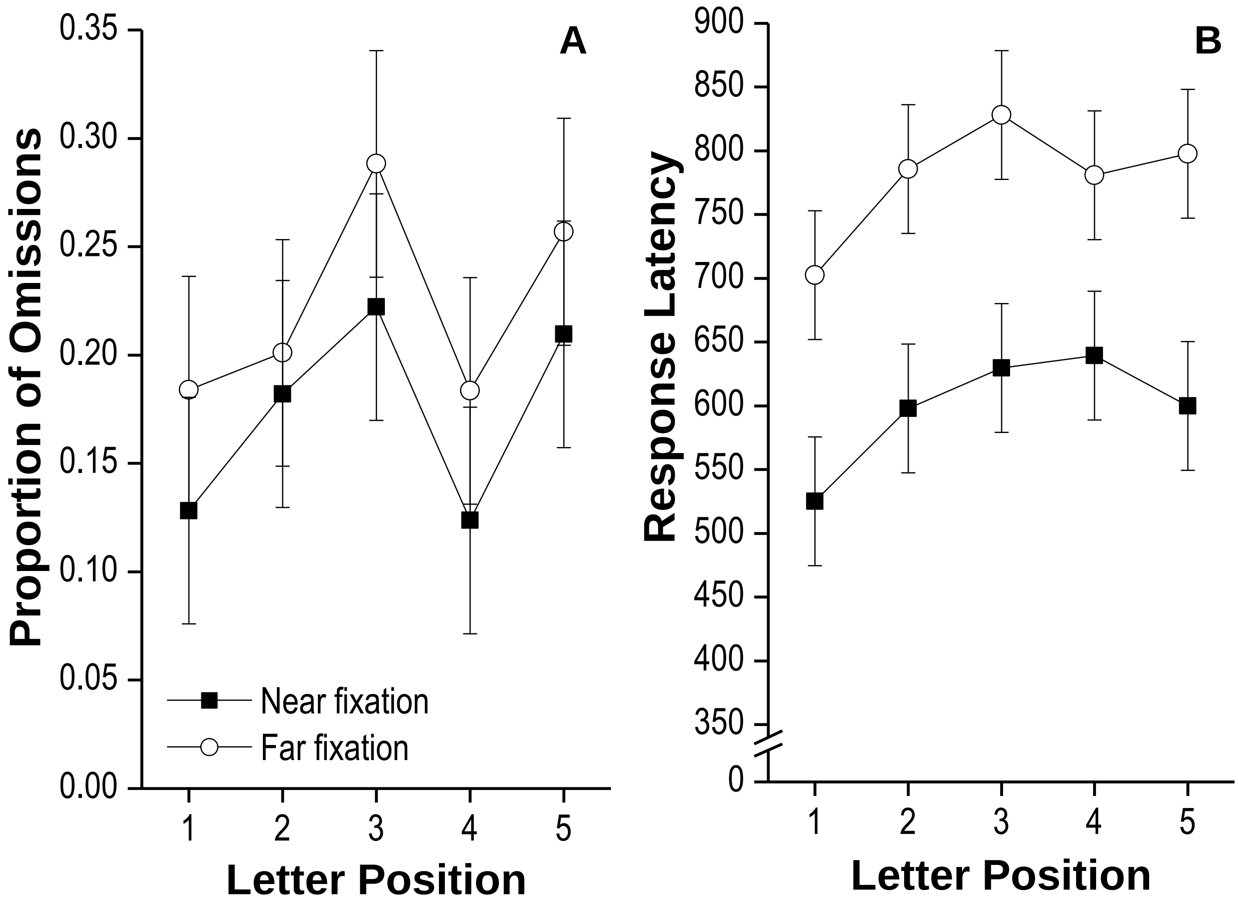

Figure 2. Proportion of omissions (panel A) and response latency (panel B) as a function of letter position and eccentricity of pre-target fixation in Experiment 2. Error bars represent 95% confidence intervals.

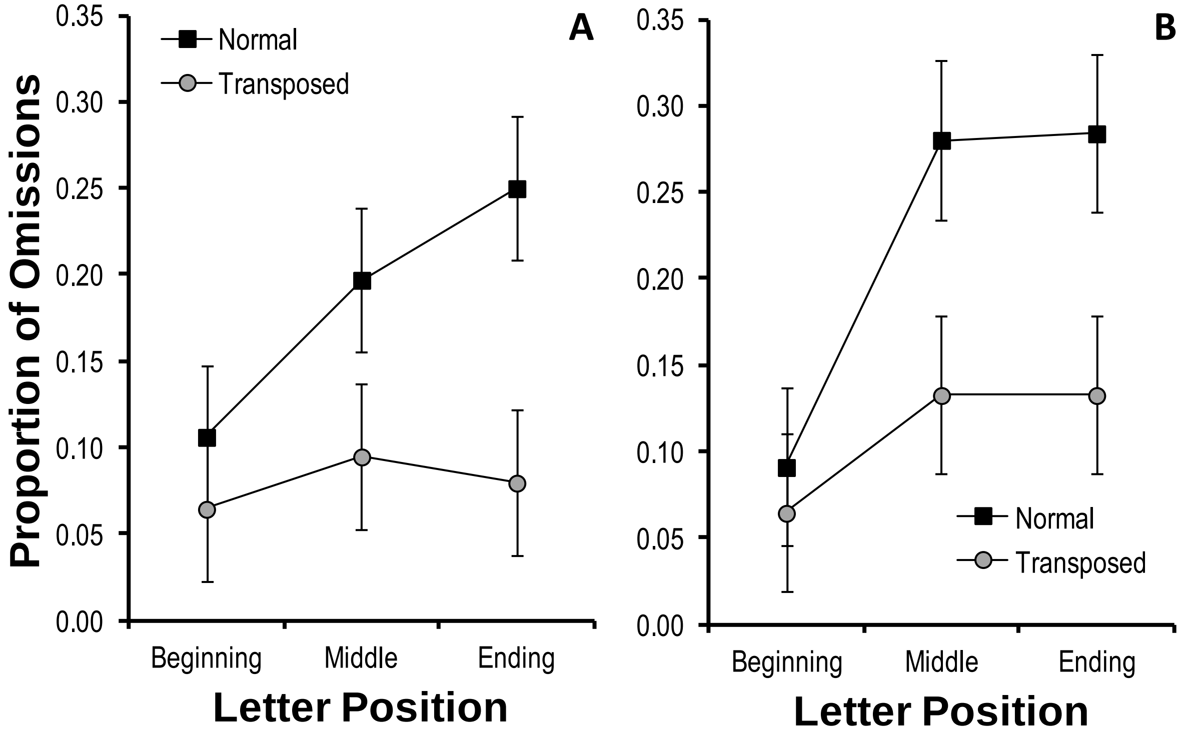

Figure 3. Proportion of omissions as a function of letter position and transposed letters condition for the *d* text (Panel A) and for the *t* text (Panel B) in Experiment 3. Error bars represent 95% confidence intervals.

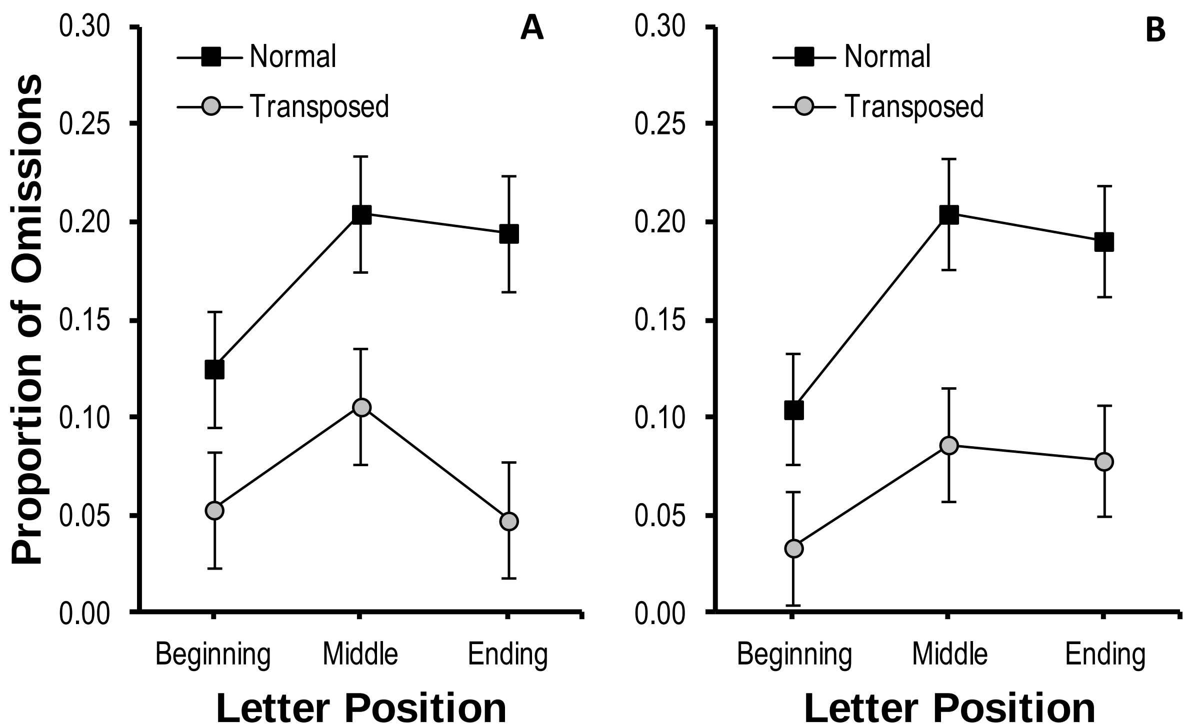

Figure 4. Proportion of omissions as a function of letter position and transposed letters condition when the target letter *r* was transposed (Panel A) and when the target letter *r* was not transposed (Panel B) in Experiment 4. Error bars represent 95% confidence intervals calculated separately for the two groups.

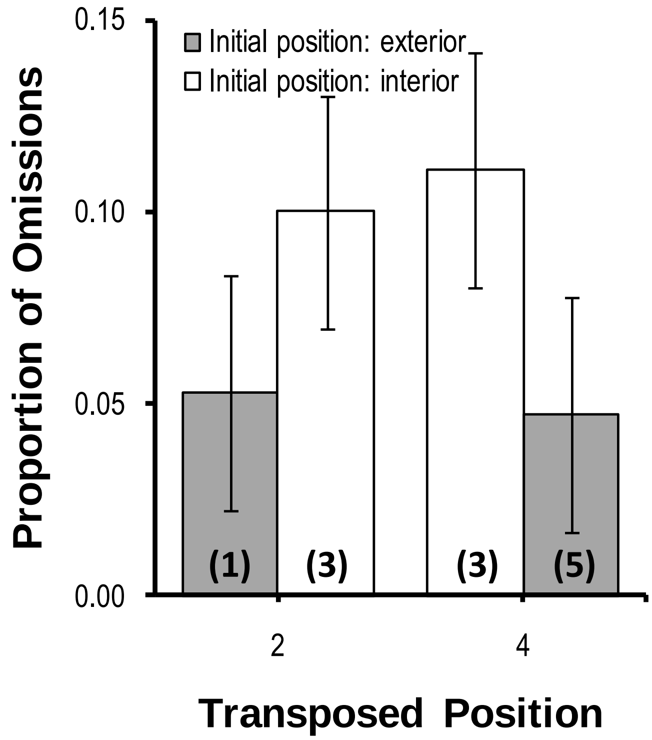

Figure 5. Proportion of omissions as a function transposed letter position for initial exterior (1, 5) and interior (3) positions when the target letter *r* was transposed in Experiment 4. The exact initial position is specified in parentheses. Error bars represent 95% confidence intervals.