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How Resilient Is Reading to Letter Rotations? A Parafoveal Preview Investigation

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Skilled readers have developed a certain amount of tolerance to variations in the visual form of words (e.g., CAPTCHAs, handwritten text, etc.). To examine how visual distortion affects the mapping from the visual input onto abstract word representations during normal reading, we focused on a single type of distortion: letter rotation. Importantly, two leading neurally inspired models of word recognition (SERIOL model, Whitney, 2001; LCD model, Dehaene et al., 2005) make distinct predictions: Whereas the SERIOL model postulates that the cost of letter rotation increases gradually, the LCD model assumes an all-or-none boundary at around 40° to 45° rotation angle. To examine these predictions in a normal reading scenario, we conducted a parafoveal preview experiment using the gaze-contingent boundary change paradigm. The parafoveal previews were identical or unrelated to the target word. Critically, each preview's individual letters were rotated 15°, 30°, 45°, or 60°. Apart from the parafoveal previews, all text, including target words, was presented with letters in their canonical upright orientation. Results showed that the advantage of the identity preview condition in eye fixation times on the target word decreased progressively by rotation angle. This pattern of results favors the view that the cost of letter rotation during normal reading increases gradually as a function of the angle of rotation.

Keywords: eye-movements, letter rotation, parafoveal processing, reading

Efficient sentence reading requires the rapid abstraction of each word's visual form onto multiple levels of information (orthography, phonology, semantics, and syntax) while the eyes move along the text (see Clifton et al., 2016; Rayner, 2009; for reviews). Because of their extensive experience across different reading conditions (e.g., numerous fonts; uppercase TEXT, handwritten text, cursive, CAPTCHA, etc.), skilled readers have developed some tolerance to noise and variations in shape (i.e., visual characteristics) of the words' constituent letters (see Grainger & Dufau, 2012).

Although often overlooked in reading research, the study of the influence of visual factors in reading and how skilled readers tolerate various kinds of shape distortion is essential for a complete understanding of the reading process (Slattery, 2016; see also Tinker, 1958; Tinker & Paterson, 1931; for reviews of early research). One of the reasons of the shortage of studies on this issue is that it is difficult to separate the effect of all the relevant variables underlying visual distortion. For instance, handwritten text, and CAPTCHAs are distorted in several dimensions, and hence any processing differences relative to the pristine written format we typically encounter when reading might be attributable to multiple factors.

To overcome this interpretative issue, in the present article we focus on a single type of visual distortion during sentence reading: the rotation of individual letters in words. An added value of studying letter rotations is that leading neural models of visual word recognition make explicit predictions about how letter rotations affect word processing. The SERIOL model of word recognition (Whitney, 2001, 2002) assumes that "input levels to letter units are reduced for rotated stimuli" (p. 119, Whitney, 2002), increasing gradually the time required to encode a letter string. Instead, the Local Combination Detectors model (henceforth, LCD model; Dehaene et al., 2005) offers an all-or-none account on how letter rotation affects letter/word processing. Specifically, the LCD model postulates that letter rotation impedes the normal

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All the data, stimuli, and R code are available at osf.io/h7uvj.

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mapping of the letter features from the visual word form onto the letter detectors for angles above 40° to 45°, but that there would be little cost for rotations below that boundary[1] (see also Cohen et al., 2008; Vinckier et al., 2006). Consistent with this latter prediction, a number of experiments have shown a cost in processing when words are rotated as a whole at 45° of rotation or larger. For instance, Cohen et al. (2008) found no differences in response times to words presented with 0° and 22.5° rotation angles, whereas there was a dramatic slow-down at angles of 45° and larger. In addition, other experiments have reported slower word identification times for rotated words at angles of 45° or larger than for their horizontally-presented counterparts (e.g., Barnhart & Goldinger, 2013 [0° vs. 90°]; Gomez & Perea, 2014 [0° vs 45° vs. 90°]; Koriat & Norman, 1984 [0° vs. 60° vs. 120° vs. 180°]).

Clearly, the above-cited studies consistently showed a cost when reading rotated words at 45° or larger. However, they were not informative as to the locus of the effect. These effects could have occurred at an early encoding stage—as the LCD or SERIOL models would predict—but they could also have been attributable to a processing cost at a late verification stage of processing where the visual percept is checked against the stored lexical unit. To directly test whether the locus of the effect of rotation occurs early in word processing, Perea et al. (2018) conducted a masked priming lexical decision experiment with 90° rotation of the whole word. The rationale of their experiment was that if the encoding of orthographic-lexical representations were hindered by rotations of 45° or larger, one would expect a dramatically reduced masked priming effect for 90° rotated words. However, they found sizable masked identity and transposed-letter priming effects in line with the effects obtained with horizontally presented stimuli (see also Yang & Lupker, 2019; for evidence of robust masked priming effects with 90° and 180° rotated words). Hence, at least when words are presented in isolation, word rotation does not seem to hinder initial access to the orthographic representations (see also Perea et al., 2020, for similar evidence with isolated letters).

The robustness of masked priming effects to word rotations is quite revealing. However, one could argue that readers might rotate the whole stimulus and then process each letter as usual (see Gomez & Perea, 2014, and Whitney, 2002, for discussion). Thus, a more stringent test for the LCD and SERIOL models would be to examine the effect of rotating the individual letters within words rather than rotating the whole word. Kim and Straková (2012) conducted a lexical decision experiment in which individual letters of words and pseudowords were rotated (0°, 22.5°, 45°, 67.5°, or 90°). Importantly, they also recorded event-related potentials (ERPs) during the task. Kim and Straková (2012) found an increase in amplitude in the P1 and N170 components (i.e., two indexes that reflect the initial contact with word-form features) for all rotation angles (i.e., including 22.5°) when compared with the horizontal format. To explain this pattern, they suggested that words whose individual letters are rotated require additional resources that are recruited very early in processing. The behavioral data showed a different picture, though. For words, response times were remarkably similar for rotation angles between 0°and 67.5°, with a large increase from 67.5° to 90°. Accuracy rates was similar for angles from 0° to 45°, slightly decreased from 45° to 67.5°, and there was a large drop from 67.5° to 90°. Thus, the behavioral data from Kim and Straková (2012) suggest that word recognition was not severely affected by rotations smaller than 45° to 67.5°—note that evidence for early ERP effects does not necessarily imply longer word identification times (see Perea et al., 2015, for discussion).

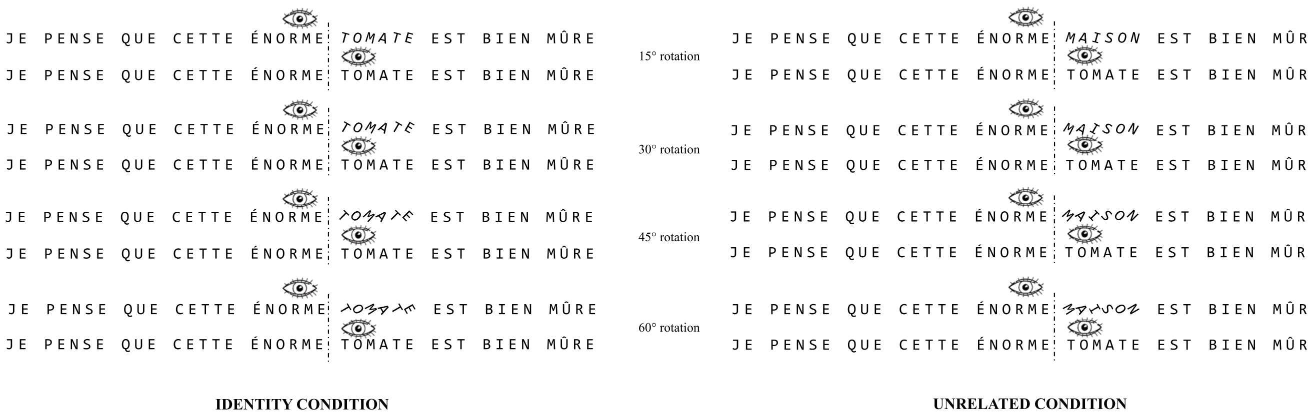
More important for the present purposes, a recent study measured participants' eye movements when reading sentences in which the individual letters within words were rotated (30°, 60°) or not (Blythe et al., 2019). Blythe et al. found an overall reading cost on sentence reading (total viewing time, number of fixations) for both rotation angles (30° and 60°) when comparing with upright presented text, and this cost was larger at the 60° than at the 30° rotation angle. They also examined whether rotation angle interacted with word frequency by embedding a high- versus low-frequency target word in each sentence. Whereas both rotation angle and word-frequency had additive effects in the first-fixation duration on the target word (30° < 60°; high-frequency < low-frequency), total fixation durations (i.e., the sum of all fixations in the target word) showed an interaction between the two factors: The magnitude of the word-frequency effect was a function of the rotation angle (i.e., the difference in eye fixation durations between high- and low-frequency target words was greater at 60°, it decreased at 30° and it was even smaller at 0°), thus suggesting that lexical access was impaired even by relatively small rotations (i.e., 30°). Blythe et al. (2019) concluded that letter detectors are affected by rotations well below 45° during sentence reading, and thereby the LCD predictions concerning letter rotations should be revised (i.e., the gradual cost of letter rotation may fit better with the SERIOL model). Although Blythe et al.'s (2019) experiment confirmed that letter rotations do affect the reading process, it does not inform us as to whether the effect of letter rotation occurs early in processing (i.e., as posited by the LCD and SERIOL models) or whether it occurs at late integration processes (keep in mind that participants could have adjusted their eye movement pattern to the rotation angle of the sentences).

The main aim of the present experiment was to examine whether the cost due to letter rotation in normal silent reading emerges early in processing, as predicted by the LCD and SERIOL models. To obtain a strict test of the resilience of letter detectors to rotations, we rotated the individual letters within words in a parafoveal word during sentence reading with the gaze-contingent boundary change paradigm (Rayner, 1975). Rayner's gaze-contingent boundary change technique allows for the manipulation of parafoveal information that is available to the reader before their eyes move to that location hence enabling foveal processing of a target word presented at the same location (see Figure 1). The rationale of this paradigm is that when we read, we extract information not only from the fixated word, but also from the following word(s) in the parafovea (Rayner et al., 1981; Rayner et al., 1982; see also Vasilev et al., 2018; for evidence with degraded previews). Thus, it is possible to infer the amount of useful information the reader obtains from the parafovea by examining how the fixation durations on a target word vary as a function of the type of parafoveal preview (e.g., identity previews vs. unrelated previews; phonological

[1] Note that the prediction of the LCD model (Dehaene et al., 2005) "letter detectors should be disrupted by rotation (>40°)" (p. 340) was based on a study conducted by Logothetis and Pauls (1995) with monkeys. Nevertheless, the empirical evidence provided by Cohen et al. (2008) and Vinckier et al. (2006) with adult readers was interpreted in light of this prediction of the model.

Figure 1

Description of an Eye Movement–Contingent Display-Change Trial With the Eight Experimental Conditions (Identity Preview Rotated at 15°, 30°, 45°, and 60°; "I Think This Huge Tomato Is Ripe"; Unrelated Preview Rotated at 15°, 30°, 45° and 60°; "I Think This Huge House Is Ripe")



Note. The eye symbol represents where the reader is fixating, and the vertical dashed line represents the invisible boundary preceding the target word. Before crossing the boundary, the sentence is presented with the rotated previews. When the eyes cross the boundary, the parafoveal preview is replaced by the target word in the canonical format.

preview vs. orthographic control preview, etc.; see Rayner et al., 2012; for review).

In the present gaze-contingent boundary change paradigm experiment, the parafoveal preview could be the same as the target (identity preview-target pairs) or a different word (unrelated preview-target pairs). We chose identity previews because they provide the largest effects in the parafovea (see Angele et al., 2013). The letters of the identity/unrelated previews could be rotated at four different angles, the difference always being 15° (15°, 30°, 45° and 60°; see Figure 1). Critically, the letters of the fixated target word—as well as the rest of the sentence—were always in the canonical upright orientation. We employed 15° of rotation as a baseline rather than 0° to avoid a perceptual continuity between preview and target in the identity condition.[2] All the sentences were presented in UPPERCASE, the reasons being that: (a) in lowercase, some letters could be ambiguous when rotated (e.g., the rotated letter *b* can be confused with the letters *p* or *q*); (b) in lowercase words, low spatial frequency information spanning the whole word (e.g., compare bishop vs. BISHOP) would have been less disrupted for smaller than for larger rotation angles (i.e., the whole visual word form of lowercase words could be more informative for smaller than for larger rotation angles). Of note, the pattern of eye movements when reading sentences is similar when written in lowercase or uppercase (see Perea et al., 2017).

The predictions were the following. First, if, as hypothesized by the LCD model (Dehaene et al., 2005), letter detectors are hindered by rotations in the first stages of orthographic-lexical processing only when they are above 40° to 45°: (a) we would expect shorter fixation durations on the target word after an identity preview than after an unrelated preview, and to a similar degree, at 15° and 30° rotations (i.e., well below 45°); and (b) we would expect a dramatic drop in preview effects when the letters of the parafoveal preview are rotated 45° or 60°. Second, if, as hypothesized by the SERIOL model (Whitney, 2002), letter rotation gradually decreases the activation reached by the letter nodes, one would expect progressively smaller advantages of the identity preview as a function of rotation angle. A final scenario is that the orthographic coding system is widely tuned to rapidly identify rotated and/or distorted letters with little cost (see Hannagan et al., 2012; Yang & Lupker, 2019; and Perea et al., 2018, 2020)—in this case, we would expect an advantage of the identity condition over the unrelated condition not only for the smaller rotation angles (15° and 30°) but also for the larger rotation angles (45° and 60°).

Method

Participants

Forty participants (18 female) were recruited at Aix-Marseille University. The participants were all native French speakers and received either course credit or monetary compensation (€10/h). All participants reported normal or corrected-to-normal vision and ranged in age from 18 to 38 years old ($M = 21.1$ y.o., $SD = 4.11$). They were naïve to the purpose of the experiment and signed an informed consent form before starting the experiment. Ethics approval was obtained from the Comité de Protection des Personnes SUD-EST IV (No. 17/051), and this research was carried out in accordance with the provisions of the World Medical Association Declaration of Helsinki.

Apparatus

Stimuli were displayed using OpenSesame (Mathôt et al., 2012) with each sentence occupying a single line. Eye movements were recorded with an EyeLink 1000 system (SR Research, Mississauga,

[2] Keep in mind that any difference between a 15° and the canonical condition could be attributable to the congruency of format (both upright) that would induce the 0° rotation angle.

ON, Canada) with high spatial resolution (.01°) and a sampling rate of 1,000 Hz—this device only recorded the right eye movements. The sentences were presented on a 20-in. ViewSonic CRT monitor with a refresh rate of 150 Hz and a screen resolution of 1,024 × 768 pixels (30 × 40 cm). Stimuli were presented in upper case 18-point monospaced font (droid sans mono; the default monospaced font in OpenSesame) and the text was presented in black (.15 cd/m^2) on a white background (21.70 cd/m^2); crosses and dots were presented with the same colors. Participants were seated 86 cm from the monitor, such that every three characters equaled approximately 1° of visual angle. The maximum validation error accepted was .63° of visual angle. A chin rest and forehead rest were used to minimize head movements.

Materials

We created 250 sentences in French, each contained an average of nine words (range 7–10). Sentences were created so as to minimize semantic predictability of the target words. This was verified via a cloze task in which the initial part of each sentence—until the word preceding the target word—was presented to four naïve individuals that were asked to predict the following word—none of these individuals took part in the experiment. The percentage of words that was predicted from the previous context was very low (<1%). The pretarget and target words had an average length of seven letters and an average Zipf frequency of 5.71 and 6.13, respectively (van Heuven et al., 2014). Word frequencies were obtained using the film subtitle frequencies of the Lexique2 database (New et al., 2004). For each target word, we created eight parafoveal previews: identity condition with (a) 15° of rotation, (b) 30° of rotation, (c) 45° of rotation, (d) 60° of rotation, and unrelated condition with (e) 15° of rotation, (f) 30° of rotation, (g) 45° of rotation, and (h) 60° of rotation (see Figure 1). The parafoveal previews were counterbalanced across eight lists following a Latin square design. Each participant received 30 trials in each of the eight conditions and the sentences were presented in a different random order. The complete set of sentences, including the parafoveal previews, is presented in the Appendix.

Procedure

The experimental session took place in a dimly lit room. Participants were first informed about the experiment procedure. Their task was to read sentences for comprehension on a computer screen while their eye movements were registered. They were told that there would be comprehension questions after each sentence. The experiment procedure began with a five-point calibration phase in which participants had to look at individual dots on the screen. This was followed by 10 practice sentences to familiarize them with the procedure. Each trial had the following arrangement. First, a drift correction dot located 12 pixels (to the right of the left edge was displayed. Second, the sentence was presented once the participant steadily looked at the drift correction dot—the starting point of the sentence was located just to the right of the dot. The display change occurred when the participant's eyes crossed an invisible boundary located between the target word and the word before (see Figure 1). Another invisible boundary was defined close to the end of the sentence (50 pixels before), such that the sentence disappeared when the eyes crossed that boundary (that is, when participants read the last word). Finally, participants were shown a yes/no comprehension question after each trial that allowed us to verify that they had read for comprehension—participants were asked to press a corresponding key on a gamepad.

Data Analyses

The critical idea underlying Rayner's (1975) boundary technique is that the parafoveal preview allows some preprocessing of the target word. Specifically, if the reader extracts useful information from the rotated-identity parafoveal preview than for the rotated-unrelated parafoveal preview, the processing time on the target word would be reduced when directly fixated, thus resulting in shorter fixation durations (see Rayner et al., 2012). We examined three early eye fixation measures on the target word (that is, the critical region): (a) the duration of the initial fixation on the target word (FFD); (b) the duration of a fixation on the target word when it was the only fixation on that word in first pass reading (SFD); and (c) the sum of fixation durations before leaving the target word (GD).

For the inferential analyses, we analyzed the eye fixation data with linear mixed effects (LME) and Bayes Factors. We employed the *lme4* (Bates et al., 2015, 2019), *lmerTest* (Kuznetsova et al., 2016), *car* (Fox & Weisberg, 2019), and the *BayesFactor .9.12-4.2* (Morey & Rouder, 2018) packages in R (R Core Team, 2020). The models included two fixed factors: (a) preview-target relationship and (b) preview rotation angle—each factor was zero-centered. Subjects and items were the random factors in the models. Variables were log-transformed to reduce highly positive skew of fixation durations and keep the normality assumption of LME models. Regarding LME analyses, the maximal random structure model that converged for the three dependent variables was (Dependent Variable) ~ Relationship × Angle + (1 + Relationship|Subject) + (1 + Relationship|Item). The *p* values for each main factor and the two-way interaction were calculated using Wald's chi-square tests. In case of a significant interaction, we computed the effect of preview-target relationship for each rotation angle with *emmeans* (Lenth et al., 2020).

Results

Participants were quite accurate in responding to the comprehension questions (mean accuracy was .91; *SD* = .0023). Trials where the display change was triggered either early or late were removed from the analyses (less than 1%). The raw data were preprocessed using EyeLink algorithms to detect saccades, fixations, and eye-blinks—the deletion of eye-blinks resulted in .5% of the data lost in the target region. Trials where the target word was skipped in first pass were excluded from the analysis (9.78%). Fixation durations of less than 80 ms and more than 800 ms and gaze durations longer than 2,000 ms on the target word were removed from the analyses. Furthermore, we removed any fixation duration measures that were more than 2.5 standard deviations for measure, condition, and subject because they are unlikely to represent normal reading—we removed the 2.07% of FFD observations, the 3.23% of GD observations and the 1.95% of SFD observations. The average eye fixation measures per condition across participants are presented in Table 1.

Table 1
Means (in ms) and Standard Errors (in Parentheses) as a Function of Rotation Angle and Preview-Target Relationship

Parafoveal preview							
Rotation angle	Preview-target relationship	First fixation duration		Single fixation duration		Gaze duration	
15°	Identity	240 (2)	**21**	243 (3)	**26**	303 (5)	**19**
	Unrelated	262 (2)		269 (3)		322 (4)	
30°	Identity	252 (2)	**8**	258 (2)	**13**	302 (4)	**12**
	Unrelated	260 (2)		271 (3)		314 (4)	
45°	Identity	254 (2)	5	261 (3)	7	307 (4)	10
	Unrelated	259 (2)		268 (3)		317 (4)	
60°	Identity	256 (2)	4	265 (3)	3	306 (4)	9
	Unrelated	260 (2)		268 (3)		315 (4)	

Note. Values in bold represent the significant parafoveal preview effects.

First Fixation Duration

On average, first-fixation durations on the target word were 9 ms shorter in the identity than in the unrelated condition, $\chi^2(1) = 25.616$, $p < .001$. We also found a main effect of angle, $\chi^2(3) = 14.840$, $p < .001$. More important, the interaction between preview-target relationship and rotation angle was significant, $\chi^2(3) = 34.392$, $p < .001$. As can be seen in Figure 2, this interaction reflected that first fixation durations on the target word increased as a function of rotation in the identity condition, as reflected by significant linear ($t = 6.029$, $p < .001$) and quadratic ($t = -3.02$, $p = .002$) contrasts. For unrelated pairs, the duration of first fixations did not change as a function of rotation (none of the contrasts approached significance, all $|ts| < 1.25$, $ps > .21$). The interplay between the two factors (i.e., preview-target relationship and angle) resulted in shorter first-fixation durations on the target word in the identity condition than in the unrelated condition when the letters of the preview were rotated 15° (21 ms; $b = -.089$, $SE = .012$, $t = -7.627$, $p < .001$) and, to a lesser degree, when rotated 30° (8 ms; $b = -.028$, $SE = .012$, $t = -2.418$, $p = .016$). Finally, the advantage of the identity condition did not reach significance when the letters of the preview were rotated 45° (5 ms) or 60° (4 ms; both $ts < -1.146$, $ps > .253$). To examine whether the null effects for the 45° and 60° were attributable to evidence of absence rather absence of evidence, we computed Bayes Factors, as these offer valuable information to express our degree of certainly that the rotation angle did not affect the effect of preview-target relationship. For computing the Bayes Factors, we employed the lmBF function from the *BayesFactor* package with the default Cauchy distribution (centered around 0 and with a width parameter $\delta = .707$; see Rouder et al., 2009; Wagenmakers et al., 2017; for discussion). The Bayes Factors for the 45° and 60° rotations were $BF_{01} > 7.508$, thus providing strong evidence toward the null hypothesis.

Single Fixation Duration

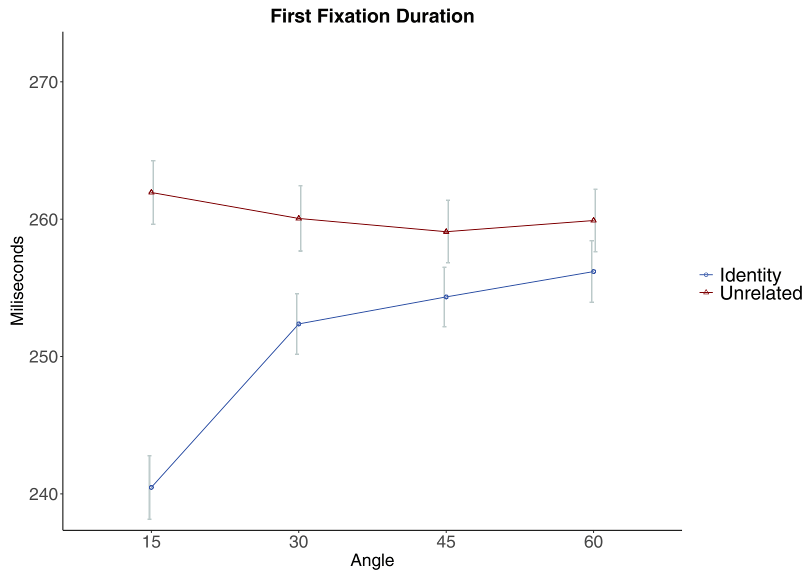
The proportion of first-pass trials with a single fixation in the target word was .66. Single fixation durations were, on average, 12 ms shorter in the identity than in the unrelated condition, $\chi^2(1) = 43.875$, $p < .001$. The effect of angle was also significant, $\chi^2(3) = 30.230$, $p < .001$, as was the interaction between the two factors, $\chi^2(3) = 41.251$, $p < .001$. This interaction showed that single fixation durations on the target increased nonlinearly with the eccentricity of letter rotation in the identity condition—this was reflected by significant linear ($t = 8.414$, $p < .001$) and quadratic ($t = -3.205$, $p = .001$) contrasts (see Figure 3). The duration of single fixations for unrelated preview-target pairs remained constant independently of the rotation angle (none of the contrasts approached significance, all $|ts| < .76$, $ps > .45$). As a result of this interaction between preview-target relationship and angle, we found that single fixation durations were shorter in the identity condition than in the unrelated condition when the preview was rotated 15° (26 ms; $b = -.111$, $SE = .012$, $t = -9.357$, $p < .001$) and, to a lesser extent, 30° (13 ms; $b = -.045$, $SE = .012$, $t = -3.831$, $p < .001$). For the 45° rotation angle, the 7-ms advantage in the identity condition, approached significance ($b = -.014$, $SE = .012$, $t = -1.187$, $p = .079$), but the evidence favored, if anything, the null hypothesis, $BF_{01} = 1.742$. Finally, for the 60° rotation angle, we found strong evidence toward the null hypothesis (3-ms advantage in the identity condition; $b = -.014$, $SE = .012$, $t = -1.187$, $p = .236$; $BF_{01} = 6.295$).

Gaze Duration

On average, gaze durations on the target word were 12 ms shorter in the identity than in the unrelated condition, $\chi^2(1) = 41.022$, $p < .001$. The effect of angle did not approach significance, $\chi^2(3) = 5.339$, $p = .149$, but, more importantly, the interaction between preview-target relationship and angle was significant, $\chi^2(3) = 20.258$, $p < .001$. This interaction showed that gaze durations on the target word increased linearly with the eccentricity of letter rotation in the identity condition—this was reflected by significant linear contrasts ($t = 8.414$, $p < .001$). The duration of gaze durations for unrelated preview-target pairs remained constant independently of the rotation angle (none of the contrasts approached significance, all $|ts| < 1.52$, $ps > .12$). As a result of this interaction between preview-target relationship and angle, we found a 19-ms advantage of the identity condition 15° rotation ($b = -.093$, $SE = .013$, $t = -6.985$, $p < .001$), which was reduced to 12 ms at the 30° rotation ($b = -.052$, $SE = .013$, $t = -3.863$, $p < .001$). For the 45° rotation, we found a small 10-ms advantage of the identity condition ($b = -.027$, $SE = .014$, $t = -2.000$, $p = .046$), which actually slightly favored the null hypothesis, $BF_{01} = 1.688$, whereas for the 60° rotation, we found strong evidence for the null hypothesis (9 ms; $b = -.019$, $SE = .014$, $t = -1.398$, $p = .163$; $BF_{01} = 6.134$; see Figure 4).

Figure 2

Mean First Fixation Durations by Condition (Identity Versus Unrelated) and Angle (15°, 30°, 45°, and 60°)



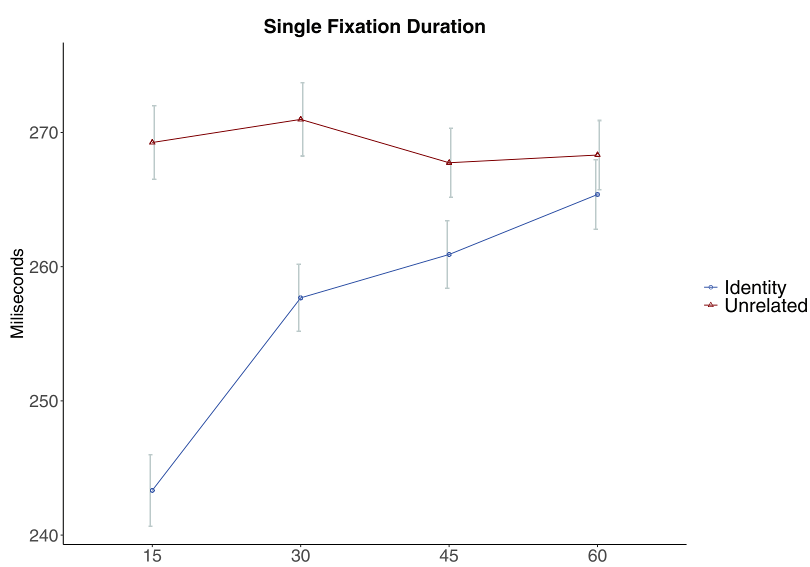
Note. See the online article for the color version of this figure.

Discussion

The present experiment was designed to test whether letter detectors are severely hampered by rotations above 40° to 45° during sentence reading, as postulated by the LCD model (Dehaene et al., 2005), or whether this cost would emerge gradually as a function of increasing letter rotation, as hypothesized by the SERIOL model (Whitney, 2002). To that end, we conducted a reading experiment with sentences in uppercase using Rayner's (1975) gaze-contingent boundary change paradigm in which we examined whether identity parafoveal previews were more effective than unrelated parafoveal previews when the previews were rotated at 15°, 30°, 45°, or 60° (see Figure 1 for illustration). We found a remarkably similar pattern of findings for all three eye fixation

Figure 3

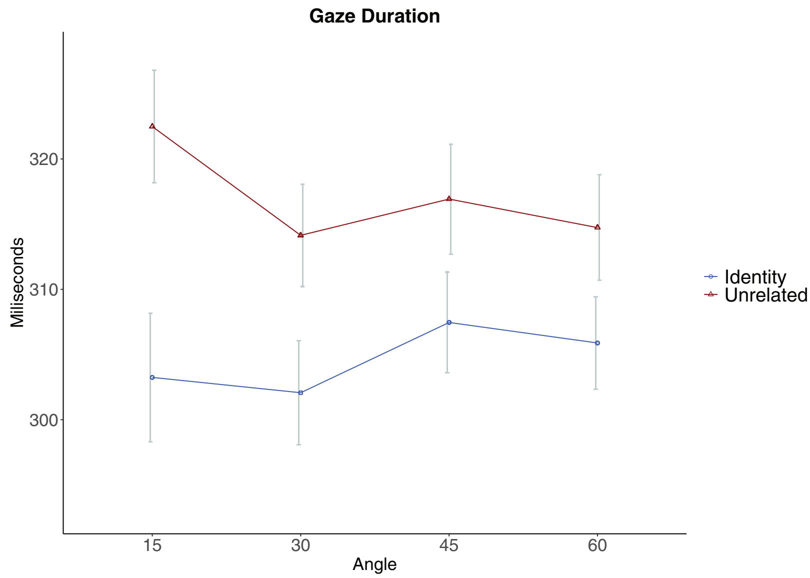
Mean Single Fixation Durations by Condition (Identity Versus Unrelated) and Angle (15°, 30°, 45°, and 60°)



Note. See the online article for the color version of this figure.

Figure 4

Mean Gaze Durations by Condition (Identity Versus Unrelated) and Angle (15°, 30°, 45°, and 60°)



Note. See the online article for the color version of this figure.

measures on the target word (i.e., first-fixation duration, single fixation duration, and gaze duration). Fixation durations were shorter when preceded by an identity preview than when preceded by an unrelated preview and, critically, this difference was modulated by rotation angle: the advantage of the identity preview condition was greatest when the letters of the preview were rotated 15° and it was numerically smaller but still robust at 30° (see Table 1). Instead, for the 45° rotations the advantage of the identity preview condition was only marginal, and the Bayes Factor analysis did not produce clear evidence in either direction—in particular for single-fixation durations and gaze durations. Finally, for the 60° rotations, there were no signs of an advantage of the identity preview condition—indeed, the evidence in favor of the null effect was strong (all $BF_{01} > 6.134$). Thus, the present results extend and qualify the findings obtained by Blythe et al. (2019) with a technique that specifically focused on early word recognition processes during sentence reading.

This pattern of results poses some problems to the predictions of the LCD model concerning the impact of letter rotation on word recognition (Dehaene et al., 2005). Although letter detectors appear to be severely disrupted at rotation angles of 45° or larger in the very early moments of processing, letter rotation also has an effect for rotation angles well below 45° in the parafovea. In the three eye fixation measures, we found a greater identity preview advantage for 15° than for 30° rotated previews. These findings, together with the data from Blythe et al. (2019) with 30° rotations, suggest that the disruption caused by letter rotations is not due to a sudden all-or-none shift at around the 40° to 45° boundary posited by the LCD model. Thus, the more parsimonious account of the current findings is that the amount of visual input reaching the letter detectors would decrease as a function of letter rotation, as proposed by the SERIOL model (see Whitney, 2002). This is also consistent with the increase in amplitude in ERP components that reflect the initial contact with word-form features (e.g., N170) even for small rotations (22.5°) of individual letters in words (Kim & Straková, 2012). Second, although the evidence of an identity preview advantage for 45° rotations was marginal, we found strong evidence for a null effect for 60° rotations, thus again suggesting a gradual nature of the cost due to letter rotations on the letter detectors of the word recognition system. Taken together, this pattern would suggest that the identity preview advantage of rotated previews during sentence reading is structured by rotation angle (i.e., greatest at 15°, intermediate at 30°, marginal at 45°, and absent at 60°). Further experiments should be conducted to test whether this pattern of results also occurs with other manipulations (e.g., phonologically or graphemically preview-target related words).

Importantly, one might argue that our findings are at odds with the presence of robust masked priming effects with rotated words found by Perea et al. (2018) and Yang and Lupker (2019). However, there are some key methodological differences between the present and the just-mentioned studies. First, in the Perea et al. (2018) and Yang and Lupker (2019) experiments, the whole word was rotated, whereas in the present experiment we rotated the individual letters of the word (i.e., the manipulation was more extreme in the present experiment). Second, in above-cited masked priming experiments, (a) both primes and targets were presented foveally instead of parafoveal-then-foveal as in the present study (and the quality of visual information is higher in the fovea) and (b) both primes and the targets were presented rotated at the same angle. In the present experiment, the previews were presented parafoveally at different rotation angles, but the target word (as well as the rest of the sentence) was always presented in the canonical upright format. Thus, our participants were reading normally oriented sentences, thus avoiding the adoption of specific strategies that might arise when reading oriented text. To further elucidate these apparent discrepancies, future research could examine the time course of masked priming words with individually rotated letters (e.g., using electrophysiological measures).

Our findings also have important implications for models of eye movement control in reading. At present, no current models of eye movement control during reading have explicit predictions on the processing of words composed of rotated letters (e.g., E-Z Reader, Reichle et al., 1998; SWIFT, Engbert et al., 2005; OB1-reader, Snell et al., 2018). This is because these models have focused on key elements of eye movement control (e.g., when and where to fixate the eyes) rather than on visual/sublexical/lexical processes. Our findings highlight the necessity of expanding these models to include early processes, including the mapping of visual information onto sublexical orthographic or phonological stages to offer a comprehensive picture of the reading process. As an example, the E-Z Reader model (Reichle et al., 1998, 2003) assumes that word identification is completed in two stages, reflecting early and late lexical processing. The first stage corresponds to the beginning of the identification of the orthographic form of the word, whereas full lexical access is reached in the second stage. The identity preview advantage observed in fixation durations when the letters of the rotated preview were 15° to 30° suggests that readers can complete the first stage of lexical processing (i.e., extract abstract letter codes) even when the individual letters of words are rotated 30° (i.e., readers are able to extract enough information to begin programming a saccade to the next word even when that information is extracted from a word with letters rotated 30°; see Angele et al., 2016, for a proposal of the mechanisms at play in parafoveal processing). As stated earlier, the cost of processing these rotated letters would be gradual (i.e., the larger the rotation angle, then smaller the information acquired in the parafovea).

In sum, skilled readers can efficiently convert parafoveal words composed of 15° to 30° rotated letters to a stable orthographic code during silent sentence reading, but not when the rotation angles are 45° or above. Thus, our data are in accordance with a gradual cost of letter rotations in the uptake of parafoveal information as a function of rotation angle, as posited by the SERIOL model of word recognition (Whitney, 2001, 2002). These findings should encourage the implementation of a more detailed account of the interface between visual form information and orthographic-lexical representations in computational models of eye movement control during sentence reading.

References

Angele, B., Slattery, T. J., & Rayner, K. (2016). Two stages of parafoveal processing during reading: Evidence from a display change detection task. *Psychonomic Bulletin & Review*, *23*(4), 1241–1249. https://doi.org/10.3758/s13423-015-0995-0

Angele, B., Tran, R., & Rayner, K. (2013). Parafoveal–foveal overlap can facilitate ongoing word identification during reading: Evidence from eye movements. *Journal of Experimental Psychology: Human Perception and Performance*, *39*(2), 526–538. https://doi.org/10.1037/a0029492

Barnhart, A. S., & Goldinger, S. D. (2013). Rotation reveals the importance of configural cues in handwritten word perception. *Psychonomic Bulletin & Review*, *20*(6), 1319–1326. https://doi.org/10.3758/s13423-013-0435-y

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2019). lme4: Linear mixed-effects models using 'eigen' and S4 (1.1-20) [Computer software]. https://CRAN.R-project.org/package=lme4

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

Blythe, H. I., Juhasz, B. J., Tbaily, L. W., Rayner, K., & Liversedge, S. P. (2019). Reading sentences of words with rotated letters: An eye movement study. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, *72*(7), 1790–1804. https://doi.org/10.1177/1747021818810381

Clifton, C., Jr., Ferreira, F., Henderson, J. M., Inhoff, A. W., Liversedge, S. P., Reichle, E. D., & Schotter, E. R. (2016). Eye movements in reading and information processing: Keith Rayner's 40 year legacy. *Journal of Memory and Language*, *86*, 1–19. https://doi.org/10.1016/j.jml.2015.07.004

Cohen, L., Dehaene, S., Vinckier, F., Jobert, A., & Montavont, A. (2008). Reading normal and degraded words: Contribution of the dorsal and ventral visual pathways. *NeuroImage*, *40*(1), 353–366. https://doi.org/10.1016/j.neuroimage.2007.11.036

Dehaene, S., Cohen, L., Sigman, M., & Vinckier, F. (2005). The neural code for written words: A proposal. *Trends in Cognitive Sciences*, *9*(7), 335–341. https://doi.org/10.1016/j.tics.2005.05.004

Engbert, R., Nuthmann, A., Richter, E. M., & Kliegl, R. (2005). SWIFT: A dynamical model of saccade generation during reading. *Psychological Review*, *112*(4), 777–813. https://doi.org/10.1037/0033-295X.112.4.777

Fernández-López, M., Mirault, J., Grainger, J., & Perea, M. (2020, November 5). *How resilient is reading to letter rotations? A parafoveal preview investigation*. osf.io/h7uvj

Fox, J., & Weisberg, S. (2019). An R companion to applied regression (R package version 3.0-8). https://CRAN.R-project.org/package=car

Gomez, P., & Perea, M. (2014). Decomposing encoding and decisional components in visual-word recognition: A diffusion model analysis. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, *67*(12), 2455–2466. https://doi.org/10.1080/17470218.2014.937447

Grainger, J., & Dufau, S. (2012). The front-end of visual word recognition. In J. S. Adelman (Ed.), *Visual word recognition* (Vol. 1, pp. 159–184). Psychology Press.

Hannagan, T., Ktori, M., Chanceaux, M., & Grainger, J. (2012). Deciphering CAPTCHAs: What a turing test reveals about human cognition. *PLoS ONE*, *7*(3), e32121. https://doi.org/10.1371/journal.pone.0032121

Kim, A. E., & Straková, J. (2012). Concurrent effects of lexical status and letter-rotation during early stage visual word recognition: Evidence from ERPs. *Brain Research*, *1468*, 52–62. https://doi.org/10.1016/j.brainres.2012.04.008

Koriat, A., & Norman, J. (1984). What is rotated in mental rotation? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *10*(3), 421–434. https://doi.org/10.1037/0278-7393.10.3.421

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2016). lmerTest: Tests for random and fixed effects for linear mixed effect models (lmer objects of lme4 package; R package Version 2.0 –33). http://CRAN.Rproject.org/packagelmerTest

Lenth, R., Singmann, H., Love, J., Buerkner, P., & Herve, M. (2020). emmeans: Estimated marginal means (R package version 1.4.8.). https://CRAN.R-project.org/package=emmeans

Logothetis, N. K., & Pauls, J. (1995). Psychophysical and physiological evidence for viewer-centered object representations in the primate. *Cerebral Cortex*, *5*(3), 270–288. https://doi.org/10.1093/cercor/5.3.270

Mathôt, S., Schreij, D., & Theeuwes, J. (2012). OpenSesame: An open-source, graphical experiment builder for the social sciences. *Behavior Research Methods*, *44*(2), 314–324. https://doi.org/10.3758/s13428-011-0168-7

Morey, R. D., & Rouder, J. N. (2018). Package 'BayesFactor' (R Package version 0.9.12-4.2). https://richarddmorey.github.io/BayesFactor/

New, B., Pallier, C., Brysbaert, M., & Ferrand, L. (2004). Lexique 2: A new French lexical database. *Behavior Research Methods, Instruments, & Computers*, *36*(3), 516–524. https://doi.org/10.3758/BF03195598

Perea, M., Marcet, A., & Fernández-López, M. (2018). Does letter rotation slow down orthographic processing in word recognition? *Psychonomic Bulletin & Review*, *25*(6), 2295–2300. https://doi.org/10.3758/s13423-017-1428-z

Perea, M., Rosa, E., & Marcet, A. (2017). Where is the locus of the lowercase advantage during sentence reading? *Acta Psychologica*, *177*, 30–35. https://doi.org/10.1016/j.actpsy.2017.04.007

Perea, M., Vergara-Martínez, M., & Gomez, P. (2015). Resolving the locus of cAsE aLtErNaTiOn effects in visual word recognition: Evidence from masked priming. *Cognition*, *142*, 39–43. https://doi.org/10.1016/j.cognition.2015.05.007

Perea, M., Vergara-Martínez, M., Marcet, A., Mallouh, R. A., & Fernández-López, M. (2020). When does rotation disrupt letter encoding? Testing the resilience of letter detectors in the initial moments of processing. *Memory & Cognition*, *48*(5), 704–709. https://doi.org/10.3758/s13421-020-01013-9

R Core Team. (2020). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. http://www.R-project.org/

Rayner, K. (1975). Parafoveal identification during a fixation in reading. *Acta Psychologica*, *39*(4), 271–281. https://doi.org/10.1016/0001-6918(75)90011-6

Rayner, K. (2009). The 35th Sir Frederick Bartlett Lecture: Eye movements and attention in reading, scene perception, and visual search. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, *62*(8), 1457–1506. https://doi.org/10.1080/17470210902816461

Rayner, K., Inhoff, A. W., Morrison, R. E., Slowiaczek, M. L., & Bertera, J. H. (1981). Masking of foveal and parafoveal vision during eye fixations in reading. *Journal of Experimental Psychology: Human Perception and Performance*, *7*(1), 167–179. https://doi.org/10.1037/0096-1523.7.1.167

Rayner, K., Pollatsek, A., Ashby, J., & Clifton, C. Jr. (2012). *Psychology of reading*. Psychology Press. https://doi.org/10.4324/9780203155158

Rayner, K., Well, A. D., Pollatsek, A., & Bertera, J. H. (1982). The availability of useful information to the right of fixation in reading. *Perception & Psychophysics*, *31*(6), 537–550. https://doi.org/10.3758/BF03204186

Reichle, E. D., Pollatsek, A., Fisher, D. L., & Rayner, K. (1998). Toward a model of eye movement control in reading. *Psychological Review*, *105*(1), 125–157. https://doi.org/10.1037/0033-295x.105.1.125

Reichle, E. D., Rayner, K., & Pollatsek, A. (2003). The EZ Reader model of eye-movement control in reading: Comparisons to other models. *Behavioral and Brain Sciences*, *26*(4), 445–526. https://doi.org/10.1017/s0140525x03000104

Rouder, J. N., Speckman, P. L., Sun, D., Morey, R. D., & Iverson, G. (2009). Bayesian *t* tests for accepting and rejecting the null hypothesis. *Psychonomic Bulletin & Review*, *16*(2), 225–237. https://doi.org/10.3758/PBR.16.2.225

Slattery, T. J. (2016). Eye movements: From psycholinguistics to font design. In M. Dyson (Ed.), *Digital fonts and reading* (pp. 54–78). World Scientific. https://doi.org/10.1142/9789814759540_0004

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

Tinker, M. A. (1958). Recent studies of eye movements in reading. *Psychological Bulletin*, *55*(4), 215–231. https://doi.org/10.1037/h0041228

Tinker, M. A., & Paterson, D. G. (1931). Studies of typographical factors influencing speed of reading. VII. Variations in color of print and background. *Journal of Applied Psychology*, *15*(5), 471–479. https://doi.org/10.1037/h0076001

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

Vasilev, M. R., Slattery, T. J., Kirkby, J. A., & Angele, B. (2018). What are the costs of degraded parafoveal previews during silent reading? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *44*(3), 371–386. https://doi.org/10.1037/xlm0000433

Vinckier, F., Naccache, L., Papeix, C., Forget, J., Hahn-Barma, V., Dehaene, S., & Cohen, L. (2006). What" and "where" in word reading: Ventral coding of written words revealed by parietal atrophy. *Journal of Cognitive Neuroscience*, *18*(12), 1998–2012. https://doi.org/10.1162/jocn.2006.18.12.1998

Wagenmakers, E.-J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Love, J., Selker, R., Gronau, Q. F., Šmíra, M., Epskamp, S., Matzke, D., Rouder, J. N., & Morey, R. D. (2017). Bayesian inference for psychology. Part I: Theoretical advantages and practical ramifications. *Psychonomic Bulletin & Review*, *25*(1), 35–57. https://doi.org/10.3758/s13423-017-1343-3

Whitney, C. (2001). How the brain encodes the order of letters in a printed word: The SERIOL model and selective literature review. *Psychonomic Bulletin & Review*, *8*(2), 221–243. https://doi.org/10.3758/bf03196158

Whitney, C. (2002). An explanation of the length effect for rotated words. *Cognitive Systems Research*, *3*(1), 113–119. https://doi.org/10.1016/S1389-0417(01)00050-X

Yang, H., & Lupker, S. J. (2019). Does letter rotation decrease transposed letter priming effects? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *45*(12), 2309–2318. https://doi.org/10.1037/xlm0000697

(*Appendix follows*)

Appendix

Sentences Used in the Experiment

The parafoveal previews (identity preview; unrelated preview) are presented in parentheses. All words were presented in uppercase letters in the experiment.

Le petit cheval sauvage (sautera; animale) sautera par dessus la barrière.

Je pense que cette énorme (tomate; maison) tomate est bien mûre.

Tu vas avec ta gentille (copine; loupes) copine pour faire des courses.

Il avait vu un méchant (requin; dormir) requin dans la mer.

Elle marche avec de belles (dames; tenir) dames dans la grande avenue.

On aime regarder les beaux (bateaux; arbitre) bateaux dans le port.

Vous avez construit de grands (immeubles; commencer) immeubles dans la ville.

Elles nagent sur des grandes (vagues; rouges) vagues dans la mer.

Je vais acheter un nouveau (chapeau; malaise) chapeau pour ton mariage.

Tu as commandé un nouvel (appareil; claviers) appareil photo pour moi.

Elle vient de jeter ses nouvelles (vestes; souris) vestes par la fenêtre.

Ils iront voir leurs rares (amies; frire) amies dans la semaine.

Vous avez vraiment fières (allures; vendues) allures dans cette voiture.

Elles ont vu une grosse (pierre; vertes) pierre tomber de la falaise.

Nous avons vu ce surprenant (spectacle; enraciner) spectacle la semaine dernière.

Ta petite pièce grise (tombe; nuits) tombe de ta veste.

Tu voudras manger et aussi (dormir; partir) dormir avant de partir.

La coureuse va presque (arriver; devrait) arriver au sommet.

Je pense que tu devrais mieux (manger; cannes) manger pour ta santé.

Tu estimes avoir assez (dormi; chose) dormi pour cette nuit.

Elle va mieux après (avoir; serez) avoir raconté ses problèmes.

Vous avez beaucoup trop (fourni; nulles) fourni de preuves au juge.

Nous allons acheter trois (lampes; redire) lampes pour décorer.

Il me faudrait quatre (piles; ronde) piles pour le jouet.

Nous avons de tout petits (pots; airs) pots de fleur.

Vous venez de construire une grosse (caisse; soleil) caisse en bois.

Une oie a perdu ses jolis (oeufs; tours) oeufs dans le lac.

On aime votre joli (stylo; dunes) stylo tout neuf.

Il a vendu un étrange (tableau; pintade) tableau très cher.

Ne va pas dans cette étrange (chambre; acheter) chambre la nuit.

Ils sont sur la grande (falaise; louange) falaise de granite.

Elle lui jeta un terrible (regard; louves) regard dès son arrivée.

Vous avez toujours plusieurs (mouchoirs; abordions) mouchoirs dans votre poche.

Il navigue sur une large (barque; renard) barque sur la mer.

A ce compte autant (venir; comme) venir en pantalon.

Il faudra très vite (revenir; chutera) revenir voir ton docteur.

Il ne peut rien faire même (marcher; joueurs) marcher est douloureux.

Toi qui adores tant (boire; roses) boire de ce soda.

Je vais prendre quelques (parts; fours) parts de cette tarte.

Elle croit que tu aimes trop (couper; montre) couper de la viande.

La petite souris blanche (regarde; admirer) regarde le fromage.

Le petit enfant blond (saute; vitre) saute dans la rue.

Ton grand frère aime (acheter; secouer) acheter du pain frais.

Mon grand oncle est parti (vendre; poires) vendre un blouson.

Le jeune homme avait (perdu; creux) perdu sa fortune.

Le chevalier est encore (venu; toute) venu nous rendre visite.

Tu viens de partir (prendre; rideaux) prendre tes outils.

Le boulanger est prêt pour (malaxer; assiste) malaxer sa pâte à pain.

Vous êtes tous partis (danser; rasent) danser sur la piste.

Elle sait que tu aimes (rire; face) rire en ce moment.

Ils sont venus pour (rigoler; plieras) rigoler toute la soirée.

On sait que vous voulez surtout (chanter; adoucit) chanter cette chanson.

Nous savons que vous aimez beaucoup (jouer; germe) jouer du piano.

Cet enfant aime vraiment (lire; mais) lire des livres.

Ce petit monsieur va encore (grimper; alarmes) grimper ce matin.

La pilote va vite (freiner; adultes) freiner dans le virage.

Tu vas utiliser cette grande (planche; montres) planche de bois.

Elle nous offre sa belle (bague; tordu) bague de mariage.

Elle avait vu un gros (mouton; poteau) mouton sur une île.

(*Appendix continues*)

Il vient de dire les dernières (phrases; argents) phrases de son discours.

Cette petite surface habitable (semblait; abattues) semblait bien décorée.

Leur grande croisière atypique (fait; irez) fait rêver leur voisin.

Votre paire de lunettes commandée (arrivera; orphelin) arrivera dans deux jours.

Ce beau riz fermenté (donnera; lecture) donnera du bon saké.

Le joli petit pâton arrondi (formera; fragile) formera un beau pain.

Le sommeil du lion balafré (aura; fade) aura duré très longtemps.

Son ami très sceptique (chercha; galerie) chercha une autre solution.

La grande table calée (tient; tapis) tient bien droit.

Leur grande école laïque (semble; taille) semble vraiment réputée.

Le passage du pont enneigé (devra; sache) devra être interdit.

Un homme a préparé un infâme (dessert; percera) dessert dans la cuisine.

Ce travail au rythme soutenu (reste; boire) reste difficile à tenir.

Les gants de ski chauffant (sont; avez) sont bien agréables.

Un plan de maison simpliste (arrange; paniers) arrange tout le monde.

Une petite ère glaciaire (approche; barreaux) approche à grand pas.

Son point de vue imposé (agace; ongle) agace les élèves.

Son triste sentiment éprouvé (faisait; serions) faisait peine à voir.

La petite lame émoussée (taillera; paisible) taillera toujours aussi bien.

Ce dur règlement appliqué (donne; tuyau) donne de bons résultats.

Voir un mariage princier (fera; suis) fera rêver les gens.

Elle parla avec un influant (locuteur; gouverna) locuteur durant des heures.

Il a pris le mauvais (livre; pause) livre dans le tiroir.

Leur grand projet futuriste (aborde; combat) aborde de nouveaux problèmes.

Le cavalier amena son brave (cheval; enlace) cheval à la victoire.

Il découvrit ce troublant (morceau; affecta) morceau dans sa poche.

Les deux femmes prévoient un alléchant (accord; braver) accord ce soir.

Cette mignonne plante moisie (pousse; paquet) pousse malgré le froid.

Elle sentit une brusque (larme; garer) larme couler sur sa joue.

Ils ont acheté un soyeux (tissu; tarda) tissu chez le marchand.

Tant de rires joviaux (font; vais) font plaisir à entendre.

De gros nuages orageux (grondent; festival) grondent dans le ciel.

Cette petite personne loquace (parle; angle) parle vraiment bien.

Des grands hommes résignés (avancent; ampoules) avancent sous la pluie.

Quelques jeunes filles ennuyées (racontent; papillons) racontent des histoires.

Le pianiste ajoute une subtile (note; menu) note dans son récital.

Son long plan saugrenu (arriva; utiles) arriva à ses fins.

Des jeunes stagiaires investis (feront; allant) feront un bon travail.

Son grand air méprisant (cachait; panique) cachait une certaine timidité.

Je repensais au déchirant (souvenir; aggraver) souvenir de son départ.

Tous les vêtements blanchis (arrivent; fontaine) arrivent de leur machine.

Elle partage ce plausible (soucis; truqua) soucis avec ses parents.

Ce beau geste amical (engendre; baguette) engendre de belles émotions.

Certains gros sons brutaux (abiment; timides) abiment leur audition.

Plusieurs jeunes chiens têtus (courent; hommage) courent après le vélo.

La longue nappe tendue (forme; votez) forme une vraie table.

Le lourd sac chargé (alourdi; dispute) alourdi le coffre.

Le petit enfant honteux (rentre; unique) rentre sans un bruit.

Ses parents adoptèrent une sévère (attitude; enrichis) attitude après cette bêtise.

Ton célèbre roman policier (renvoie; poumons) renvoie à des faits réels.

Votre jolie carte postale (plait; sport) plait à toute ma famille.

Toutes les touches visibles (percutent; mannequin) percutent les cordes du piano.

Il vécut un insolite (moment; presse) moment avec son ami.

Il semblait jouer sur un banal (piano; nagea) piano durant le concert.

Elle a quitté son odieux (mari; taxe) mari pour être libre.

Ils habitent un hostile (lieu; bise) lieu au bout de la rue.

Il lui autorise un ultime (tournoi; daterai) tournoi dans la semaine.

(*Appendix continues*)

Son superbe sourire éclatant (rayonne; baleine) rayonne de bonheur.

Ils ont partagé un intense (sourire; sources) sourire durant la danse.

Les mariés ont prévu trente (convives; coiffait) convives pour le repas.

Cet homme a vu un ignoble (cafard; casser) cafard sous son lit.

Son pauvre air navré (change; examen) change quand tu es présent.

Il a dormi dans cet abrupte (cachot; phrase) cachot chaque nuit.

Tu sens venir une intense (fatigue; emplois) fatigue dès maintenant.

Il regarda les cages et fortement (envoya; cabine) envoya le ballon.

Elle saisit une occasion et amicalement (invite; cahier) invite ses collègues.

Il parlait et consciemment (affichait; synergies) affichait ses opinions.

Elle réussit à lever ce lourd (marteau; gravure) marteau plusieurs fois.

Adrien est heureux et gaiement (chantonne; clochette) chantonne son air favori.

Ce livre très technique (fascina; globule) fascina ce jeune enfant.

Ils mirent en ordre cette large (faction; cracher) faction très armée.

Prenez en compte cette forte (amplitude; chalutier) amplitude pour atterrir.

Je veux visiter ces effroyables (caves; accru) caves du château.

Tu cuisines une fantastique (tarte; rhums) tarte à la rhubarbe.

Il faut faire assez (mariner; neigera) mariner pour le manger.

Il va falloir certainement (ajuster; ondoyer) ajuster ces boutons de manchette.

Les chevaliers voulaient bravement (prier; ceint) prier pour leur victoire.

Le juge de manière juste (accorda; sonneur) accorda la liberté au malheureux.

Nous devons soigner cette pathologique (toux; tact) toux avant Noël.

Je veux acheter ces charmants (tableaux; alluvion) tableaux dès demain.

Je transporte un fragile (carton; migrer) carton de décorations africaines.

Ton frère effectue de fières (actions; anoblie) actions dans son travail.

Il frémit peu puis (actionna; abattoir) actionna le levier.

Je ne peux objectivement (consentir; chapelles) consentir à cet accord.

Tu peux demander à son proche (cousin; infusa) cousin un avis.

Mon colocataire aime les franches (rigolades; immortels) rigolades avec ses amis.

Ta mère *SE* tient debout (face; lion) face au vent.

Parmi ces gens peu (acceptent; confiance) acceptent cette dure vérité.

Mon chien a environ (pris; rite) pris la moitié de sa gamelle.

Cet évènement est historiquement (compris; visages) compris comme le commencement.

Il aurait voulu calmement (attendre; tringles) attendre la fin du récit.

Dors bien et demain (apportera; dictature) apportera de nouvelles perspectives.

Cette femme bien gentille (proposa; douille) proposa son aide.

Son grand père autrefois (rencontra; dominante) rencontra une bête velue.

Elle a obtenu une couverte (toiture; bouture) toiture pour cet hiver.

Je pense que demain (sera; ayez) sera un jour exceptionnel.

Je te voue une éternelle (affection; embauches) affection pour que tu restes.

Voilà encore une étrange (substance; attendons) substance à ne pas consommer.

Il faut procéder à un écologique (changement; tapisserie) changement pour la suite.

Elle a entendu une faible (voix; urne) voix murmurer à mon oreille.

Chaque nuit une étrange (vision; biches) vision *SE* présente à moi.

Tu as construit cette blanche (cabane; rester) cabane de tes mains.

Il adore son fraternel (cadeau; rivait) cadeau de Noël.

Il donna un mortifère (conseil; jubiler) conseil à son ami.

Elle effectue son premier (calibrage; robotique) calibrage sur cet appareil.

Ce sera le dernier (patron; coller) patron de ma vie.

Ce grand oiseau brièvement (admire; encode) admire un poisson dans le lac.

Toute cette pagaille énorme (engendrera; aérobiques) engendrera une fin terrible.

Il *SE* baigne dans la solaire (piscine; ligoter) piscine des voisins.

Il est en retard et finement (essaye; anneau) essaye discrètement de rentrer.

Ils offrent une moisie (couverture; carnivores) couverture pour la nuit.

Il faut entreprendre une militante (action; pagode) action pour marquer les esprits.

(*Appendix continues*)

Elle présente sa fière (invention; musiciens) invention au concours.

Il nettoie cette lumineuse (vitre; clore) vitre pour bien voir.

Derrière la porte il a fixement (entendu; souries) entendu la conversation.

Les américains larguent une atomique (bombe; savon) bombe sur le Japon.

Elle exhibe une tranchante (lame; posa) lame pour frimer.

Prudence avec cette fragile (barge; grise) barge pour touristes.

Le gouvernement promeut cette nationale (industrie; vagabonds) industrie pour notre économie.

Elle a comme une étrange (envie; devin) envie de partir loin.

Fais attention à la petite (marche; manger) marche sur le palier.

Il avait remarqué une étrange (lueur; nuage) lueur sur la montagne.

Ce petit animal bizarre (ressemble; entonnoir) ressemble à une tortue.

Le gros chien avait fortement (mordu; canne) mordu cette personne.

La hauteur de cette grande (tour; rive) tour est impressionnante.

Tous les enfants sages (auront; alliez) auront une surprise.

Nous avons vécu une sacrée (histoire; explorer) histoire ce weekend.

Elle a endommagé le superbe (collier; trouver) collier de son anniversaire.

Il disait que cette nouvelle (image; chien) image était parfaite.

Nous étions fiers de notre récent (record; visage) record sur la course.

Il a adoré les délicieux (plats; niche) plats de ma grand mère.

Il suffit juste de bien (retenir; horizon) retenir les consignes.

Cette équipe recueille de nombreux (joueurs; exemple) joueurs très réputés mondialement.

Les personnes peuvent toujours (partir; copier) partir quand elles le souhaitent.

On pouvait trouver de grosses (erreurs; abandon) erreurs dans ses explications.

Vous avez acheté une splendide (voiture; activer) voiture de course.

Il ne faut jamais (courir; radote) courir au bord de la piscine.

Il aurait fallu seulement (quitter; enfants) quitter ses affaires.

Si seulement tu pouvais vraiment (analyser; panneaux) analyser la situation.

Tous ses amis ont encore (voulu; dises) voulu venir à la soirée.

Il suffisait de purement (organiser; libraires) organiser tes devoirs à faire.

Le tout est de bien (regarder; anecdote) regarder ce qui est présenté.

Nous avons dégusté un succulent (repas; vitre) repas cette soirée là.

La vieille voiture rouge (fonce; tenir) fonce à vive allure.

Le nouveau conseil restreint (envisage; annuelle) envisage une réforme complète.

De nombreux pays libres (veulent; vaudras) veulent rejoindre les nations unies.

Elle aime créer de nouvelles (recettes; postures) recettes pour chaque occasion.

Le petit ventilateur orange (souffle; segment) souffle vraiment trop fort.

La table en fer forgé (rend; doux) rend beaucoup service.

Le chien du voisin avait encore (grandi; treize) grandi dans la nuit.

Tu dois suivre le seul (protocole; retombait) protocole obligatoire pour ce travail.

Nous pourrions devenir de grandes (stars; herbe) stars de la musique.

Tu dois écouter ce vieil (homme; pensa) homme qui donne des conseils.

Cette belle cité ancienne (repose; citron) repose sous les fonds marins.

Il a trouvé cette petite (merveille; cependant) merveille dans son jardin.

Cette recette est un grand (secret; violon) secret chez les cuisiniers.

Tous mes cousins éloignés (donnent; petites) donnent des nouvelles.

Ces petites affaires secrètes (choquent; accident) choquent tout le monde.

Les inscriptions aux nouveaux (cours; fleur) cours *SE* font dès maintenant.

Un retard aussi infime (serait; dirais) serait certainement pardonné.

Elles ont envoyé un grand (nombre; ruelle) nombre de lettres.

Le tout est de vraiment (persuader; campement) persuader le grand public.

Elle nous a dit de mieux (scruter; session) scruter la falaise.

Ils devraient tous justement (suivre; parlas) suivre ton exemple.

Il a découvert une obscure (grotte; ruines) grotte dans cette région.

Les élections font beaucoup (parler; preuve) parler en ce moment.

Le gagnant de cet étrange (concours; boissons) concours est toujours inconnu.

Il a fait un délicieux (cookie; rendre) cookie pour toute la famille.

(*Appendix continues*)

Nous avons construit une grande (maison; rapace) maison sur les hauteurs.

Ils ne veulent plus (entendre; culturel) entendre parler de cette histoire.

Les rumeurs sur cette ville mythique (restent; trieuse) restent encore peu répandues.

Cet ordinateur est une rapide (machine; textuel) machine comparée aux autres.

Cette grande avancée majeure (renforce; surmonta) renforce nos prédictions.

Avance prudemment sur cette grande (route; jalon) route pendant la nuit.

Toute la police locale (surveille; bravoures) surveille ses faits et gestes.

Il a acheté de fameux (fruits; persil) fruits au primeur du coin.

Le petit chiot adorable (remue; buste) remue la queue sans arrêt.

Nous remporterons cette dernière (bataille; souhaits) bataille contre nos ennemis.

Il est important de bien (situer; bronze) situer le contexte.

Cette vieille loi injuste (subsiste; purifies) subsiste dans notre pays.

Cette nouvelle rue étroite (devrait; prenais) devrait être plus sécurisée.

Il faut voir ce superbe (spectacle; attachera) spectacle la semaine prochaine.

Nous avons connu une horrible (aventure; chasseur) aventure la nuit dernière.

Tu dois imaginer un immense (espace; orange) espace plein de mystères.

Nous voyons toujours ce vieux (chantier; trancher) chantier devant notre maison.

Des billets pour ce fabuleux (stade; poney) stade sont en vente.

Cette fameuse nouvelle excitante (contient; maillons) contient des faits mensongers.

Cette famille a de charmants (enfants; cherche) enfants très bien éduqués.

Il *SE* réveillera avec un sublime (paysage; montres) paysage autour de lui.

La nouvelle série hilarante (promet; votera) promet un grand succès.

Chaque année ces effarants (touristes; tacticien) touristes saccagent nos littoraux.

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