Acta Psychologica 130 (2009) 127–137

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

Does letter position coding depend on consonant/vowel status? Evidence with the masked priming technique

Manuel Perea *, Joana Acha

Departamento de Metodología, Facultad de Psicologia, Universitat de València, Av. Blasco Ibáñez. 21, 46010 Valencia, Spain

ARTICLE INFO

Article history:
Received 28 February 2008
Received in revised form 3 November 2008
Accepted 4 November 2008
Available online 9 December 2008

PsycINFO classification:
2300
2340

Keywords:
Masked_priming
Letter_encoding
Consonants_vowels
Word_recognition

ABSTRACT

Recently, a number of input coding schemes (e.g., SOLAR model, SERIOL model, open-bigram model, overlap model) have been proposed that capture the transposed-letter priming effect (i.e., faster response times for jugde-JUDGE than for jupte-JUDGE). In their current version, these coding schemes do not assume any processing differences between vowels and consonants. However, in a lexical decision task, Perea and Lupker (2004, JML; Lupker, Perea, & Davis, 2008, L&CP) reported that transposed-letter priming effects occurred for consonant transpositions but not for vowel transpositions. This finding poses a challenge for these recently proposed coding schemes. Here, we report four masked priming experiments that examine whether this consonant/vowel dissociation in transposed-letter priming is task-specific. In Experiment 1, we used a lexical decision task and found a transposed-letter priming effect only for consonant transpositions. In Experiments 2–4, we employed a same–different task – a task which taps early perceptual processes – and found a robust transposed-letter priming effect that did not interact with consonant/vowel status. We examine the implications of these findings for the front-end of the models of visual word recognition.

1. Introduction

A critical goal for any computational model of visual word recognition is to determine how the brain encodes letter identity and letter position within a printed word (see Davis & Bowers, 2006; Grainger, 2008; Guerrera & Forster, 2007; Rayner, White, Johnson, & Liversedge, 2006, for review). A large body of research has shown that letter position and letter identity do not go hand in hand: a transposed-letter nonword such as *mohter* is frequently misperceived as the word mother (e.g., Bruner & O'Dowd, 1958; O'Connor & Forster, 1981; Perea & Estévez, 2008; Perea & Fraga, 2006). Furthermore, in a masked priming paradigm, a target word is recognized faster when it is preceded by a briefly presented transposed-letter nonword prime (jugde–JUDGE) than when it is preceded by an orthographic control (jupte–JUDGE) (see Castles, Davis, & Forster, 2003; Forster, Davis, Schoknecht, & Carter, 1987; Lupker, Perea, & Davis, 2005; Perea & Carreiras, 2006a; Perea & Carreiras, 2006b; Perea & Lupker, 2003; Perea & Pérez, in press; Perea, Duñabeitia, & Carreiras, 2008; Schoonbaert & Grainger, 2005). Furthermore, transposed-letter effects also occur when two nonadjacent letter positions are transposed (e.g., relovution primes REVOLUTION; Perea & Lupker, 2004; see also Guerrera & Forster, 2007; Perea & Carreiras, 2006a; Perea & Carreiras, 2006b; Perea & Carreiras, 2006c). Finally, transposed-letter effects have also been found in normal silent reading when the participants' eye movements are monitored (see Acha & Perea, 2008; Johnson, 2007; Johnson, Perea, & Rayner, 2007; Rayner et al., 2006; White, Johnson, Liversedge, & Rayner, 2008).

As Grainger (2008) pointed out, the presence of transposed-letter effects in normal reading poses serious problems for models that use position-specific ("slot") coding schemes, such as the interactive activation model (McClelland & Rumelhart, 1981), the multiple read-out model (Grainger & Jacobs, 1996), the dual route cascaded model (Coltheart, Rastle, Conrad, Langdon, & Ziegler, 2001), and the CDP+ model (Perry, Ziegler, & Zorzi, 2007). For this reason, in the past years, several orthographic coding schemes have been proposed that can successfully accommodate transposed-letter effects (SOLAR model, Davis, 1999; SERIOL model, Whitney, 2001; open-bigram model, Grainger & van Heuven, 2003; overlap model, Gomez, Ratcliff, & Perea, 2008; local combination detectors (LCDs) model, Dehaene, Cohen, Sigman, & Vinckier, 2005). For instance, the SOLAR model (Davis, 1999) uses activation levels to code letter position (i.e., the first letter is coded by the highest activation value, the second letter is coded with a slightly smaller activation value, etc.). In this way, the nonword *jugde* and its base word *judge* share the same set of letter nodes, but they produce different spatial patterns. The SOLAR model also assumes the presence of a left-to-right serial input (in Western languages), such that the letters are processed sequentially. Because serial position is coded by relative activities rather than via

* Corresponding author. Tel.: +34 96 3864512; fax: +34 96 3864697.
E-mail address: mperea@valencia.edu (M. Perea).
URL: http://www.valencia.edu/mperea (M. Perea).

0001-6918/$ - see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.actpsy.2008.11.001

position-specific codes and because of the way the network computes bottom-up input, *jugde* and *judge* are more similar, and hence, more confusable than *jupte* and *judge*. Thus, the SOLAR model can readily accommodate transposed-letters similarity effects.

Common to all these input coding schemes are the notions that (i) letters are basic perceptual reading units and (ii) there are no inbuilt differences between consonants and vowels in the front-end of letter position coding. However, there is one recent finding that seems to pose a serious problem for this latter assumption: consonants and vowels seem to play a different role in transposed-letter priming effects. In a lexical decision task with Spanish stimuli, Perea and Lupker (2004) found that the transposed-letter prime advantage occurred only when two consonants were transposed (e.g., caniso-CASINO) and not when two vowels were transposed (e.g., anamil-ANIMAL). This finding has recently been replicated, with English stimuli, by Lupker et al. (2008) in a lexical decision task. The consonant/vowel dissociation cannot be explained by the current version of the SERIOL, SOLAR, open-bigram overlap, or LCD models, since none of these models distinguishes between vowels and consonants. Keep in mind that although a number of experimental phenomena are modulated by the consonant/vowel status of the letters (e.g., Berent & Marom, 2005; Buchwald & Rapp, 2006; Carreiras, Gillon-Dowens, Vergara, & Perea, in press; Cutler, Sebastián-Gallés, Soler-Vilageliu, & van Ooijen 2000; Lee, Rayner, & Pollatsek, 2001), it is uncertain when the vowel/consonant status begins to matter in word processing.

Given the critical relevance of the consonant/vowel dissociation for the front-end of models of visual word recognition, and before attempting to propose any modification in the models, it is important to examine in detail the nature of the consonant/vowel differences. One potential difference between vowels and consonants is in terms of letter frequency: vowels are more frequent than consonants. For instance, one might argue that more frequent letters may be more easily processed and more readily tied to their positions (Lupker et al., 2008). Consistent with this prediction, Lupker et al. found a greater transposed-letter prime advantage when the transposed consonants were of low-frequency than when they were of high-frequency with English stimuli (34 vs. 11 ms). Duñabeitia, Gutiérrez, and Mena (2006) successfully replicated the same pattern of data with Spanish stimuli (36 vs. 10 ms for low-frequency consonant transpositions and high-frequency consonant transpositions, respectively). However, as Lupker et al. (2008) indicated, "these results do not prove that the difference between transposed-letter effects for C–C (consonant–consonant) primes versus V–V (vowel–vowel) primes in those experiments is completely due to the frequency difference between consonants and vowels" (p. 106). For instance, Lupker et al. (2005) reported a robust effect for C–V transpositions in a masked priming lexical decision task (see also Christianson, Johnson, & Rayner, 2005, for a similar pattern in a masked priming naming task). This priming effect for C–V transpositions was numerically greater than that for C–C transpositions, and this poses some limits on the generality of the letter frequency account: a letter frequency account would predict stronger priming for C–C transpositions than for C–V transpositions.

Here, we adopt a different strategy. If letter position coding differs for consonants and vowels, the dissociation between consonant and vowel transpositions should appear in all visual word recognition tasks – and it would require the modification of a basic tenet of the recently proposed orthographic coding schemes. However, a recent report by Johnson (2007) casts some doubts on the necessity of this amendment. Johnson employed a parafoveal transposed-letter priming procedure (i.e., the boundary technique; Rayner, 1975) in the context of normal silent reading while the participants' eye movements were monitored. In this technique, readers are presented with a parafoveal preview of a target word. When the readers' eyes cross an invisible boundary location, the preview (i.e., the prime) is changed to the target word. Note that the change occurs during a saccade (when visual input is suppressed), so readers do not consciously notice it. By using this procedure, Johnson (2007) failed to obtain any signs of dissociation between C–C and V–V transpositions: she found that reading times to a target word (e.g., forest) were faster when it had been preceded by a transposed-letter parafoveal preview (fosert) than by a replacement-letter parafoveal preview (fonewt): this transposed-letter priming effect was approximately the same size for C–C transpositions (e.g., fosert–forest vs. fonewt–forest) and for V–V transpositions (e.g., flewor–flower vs. flawur–flower). Johnson (2007) indicated that parafoveal transposed-letter effects "are likely to occur at a very low-level of visual word recognition, before the encoding of a vowel/consonant label and the phonological attachment of letters to sounds". Johnson, however, did not test these materials in a masked priming lexical decision task (i.e., a foveal presentation) or with any other procedure, so we cannot know for sure whether the lack of interaction between the magnitude of the priming effect and consonant/vowel status was due to the characteristics of the task or the characteristics of the stimuli. We believe that it is critical to find out whether the consonant/vowel dissociation obtained by Perea and Lupker (2004) may be a by-product of the specific characteristics of the masked priming lexical decision task. As noted by Gibbs and Van Orden (1998), "stimulus effects are always seen through the distorting lens of a laboratory task" (p. 1163). Thus, it is important to find out which processes are common to normal word processing. To reiterate, if the consonant/vowel dissociation in masked transposed-letter priming is task-dependent, the front-end of the recently proposed orthographic coding schemes does not need to be amended. For instance, consonant and vowel differences could arise at a later sublexical phonological level (we discuss the influence of phonology in masked transposed-letter priming in the general discussion). Alternatively, if letter position coding co-occurs with the consonant/vowel distinction, the front–end of the recently proposed orthographic coding schemes would need to be modified.

Indeed, there are some additional data that suggest that consonants and vowels may be encoded in a similar way in the early stages of word processing. To examine in detail the time course of consonant and vowel activation, Carreiras, Vergara, and Perea (2007) recorded electrophysiological measures (event-related potentials, ERPs) in a single-presentation lexical decision experiment. ERPs are functionally decomposable to a greater extent than response times, thus enabling us to draw conclusions not only about the existence of processing differences between vowels and consonants, but more importantly, about the timing at which these differences occur. As in previous research, pseudowords created by replacing two consonants from a base word (*relovution*) produced slower correct lexical decision times and substantially more errors than the pseudowords created by transposing two vowels (*revulotion*; see also Lupker et al., 2008; Perea & Carreiras, 2006c; Perea & Lupker, 2004). But the remarkable feature of the ERP study of Carreiras et al. (2007) was that transposed-letter consonant nonwords and transposed-letter vowel nonwords in single-presentation lexical decision showed very similar ERP waves in early time windows (e.g., 300–500 ms). Indeed, it was only in late time windows (500–600 ms) – and in the lexical decision times – when there was a dissociation between consonant and vowel transpositions. This dissociating pattern between consonant/vowel transpositions at a late window and in behavioral measures may well be due to (relatively) late processes during lexical decision (e.g., see Gomez, Ratcliff, & Perea, 2007; Norris, 2006; Ratcliff, Gomez, & McKoon, 2004, for quantitative analyses of the lexical decision task).

The main goal of the present paper is to examine in depth whether the modulation of the transposed-letter priming effect in response times by consonant/vowel status is task-specific or task-independent. We do so by using the same materials in a masked priming paradigm with a lexical decision task and with another task: the cross-case same–different task – a task which presumably taps low-level (presumably prelexical) processing (as in the Johnson, 2007, experiment). In the cross-case same–different task, a probe is presented before a target stimulus which is presented in different case. The same–different task has a long history (e.g., see Van Zandt, Colonius, & Proctor, 2000, for review and for a mathematical model of the task) and it was actually the task employed in the experiments on the overlap model of Ratcliff (1981) – although in this and other studies the probe and the target had the same case. The cross-case same–different task is based on processing of abstract letter identities rather than on physical identity (i.e., the probe and the target are in different case), and it seems to be insensitive to the phonological code (e.g., lack of a difference between *HYLE-hile* and *HYLE-hule*; see Besner, Coltheart, & Davelaar, 1984), and hence, it is assumed to reflect the earliest stages of visual processing (see Norris & Kinoshita, 2008, for a detailed analysis of the cross-case masked priming same–different task in the framework of the Bayesian Reader model).

Recently, Norris and Kinoshita (2008); see also Kinoshita & Norris, in press) used the cross-case same–different task associated with a masked priming paradigm. For instance, Kinoshita and Norris (in press) showed that when the probe and target were the same (e.g., probe: faith, target: FAITH), a transposed-letter prime (e.g., fiath) produced a transposed-letter prime advantage in response time relative to a replacement-letter prime (e.g., fouth). This effect occurred to a similar degree for both word and nonword targets – note that masked priming effects are usually restricted to word targets in the lexical decision task. Furthermore, the size of priming obtained with this task was not affected by word frequency or lexical status (see also Norris & Kinoshita, 2008), which strongly suggests that this task, unlike lexical decision, is not lexically mediated. Thus, the cross-case same–different masked priming task seems to be an appropriate technique to examine any consonant/vowel differences in the earliest stages of visual word recognition. What we should note here is that one basic tenet of the Bayesian Reader model is that masked priming depends on the hypotheses that support the decision required to make a response. In lexical decision, masked priming is driven mainly by integrating evidence at the word level. In contrast, the same–different decision is made by comparing the likelihood that the target has the same form as the probe with the likelihood that it is different, so that masked priming would happen regardless of lexical status when probe and target are the same (i.e., the effects would be prelexical in nature), but not when they are different. Thus, the comparison between the two tasks (lexical decision vs. same–different) is particularly useful to shed more light on the nature (prelexical vs. lexical) of the transposed-letter priming effects with consonants vs. vowels.

To sum up, in Experiment 1 we use a lexical decision task to re-examine whether C–C transpositions produce a transposed-letter priming effect while V–V transpositions do not. To anticipate the results, we found a transposed-letter priming effect only for C–C transpositions – replicating Perea and Lupker (2004) and Lupker et al. (2008). In Experiments 2–4, we used a cross-case same–different task to examine whether the same pattern holds for a task that (allegedly) taps very early processes in lexical access. If the magnitude of the transposed-letter priming effect is not modulated by consonant/vowel status in this low-level task, this would suggest that the consonant/vowel differences do not occur at the earliest stages of visual processing.

2. Experiment 1 (lexical decision)

2.1. Method

2.1.1. Participants

Twenty-six undergraduates from the University of Valencia received course credit for participating in the experiment. All of them had either normal or corrected-to-normal vision and were native speakers of Spanish.

2.2. Materials

The targets were 104 Spanish words that were six letters long. Fifty-two of these words (mean word frequency per one million words: 19, range: 3–168; mean Coltheart's *N*: 0.6, in the Davis & Perea, 2005, count) were presented in uppercase and were preceded by primes in lowercase that were (1) the same except for a transposition of two adjacent internal consonants (TL-consonant condition), e.g., catrel–CARTEL, or (2) the same except for the replacement of the corresponding internal consonants (RL-consonant condition), cafnel–CARTEL. The remaining 52 words (mean word frequency per one million words: 19, range: 2–167; mean Coltheart's N: 0.7, in the Davis & Perea, 2005, count) were also presented in uppercase and were preceded by primes in lowercase that were (1) the same except for a transposition of two internal vowels (TL-vowel condition), craota–CROATA, or (2) the same except for the substitution of the corresponding internal vowels (RL-consonant condition), creita–CROATA. Primes were always nonwords. The letter transposition/replacement did not cross any morpheme boundaries (Duñabeitia, Perea, & Carreiras, 2007). The mean log bigram frequencies were similar for the transposed-letter and replacement-letter primes in the Spanish database (Davis & Perea, 2005). An additional set of 104 target nonwords that were six letter long (e.g., LARTUS, IROIFA) was included for the purposes of the lexical decision task. The manipulation of the nonword trials was the same as that for the word trials. Two lists of materials were constructed so that each target appeared once in each list, but each time in a different priming condition. Different groups of participants were used for each list.

2.3. Procedure

Participants were tested either individually or in groups of up to four people. The stimuli were presented using PCs running the DMDX software for Windows (Forster & Forster, 2003) on a CRT monitor with a 16.6 ms refresh rate. Reaction times were measured from target onset until the participant's response. In each trial, a forward mask consisting of a row of six hash marks (######) was presented for 500 ms in the center of the screen. Next, a centered lowercase prime was presented for 50 ms. Primes were immediately replaced by an uppercase target item, which remained on the screen until the response. Participants were told that they would see strings of letters, and that they were to press the button marked "SÍ" [*YES*] (with their right index finger) if they thought the letter string spelled a real Spanish word, and they were to press the button marked "NO" (with their left index finger) if they thought the letter string did not spell a real Spanish word. Participants were instructed to make this decision as quickly and as accurately as possible. Participants were not informed of the presence of lowercase items. Each participant received a different, randomized order of trials. There were 20 practice trials in Experiment 1. The experiment lasted for less than 12 min.

2.4. Results

Incorrect responses (5.3% of the word trials) and response times greater than 1500 ms (less than 1% of the trials) were excluded from the latency analysis. The mean response times and error percentages from the participant analysis for the word and nonword data are presented in Table 1. ANOVAs based on the participant and item mean correct response times and error rates were conducted based on a two (Prime type: transposition, replacement) $\times$ 2 (Letter type: consonants, vowels) $\times$ 2 (list: list 1, list 2) design. List was included as a dummy variable in the ANOVAs to extract the variance due to the error associated with the random assignment of items to lists (Pollatsek & Well, 1995). As usual, word and nonword data were analyzed separately.

2.4.1. Word data

In the latency data, the main effect of Letter type was significant, $F_1(1,24) = 36.99$, $MSe = 351$, $p < .001$; $F_2(1,100) = 6.84$, $MSe = 4749$, $p < .02$, while the main effect of Prime type was not significant, both Fs < 1. More importantly, there was a significant interaction between these two factors, $F_1(1,24) = 6.60$, $MSe = 463$, $p < .02$; $F_2(1,100) = 4.57$, $MSe = 1696$, $p < .035$. As in previous research (Lupker et al., 2008; Perea & Lupker, 2004), this interaction was due to the fact that the TL–RL difference was larger in the C–C condition (14 ms) than in the V–V condition (−8 ms). The former difference was significant, $F_1(1,24) = 4.31$, $MSe = 658$, $p < .05$; $F_2(1,50) = 4.31$, $MSe = 1458$, $p < .05$, whereas the latter was not, both Fs < 1.

The ANOVA on the error data only showed a significant effect of Letter type in the analysis by participants, $F_1(1,24) = 7.61$, $MSe = 15.7$, $p < .02$; $F_2(1,100) = 3.63$, $MSe = 70.6$, $p = .06$. The other effects did not approach significance (all ps > .20).

2.4.2. Nonword data

The ANOVA on the latency data did not show any significant effects (all Fs < 1). The ANOVA on the error data showed a significant effect of Letter type, $F_1(1,24) = 13.53$, $MSe = 14.0$, $p < .002$, $F_2(1,100) = 6.54$, $MSe = 53.3$, $p < .015$. The effect of Prime type approached significance, $F_1(1,24) = 3.90$, $MSe = 15.2$, $p = .06$, $F_2(1,100) = 3.85$, $MSe = 26.7$, $p = .053$. The interaction between the two factors did not approach significance (both ps > .12).

The results are straightforward: in the C–C condition, there was a significant transposed-letter prime advantage for word targets – in comparison to the replacement-letter primes. In the V–V condition, there was no such advantage. This result closely replicates the results reported by Perea and Lupker (2004) and Lupker et al. (2008).

It may be worth noting that for the targets with vowel transpositions, half of the primes involved vowels that crossed the syllable boundary (i.e., a hiatus), as in fliudo–FLUIDO (/flu.i.do/), whereas the other half involved two vowels that formed part of the same syllable (i.e., a diphthong), as in biutre-BUITRE (/bui.tre/). If transposed-letter priming effects have a syllabic nature, then one would expect that crossing the syllable boundary would reduce the magnitude of the transposed-letter priming effect (as occurs with morphological boundaries; see Duñabeitia et al., 2007). However, the size of the transposed-letter priming effect for words was very similar for the two conditions with vowel transpositions (−6 and −10 ms for the diphthong and hiatus transpositions, respectively). This confirms and extends the findings of Perea and Carreiras (2006c), this time with a masked priming paradigm instead of a single-presentation paradigm: transposed-letter effects do not seem to be sensitive to syllabic boundaries. This again reinforces the view that transposed-letter priming effects have a very early locus. Note, however, that in the present experiment the cognitive system would require a well-developed phonological representation to determine the syllable boundaries across two adjacent vowels.

Table 1
Mean response times (in ms), standard error response times (underlined) and percentage of errors (in parentheses) for word and nonword targets in Experiment 1.

	Type of prime		
	TL	RL	TL priming
Word trials			
Consonant–consonant	635 <u>19.6</u> (3.7)	649 <u>20.4</u> (4.7)	14 (1.0)
Vowel–vowel	668 <u>21.7</u> (6.1)	660 <u>20.7</u> (6.7)	−8 (0.6)
Nonword trials			
Consonant–consonant	739 <u>25.9</u> (7.0)	745 <u>26.3</u> (4.4)	6 (2.6)
Vowel–vowel	742 <u>29.2</u> (3.3)	745 <u>28.8</u> (2.7)	3 (0.6)

Note: TL, transposed-letter prime; RL, replacement-letter prime.

3. Experiment 2 (same–different task)

In Experiment 2, we used the same pairs from Experiment 1 for the "same" responses. This allowed us to directly compare the priming effects with word and nonword targets. Bear in mind that in a lexical decision task, "no" responses may be, to some degree, the result of some deadline mechanism that is insensitive to the priming manipulation (see Forster, 1998; Perea, Rosa, & Gómez, 2005). In contrast, in the same–different task, both word and nonword targets require the same response ("yes"). For the purposes of the same–different task, we also included a set of items for the "different" responses.

3.1. Method

3.1.1. Participants

Thirty undergraduates from the University of Valencia received course credit for participating in the experiment. All of them had either normal or corrected-to-normal vision and were native speakers of Spanish. They had not participated in Experiment 1.

3.1.2. Materials

For the "same" response condition, we used the 104 word targets and 104 nonword targets from Experiment 1 (e.g., for the probe cartel, the primes could be either the transposed-letter prime catrel or the replacement-letter prime cafnel, and the target would be CARTEL). For the "different" response condition, we selected 104 word targets that were matched in length and frequency to the 104 words of the "same" condition. The construction of the transposed-letter and replacement-letter primes was identical to that of the critical items used in the "same" response condition. Each target was paired with 104 additional probe words that were different (but equal in length) from the target (e.g., probe: carril, target: SARTÉN). We did the same with the 104 nonword targets for the "different" response condition – except that the probes/targets were nonwords. As in Experiment 1, we created two lists that were counterbalanced across participants, so that each target was seen by a participant once, and appeared in each prime condition once across every two participants.

3.1.2. Procedure

Participants were tested either individually or in groups of up to four people. The hardware/software was the same as in Experiment 1. In each trial, a probe printed in lowercase was presented above a forward mask consisting of six hash marks (######) for 1000 ms. Next, the probe disappeared, and the forward mask was replaced by a prime in lowercase presented for 50 ms, which was replaced by a target presented in uppercase. The target stimulus remained on the screen until the response. Participants were told that they would see strings of letters, and that they were to press the button marked "SÍ" [*YES*] (with their right index finger) if they thought the probe and target were the same stimulus, and they were to press the button marked "NO" (with their left index finger) if they thought the probe and target were a different stimulus. Participants were instructed to make this decision as quickly and as accurately as possible. Participants were not informed of the presence of prime stimuli. Each participant received a different, randomized order of trials. There were 20 practice trials. The experiment lasted for less than 18 min.

3.2. Results

Incorrect responses (5.2% of trials) and response times greater than 1500 ms (less than 1% of the trials) were excluded from the latency analysis. The mean response times and error percentages from the participant analysis for the word and nonword data are presented in Table 2. The experimental design was the same as in Experiment 1. We analyzed separately "same" and "different" responses.

3.2.1. "Same" responses

3.2.1.1. Word data. In the latency data, the ANOVA showed that responses to words preceded by a transposed-letter prime were 27 ms faster than the responses to words preceded by a replacement-letter prime, $F_1(1,28) = 26.72$, $MSe = 847$, $p < .001$; $F_2(1,100) = 22.71$, $MSe = 1810$, $p < .001$, while the main effect of Letter type was not significant (both $Fs < 1$). The magnitude of the transposed-letter priming effect was the same for consonant and vowel transpositions (27 ms), and hence, there were no trends of an interaction effect (both $Fs < 1$).

The ANOVA on the error data failed to show any significant effects.

3.2.1.2. Nonword data. In the latency data, the main effect of Letter type was significant, $F_1(1,28) = 30.59$, $MSe = 779$, $p < .001$; $F_2(1,100) = 6.84$, $MSe = 4749$, $p < .02$ while the main effect of Prime type approached significance, $F_1(1,28) = 3.63$, $MSe = 1171$, $p = .063$; $F_2(1,100) = 3.59$, $MSe = 2513$, $p = .061$. More importantly, there was a significant interaction between these two factors, $F_1(1,24) = 5.05$, $MSe = 1248$, $p < .035$; $F_2(1,100) = 4.91$, $MSe = 2513$, $p < .03$. This interaction was due to the fact that the TL–RL difference was larger in the V–V condition (26 ms) than in the C–C condition (−2 ms). The former difference was significant, $F_1(1,28) = 8.68$, $MSe = 1205$, $p < .007$; $F_2(1,50) = 4.31$, $MSe = 1458$, $p < .05$, whereas the latter was not, both $Fs < 1$.

The ANOVA on the error data only showed that the main effect of Prime type approached significance in the analysis by participants, $F_1(1,28) = 3.32$, $MSe = 26.1$, $p = .079$; $F_2(1,100) = 2.18$, $MSe = 43.2$, $p = .14$.

3.2.2. "Different" responses

3.2.2.1. Word data. None of the effects approached significance in the latency/error data (all $ps > .12$),

3.2.2.2. Nonword data. None of the effects approached significance in the latency/error data (all $ps > .10$).

The results of the present experiment are clear-cut. As in previous research, a transposed-letter priming effect was found with "same" responses, but not with "different" responses (as reported by Kinoshita & Norris, in press, and Norris & Kinoshita, 2008). More important, for word stimuli, we found a robust 27 ms transposed-letter priming effect that was unaffected by the consonant/vowel status of the transposed-letters. That is, unlike the results with the lexical decision task, there were no signs of a vanishing transposed-letter priming effect for vowel transpositions in the same–different task.

As indicated in the Introduction, the masked priming same–different task is assumed to tap very early processes in visual word identification. Thus, it is hardly surprising that response times in the same–different task were substantially faster than in the lexical decision task (524 vs. 653 ms for word targets). Nonetheless, what we should also note is that results of Experiment 2 show a small lexicality effect for "same" responses (i.e., a sign of lexical involvement): Responses to words were 37 ms faster than responses to nonwords, $F_1(1,28) = 70.89$, $MSe = 1175$, $p < .001$; $F_2(1,200) = 62.77$, $MSe = 2317$, $p < .001$, and responses to words were more accurate than responses to nonwords, $F_1(1,28) = 10.98$, $MSe = 27.9$, $p < .004$; $F_2(1,200) = 12.74$, $MSe = 34.4$, $p < .001$. One reason of this small "lexicality" effect is that, in a same–different task, it is easier to encode words than nonwords (see Gomez et al., 2008, for a similar pattern in a perceptual two-choice matching task).

Finally, as in prior research with the same–different task (Norris & Kinoshita, 2008), we failed to find any priming effects in the "different" response condition. As noted by Norris and Kinoshita

Table 2
Mean response times (in ms), standard error response times (underlined) and percentage of errors (in parentheses) for word and nonword targets in Experiment 2.

	Type of prime		
	TL	RL	TL priming
SAME responses			
Word trials			
Consonant–consonant	507 <u>16.0</u> (5.1)	534 <u>17.5</u> (5.9)	27 (0.8)
Vowel–vowel	514 <u>17.0</u> (4.6)	541 <u>16.0</u> (6.2)	27 (1.6)
Nonword trials			
Consonant–consonant	548 <u>17.8</u> (6.0)	546 <u>18.2</u> (7.7)	−2 (1.7)
Vowel–vowel	562 <u>19.3</u> (7.7)	588 <u>20.8</u> (9.4)	26 (1.7)
Different responses			
Word trials			
Consonant–consonant	560 <u>18.1</u> (4.9)	564 <u>17.7</u> (3.5)	4 (1.4)
Vowel–vowel	563 <u>18.3</u> (4.0)	557 <u>20.1</u> (2.9)	−6 (1.1)
Nonword trials			
Consonant–consonant	566 <u>17.1</u> (3.6)	563 <u>16.7</u> (4.1)	−3 (0.5)
Vowel–vowel	554 <u>15.5</u> (3.5)	559 <u>17.7</u> (4.2)	5 (0.7)

Note: TL, transposed-letter prime, RL, replacement-letter prime.

(2008), this is hardly surprising because both the transposed-letter prime and the replacement-letter prime provide letter information that is different from the probe.

There is one caveat, though: when examining the results for the nonword stimuli, V–V transpositions were more effective as primes than C–C transpositions in the latency data. However, rather than speculating for the potential reasons responsible for the lack of priming in this condition, we believe that it is important to replicate the basic findings of Experiment 2 – it may well be a type II error. Experiment 3 has two basic aims. Firstly, we believe that it is important to replicate a novel finding (i.e., the presence of a transposed-letter priming effect of similar magnitude for consonants and vowels on word stimuli), and secondly, it is important to re-examine whether the surprising null effect of C–C transpositions on nonword stimuli in Experiment 2 was the right outcome or just an empirical anomaly. Furthermore, in Experiment 3, we increased the number of selected items and included two additional (control) priming conditions: an identity prime and an unrelated prime. Previous research with the same–different task has shown that the transposed-letter priming condition behaves very similarly to the identity priming condition, whereas the unrelated priming condition produces slow and error-prone responses – relative to the replacement-letter condition (Norris & Kinoshita, 2008).

4. Experiment 3 (same–different task)

4.1. Method

4.1.1. Participants

Twenty undergraduates from the Universidad del País Vasco participated voluntarily in the experiment. All of them had either normal or corrected-to-normal vision and were native speakers of Spanish.

4.1.2. Materials

For the ‘‘same” response condition, we selected 160 word targets and 160 nonword targets of six and seven letters long (mean number of letters: 6.2) from the Spanish database (Davis & Perea, 2005). In eighty of these words (mean word frequency per one million words: 15.8, range: 0.18–168; mean Coltheart's N: 1.7, in the Davis & Perea, 2005, count), for each probe (e.g., reptil-######-REPTIL) the primes were (1) the same to the target except for a transposition of two adjacent internal consonants (TL-consonant condition), retpil-REPTIL, (2) the same except for the replacement of the corresponding internal consonants (RL-consonant condition), redjil-REPTIL, (3) a word unrelated with the target but with the same frequency and length (unrelated condition), flanco-REPTIL, or (4) the same as target word (identity condition), reptil-REPTIL. In the remaining eighty words (mean word frequency per one million words: 15.5, range: 0.18–162; mean Coltheart's N: 1.7, in the Davis & Perea, 2005, count), for each probe (e.g., croata–######–CROATA) the primes were (1) the same to the target except for a transposition of two internal vowels (TL-vowel condition), craota–CROATA, (2) the same except for the substitution of the corresponding internal vowels (RL-consonant condition), creita–CROATA, (3) a word unrelated with the target but with the same frequency and length (unrelated condition), espiar–CROATA, or 4) the same as the target word (identity condition), croata–CROATA. For the ‘‘different” response condition, we selected 160 word targets that were matched in length and frequency to the 160 words of the ‘‘same” condition. The construction of the transposed-letter, replacement-letter, unrelated, and identity primes was identical to that of the critical items used in the ‘‘same” response condition. Each target was paired with 160 additional probe words that were different (but equal in length) from the target (e.g., probe: cirios, target: TECLAS). We did the same with the 160 nonword targets for the ‘‘different” response condition. We created four lists that were counterbalanced across participants, so that each target was seen by a participant once, and appeared in each prime condition once across every four participants.

4.1.2. Procedure

This was the same as in Experiment 2.

4.2. Results

Incorrect responses (4.7% of trials) and response times greater than 1500 ms (less than 0.8% of the trials) were excluded from the latency analysis. The mean response times and error percentages from the participant analysis for the word and nonword data are presented in Table 3. ANOVAs based on the participant and item mean correct response times and error rates were conducted based on a 4 (Prime type: identity, transposition, replacement, unrelated) $\times$ 2 (Letter type: consonants, vowels) $\times$ 2 (list: list 1, list 2) design. As in Experiment 2, we analyzed separately ‘‘same” and ‘‘different” responses.

Table 3
Mean response times (in ms), standard error response times (underlined) and percentage of errors (in parentheses) for word and nonword targets in Experiment 3.

	Type of prime			
	ID	TL	RL	Unrelated
SAME responses				
Word trials				
Consonant–consonant	460 21.2 (2.3)	465 19.7 (3.0)	487 21.6 (6.0)	541 19.6 (18.3)
Vowel–vowel	470 21.5 (1.3)	475 22.1 (2.0)	502 22.3 (4.5)	558 23.1 (16.0)
Nonword trials				
Consonant–consonant	492 21.6 (2.5)	490 21.8 (2.6)	511 23.1 (4.9)	565 21.7 (14.5)
Vowel–vowel	502 26.1 (5.5)	506 25.6 (4.8)	528 25.5 (6.0)	571 24.0 (15.5)
Different responses				
Word trials				
Consonant–consonant	511 17.4 (4.2)	516 19.5 (3.2)	508 20.3 (4.0)	515 19.2 (2.0)
Vowel–vowel	516 19.4 (2.5)	515 19.7 (2.2)	512 19.0 (3.7)	523 19.8 (1.2)
Nonword trials				
Consonant–consonant	518 19.2 (2.8)	521 20.4 (1.5)	511 18.9 (2.3)	511 20.2 (2.0)
Vowel–vowel	522 20.0 (1.5)	520 19.8 (2.0)	524 22.4 (2.3)	517 18.1 (2.0)

Note: ID, identity prime; TL, transposed-letter prime; RL, replacement-letter prime.

4.2.1. "Same" responses

4.2.1.1. Word data. In the latency data, the ANOVA showed a main effect of Prime type, $F_1(3,48) = 109.91$, $MSe = 547$, $p < .001$; $F_2(3,456) = 89.53$, $MSe = 3510$, $p < .001$, and a main effect of Letter type, $F_1(1,16) = 13.08$, $MSe = 513$, $p < .003$; $F_2(1,152) = 12.44$, $MSe = 3752$, $p < .001$. There were no signs of an interaction between the two factors (both *F*s < 1) (note that if we only include in the Prime type factor the transposed-letter priming condition and the replacement-letter condition, the ANOVA on the latency data also fails to show any trends of an interaction between the two factors, both *F*s < 1). Planned comparisons showed the usual transposed-letter priming effect, $F_1(1,16) = 8.62$, $MSe = 379$, $p < .01$; $F_2(1,152) = 51.0$, $MSe = 2776$, $p < .001$. Furthermore, the transposed-letter condition did not differ from the identity condition, both *F*s < 1. Finally, the unrelated condition showed longer latencies than the replacement-letter condition, $F_1(1,16) = 9.37$, $MSe = 542$, $p < .008$; $F_2(1152) = 91.7$, $MSe = 4034$, $p < .001$.

The ANOVA on the error data showed a main effect of Prime type, $F_1(3,48) = 30.42$, $MSe = 547$, $p < .001$; $F_2(3,456) = 66.40$, $MSe = 1810$, $p < .001$, and a marginal main effect (in the analysis by participants) of Letter type, $F_1(1,16) = 3.48$, $MSe = 23.75$, $p = .08$; $F_2(1,152) = 2.56$, $MSe = 129.3$, $p = .11$. There were no signs of an interaction between the two factors, both *F*s < 1. Planned comparisons showed a transposed-letter priming effect (relative to the replacement-letter control), $F_1(1,16) = 6.96$, $MSe = 21.72$, $p < .02$; $F_2(1,152) = 9.21$, $MSe = 65.7$, $p < .004$. The difference between the identity condition and the transposed-letter condition was not significant (both *p*s > .15). Finally, error rates were substantially higher in the unrelated condition than in the replacement-letter condition, $F_1(1,16) = 32.82$, $MSe = 85.94$, $p < .001$; $F_2(1,152) = 54.63$, $MSe = 206.5$, $p < .001$.

4.2.1.2. Nonword data. In the latency data, the ANOVA showed a main effect of Prime type, $F_1(3,48) = 53.90$, $MSe = 813$, $p < .001$; $F_2(3,456) = 60.99$, $MSe = 3244$, $p < .001$, and a main effect of Letter type, $F_1(1,16) = 4.74$, $MSe = 1137$, $p < .05$; $F_2(1,152) = 3.70$, $MSe = 3956$, $p < .05$. There were no signs of an interaction between the two factors (both *F*s < 1) (note that if we only include in the Prime type factor the transposed-letter priming condition and the replacement-letter condition, the ANOVA on the latency data also fails to show any trends of an interaction between the two factors, both *F*s < 1). Planned comparisons showed that the usual transposed-letter priming effect, $F_1(1,16) = 23.96$, $MSe = 384$, $p < .001$; $F_2(1,152) = 10.31$, $MSe = 2817$, $p < .001$. Furthermore, the transposed-letter condition did not differ from the identity condition, both *F*s < 1. Finally, the unrelated condition showed longer latencies than the replacement-letter condition, $F_1(1,16) = 37.17$, $MSe = 1284$, $p < .001$; $F_2(1,152) = 69.37$, $MSe = 3491$, $p < .001$.

The ANOVA on the error data showed a main effect of Prime type, $F_1(3,48) = 12.76$, $MSe = 90.19$, $p < .001$; $F_2(3,456) = 33.58$, $MSe = 114.0$, $p < .001$. The main effect of Letter type was not significant, both *p*s > .10. More important, there were no signs of an interaction between the two factors, both *F*s < 1. Planned comparisons failed to show a significant transposed-letter priming effect (relative to the replacement-letter control), both *p*s > .15, or any differences between the identity condition and the transposed-letter condition (both *p*s > .15). Finally, error rates were substantially higher in the unrelated condition than in the replacement-letter condition, $F_1(1,16) = 13.52$, $MSe = 134.5$, $p < .001$; $F_2(1,152) = 33.10$, $MSe = 177.6$, $p < .001$.

4.2.2. "Different" responses

4.2.2.1. Word data. None of the effects was significant in the latency/error data.

4.2.2.2. Nonword data. None of the effects was significant in the latency/error data, except for the main effect of Letter type in the latency data (in the analysis by participants), $F_1(1,16) = 4.58$, $MSe = 230.5$, $p < .05$; $F_2(1,152) = 1.05$, $MSe = 3016$, $p > .15$.

As in Experiment 2, we found a robust transposed-letter priming effect with "same" responses, but not with "different" responses (also replicating Norris & Kinoshita, 2008). More important for the present purposes, this transposed-letter priming effect was unaffected by the consonant/vowel status of the transposed-letters. Furthermore, the same pattern of priming effects appears for both word and nonword stimuli: the transposed-letter priming effect was around 21–25 ms for word and nonword stimuli – this strongly suggests that the lack of a transposed-letter priming effect for consonant transpositions in the nonword stimuli from Experiment 2 was a type II error.

Furthermore, as in the experiments reported by Norris and Kinoshita (2008), Kinoshita & Norris, in press) with English stimuli, we found that the identity priming and the transposed-letter priming behaved in a similar way with Spanish stimuli, and that the unrelated condition produced slower (and more error prone) responses than the replacement-letter condition. This finding strongly suggests that the early stages of letter position coding are, to a large degree, independent of language – despite the obvious differences between the English and the Spanish orthography (see also Lupker et al., 2008, for a similar point).

As in Experiment 2, masked priming effects were restricted to the "same" response condition –there were no signs of a priming effect with the "different" response condition. However, one could argue that neither in Experiments 2 and 3 nor in the experiments of Norris and Kinoshita (2008), Kinoshita & Norris, in press) there is ever a condition in which probe and prime are orthographically related with a "different" response. Perhaps the absence of priming effects for the "different" response condition in the cross-case same/different task was due to the fact that participants based their responses on the relationship between probe and prime rather than between prime and target.

To avoid this potential confound, Experiment 4 examines the presence of transposed-letter priming effects when probe/prime similarity has zero validity for predicting whether the target is the same or different from the probe. More specifically, for "same" trials, we compare reptil-retpil-REPTIL (probe, prime, target) vs. reptil-redjil-REPTIL, whereas for "different" trials we compare lanzar-laznar-MÁRMOL vs. lanzar-lamrar-MÁRMOL. Under these conditions, the relationship between probe and prime cannot be used to predict whether the response is going to be "same" or "different" (i.e., a zero contingency experiment). (As in Experiments 1–3, we again compare the effects of two consonant transpositions vs. two vowel transpositions.) In terms of the Bayesian Reader model (Kinoshita & Norris, in press; Norris & Kinoshita, 2008), the pattern of masked priming effects under "zero contingency" (Experiment 4) in the cross-case same/different task should be the same as in "standard" conditions (Experiments 2 and 3): a robust transposed-letter priming effect for "same" responses and a negligible/null effect for "different" responses.

5. Experiment 4 (same–different task: zero contingency)

5.1. Method

5.1.1. Participants

Twenty undergraduates from the Universitat de València participated voluntarily in the experiment. All of them had either normal or corrected-to-normal vision and were native speakers of Spanish.

5.1.2. Materials

For the "same" response condition, we selected 80 word targets and 80 nonword targets from Experiment 3. In forty of these words (mean word frequency per one million words: 10.4, range: 3.2–51.4; mean Coltheart's *N*: 0.7, in the Davis & Perea, 2005, count), for each probe (e.g., reptil) the primes were (1) the same to the prime/target except for a transposition of two adjacent internal consonants (TL-consonant condition), retpil-REPTIL, (2) the same except for the replacement of the corresponding internal consonants (RL-consonant condition), redjil-REPTIL. In the remaining forty words (mean word frequency per one million words: 13.8, range: 2.5–116.2; mean Coltheart's N: 0.7, in the Davis & Perea, 2005, count), for each probe (e.g., croata) the primes were (1) the same to the prime/target except for a transposition of two internal vowels (TL-vowel condition), craota–CROATA, 2) the same except for the substitution of the corresponding internal vowels (RL-consonant condition), creita–CROATA.

For the "different" response condition, we selected another set of 80 word targets that were matched in length, N and frequency to the 80 words of the "same" response. In forty of these words, the primes were (1) the same to the probe except for a transposition of two adjacent internal consonants (TL-consonant condition), e.g., probe: lanzar, prime: laznar, target: MÁRMOL, (2) the same except for the replacement of the corresponding internal consonants (RL-consonant condition), e.g., probe: lanzar, prime: lamrar, target: MÁRMOL. In the remaining forty words, for each probe (e.g., croata–######–CROATA) the primes were (1) the same to the probe except for a transposition of two internal vowels (TL-vowel condition), e.g., probe: etíope, prime: etoípe, target: ACUOSO, or (2) the same except for the substitution of the corresponding internal vowels (RL-consonant condition), e.g., probe: etíope, prime: etuape, target: ACUOSO. We did the same with the 80 nonword targets for the "different" response condition. We created two lists that were counterbalanced across participants, so that each target was seen by a participant once, and appeared in each prime condition once across every four participants.

5.1.2. Procedure

This was the same as in Experiments 2 and 3.

5.2. Results

Incorrect responses (5.8% of trials) and response times greater than 1500 ms (less than 1% of the trials) were excluded from the latency analysis. The mean response times and error percentages from the participant analysis for the word and nonword data are presented in Table 4. The experimental design was the same as in Experiment 2. We analyzed separately "same" and "different" responses.

5.2.1. "Same" responses

5.2.1.1. Word data. In the latency data, responses to words preceded by a transposed-letter prime were 23 ms faster than the responses to words preceded by a replacement-letter prime, $F_1(1,18) = 13.24$, $MSe = 759$, $p < .001$; $F_2(1,76) = 18.51$, $MSe = 1278$, $p < .001$. In addition, words containing a consonant cluster were read 21 ms faster than words that contained a vowel cluster, $F_1(1,18) = 26.36$, $MSe = 335$, $p < .001$; $F_2(1,76) = 10.70$, $MSe = 1736$, $p < .002$. More important, there were no trends of an interaction effect (both Fs < 1): the magnitude of the transposed-letter priming effect was very similar for consonant and vowel transpositions (25 vs. 20 ms, respectively).

The ANOVA on the error data showed a transposed-letter priming effect in the participant analysis, $F_1(1,18) = 5.12$, $MSe = 115$, $p < .03$; $F_2(1,76) = 3.24$, $MSe = 43$, $p = .07$. Words preceded by a transposed-letter prime showed a lower error rate than words preceded by a replacement-letter prime (3.6 vs. 5.3% of errors, respectively). The other effects were not significant.

5.2.1.2. Nonword data. Responses to nonwords preceded by a transposed-letter prime were 24 ms faster than responses to nonwords preceded by a replacement-letter prime, $F_1(1,18) = 26.31$, $MSe = 4291$, $p < .001$; $F_2(1,76) = 24.72$, $MSe = 1398$, $p < .001$: In addition, nonwords containing a consonant cluster were read 21 ms faster than words that contained two vowels. $F_1(1,18) = 11.93$, $MSe = 773$, $p < .003$; $F_2(1,76) = 4.41$, $MSe = 2596$, $p < .03$. Again, there were no signs of an interaction between these two factors – the transposed-letter priming effects for consonants and for vowels were 27 and 21 ms, respectively.

The ANOVA on the error data only showed that nonwords preceded by a transposed-letter prime showed a lower error rate than words preceded by a replacement-letter prime (4.6 vs. 6.0% of errors, respectively), $F_1(1,18) = 40.13$, $MSe = 4$, $p < .003$; $F_2(1,76) = 3.44$, $MSe = 47$, $p = .06$. The other effects were not significant.

5.2.2. "Different" responses

5.2.2.1. Word data. The ANOVA on the latency data failed to reveal any significant effects (all ps > .2).

The ANOVA on the error data only showed that the interaction between Prime type and Letter type was significant in the analysis

Table 4
Mean response times (in ms), standard error response times (underlined) and percentage of errors (in parentheses) for word and nonword targets in Experiment 4.

	Type of prime		
	TL	RL	TL priming
SAME responses			
Word trials			
Consonant–consonant	447 21.9 (2.8)	471 19.6 (5.0)	24 (2.2)
Vowel–vowel	470 22.9 (4.5)	490 21.6 (5.6)	20 (1.1)
Nonword trials			
Consonant–consonant	485 21.8 (4.0)	512 24.0 (5.2)	27 (1.2)
Vowel–vowel	510 25.5 (5.2)	530 26.9 (6.8)	20 (1.6)
Different responses			
Word trials			
Consonant–consonant	538 23.2 (3.8)	527 23.1 (4.8)	-11 (1.0)
Vowel–vowel	540 20.2 (8.0)	532 24.0 (4.2)	-8 (-3.8)
Nonword trials			
Consonant–consonant	536 22.8 (3.5)	529 24.2 (3.3)	-7 (-0.2)
Vowel–vowel	543 21.4 (2.9)	536 23.7 (2.3)	-7 (-0.6)

Note: TL, transposed-letter prime; RL, replacement-letter prime.

by items, $F_1(1,18) = 3.94$, $MSe = 29.6$, $p = .062$; $F_2(1,76) = 4.82$, $MSe = 42.0$, $p < .05$.

5.2.2.2. Nonword data. The ANOVA on the latency data failed to reveal any significant effects (all $ps > .19$).

The ANOVA on the error data only showed that the effect of Letter type approached significance in the analysis by participants, $F_1(1,18) = 3.83$, $MSe = 3.6$, $p = .066$; $F_2(1,76) = 1.57$, $MSe = 25.5$, $p > .20$.

As in Experiments 2 and 3, we found a robust transposed-letter priming effect for both consonant and vowel transpositions for "same" responses, while there were no clear signs of a transposed-letter priming effect for "different" responses. Thus, the pattern of transposed-letter priming effects was remarkably similar under "standard" conditions (Experiments 2 and 3) and under a "zero contingency" condition (Experiment 4). We should note here that Kinoshita and Norris (submitted for publication) failed to find an identity priming effect for "different" responses under a "zero contingency" condition when the primes were masked – in their experiment, prime diagnosticity only played a role when the primes were visible.

6. General discussion

The results of the present masked priming experiments provide important clues on whether the brain encodes differently letter position for vowels and consonants. In a lexical decision task (Experiment 1), the transposed-letter priming effect to target words was greater for primes formed by transposing consonants than for primes formed by transposing vowels, thus replicating the pattern reported by Perea and Lupker (2004) and Lupker et al. (2008). More important, using the same materials in a low-level perceptual task (a cross-case same–different task; Experiments 2–4), the transposed-letter priming effect for word stimuli was essentially of the same magnitude for C–C and V–V transpositions. Furthermore, the fact that nonword stimuli show robust masked priming effects in the cross-case same–different task – which is a task unaffected by phonology (Besner et al., 1984; Norris & Kinoshita, 2008) – strongly suggests that this task taps very early prelexical processes. Finally, prime diagnosticity had no effect on the magnitude of the transposed-letter priming effect (Experiment 4). Therefore, the present findings are consistent with the idea that letter position coding takes place before the consonant/vowel distinction starts to matter. We examine the implications of these findings in the following paragraphs.

As stated in the Introduction, Perea and Lupker (2004) indicated that the presence of a greater transposed-letter priming effect for consonant transpositions than for vowel transpositions in lexical decision posed a serious problem for the input coding schemes of models that successfully deal with transposed-letter effects (e.g., SOLAR model, SERIOL model, open-bigram model, overlap model, and LCD model). None of these models has a mechanism for explaining why transposed-letter priming effects should vary as a function of whether the letters in question are vowels or consonants. Therefore, none of these models can easily accommodate the results with the masked priming lexical decision task reported by Perea and Lupker (2004), by Lupker et al. (2008), or Experiment 1 in the present study.

Obviously, before amending these orthographic coding schemes, it is important to make sure that the consonant/vowel dissociation occurs across a variety of tasks that tap early visual word processing – and not just due to a given laboratory word identification task (i.e., lexical decision). To reiterate, the presence of a similar transposed-letter priming effect for C–C and V–V transpositions in paradigms that tap very early processing strongly would suggest that letter position coding occurs before the consonant/vowel distinction starts to matter. As indicated in the Introduction, Johnson (2007) failed to find any signs of dissociation between consonant and vowels transpositions with a parafoveal priming manipulation in the context of normal silent reading. Johnson suggested that parafoveal effects would reflect low-level processing which occurs "before the encoding of a vowel/consonant label and the phonological attachment of letters to sounds". Here, we have extended this observation to a foveal presentation (via masked primes) and a low-level perceptual task: the cross-case same–different task (Experiments 2–4). In the cross-task same–different task (Experiments 2–4), we found a large (around 20–27 ms) transposed-letter priming effect for word targets, which occurred independently of whether the transposed-letters were consonants or vowels (note that these materials in a lexical decision task produced the expected modulation of the transposed-letter priming effect by consonant/vowel status). Finally, this outcome is also consistent with the findings of Carreiras et al. (2007), in which the ERP waves in early time windows were similar to transposed-letter consonant pseudowords (*relovution*) and to transposed-letter vowel pseudowords (*revulotion*), and it was only in late time windows (and in the lexical decision times) that there was a dissociation between consonant and vowel transpositions. Taken together, these findings strongly suggest that letter position coding occurs before the consonant/vowel distinction starts to matter.

Importantly, in terms of the Bayesian Reader model (Norris, 2006; Norris & Kinoshita, 2008), the divergence across masked priming effects in lexical decision and cross-case same–different tasks is due to the nature of decision required by the task and of the representations used to make the decision. In the Bayesian Reader model, priming effects depend on the hypotheses that support the decision required to make a specific response – note that this idea readily explains why the pattern of data of the letter-matching experiments of Norris and Kinoshita (2008) varied as a function of the task instructions. More specifically, Norris and Kinoshita (2008) used prime-target letter pairs that were cross-case similar (e.g., c/C) and dissimilar (e.g., a/A). When the participants' decision was required at the level of abstract letter identity (responding "*same*" to a–A or c–C), the magnitude of repetition priming effect was not modulated by cross-case letter similarity. In contrast, when decision was at the level of case-specific letter identity (responding "*same*" to a–a or C–C but "*different*" to a–A), only similar letters showed a priming effect. Thus, physical similarity between the probe and the prime is not the responsible factor for the presence of a priming effect in a same–different task when the decision is at the level of abstract level identities – as was the case in the present experiments. Finally, as predicted by the Bayesian Reader model, prime diagnosticity does not have an effect on the magnitude of masked transposed-letter priming (Experiment 4).

To explain the dissociation between consonant/vowel processing in lexical decision, the Bayesian Reader model would need to assume some dissociation between vowel and consonant processing during lexical access. What is then the locus of the consonant/vowel dissociation in masked priming (and single-presentation) lexical decision? One obvious candidate is sublexical phonology – keep in mind that unlike lexical decision, the same–different task does not seem to be affected by phonological processing (see Besner et al., 1994; Kinoshita & Norris, in press). As noted by Perea and Lupker (2004), the transposition of two consonants appears to preserve more of the sound of the original word than the transposition of two vowels (e.g., compare the TL-consonant nonword *RELOVUCION* to its base word, *REVOLUCION*, in contrast to the TL-vowel nonword *REVULOCION*). Indeed, there is some (fragile) empirical evidence of phonological influences in transposed-letter lexical decision experiments. In a single-presentation lexical decision experiment, Perea and Carreiras (2006a; Experiment 3) found a small effect of phonology (i.e., a difference between pseudowords like *RELOBUCIÓN* and *RELODUCIÓN*; note that B and V are pronounced the same in Spanish). However, this effect was restricted to the false alarm rates (an effect of around 5%). In addition, Perea and Carreiras (2008) reported a slightly higher masked transposed-letter priming effect (at a 50 ms SOA) when the internal transposition involved the letter "*c*" and kept the same sound (23 ms, *cholocate-CHOCOLATE*) than when the internal transposition involved the letter "*c*" and modified its sound (16 ms, *racidal-RADICAL*) – the critical interaction was not significant, though. A recent paper of Frankish and Turner (2007) has been taken as more compelling evidence of phonological involvement in letter position encoding. Frankish and Turner found that (briefly presented) nonwords formed by transposing two letters were more likely to be misclassified as words if the nonwords were unpronounceable (*sotrm*; i.e., via in illegal bigram) than if they were pronounceable (*strom*; via a legal bigram). Interestingly, Frankish and Turner found that the presence of this "bigram frequency" effect in letter transpositions occurs in normal individuals but not in dyslexic participants. In Frankish and Turner's view, phonological feedback modulates transposed-letter effects: when the letter transposition forms a legal/pronounceable sequence, the activation of the corresponding phonemes can then stabilize the transposed-letter sequence via feedback connections from phonemes to letters in a later stage. Consistent with this view, Perea and Carreiras (2008) found that masked transposed-letter priming effects were greater when the transposed-letter primes formed an illegal letter string (e.g., *comsos–COSMOS*; 'ms' is an illegal bigram in Spanish) than when the transposed-letter primes formed a legal letter string (e.g., *vebral-VERBAL*; see Frankish & Barnes, 2008; for a parallel finding with English stimuli). Finally, a caveat on the phonological evidence based on bigram frequency in the above-cited experiment: As Grainger (2008) indicated, given that "orthotactics was again (and inevitably so) confounded with pronounceability (...), it would appear premature to draw any firm conclusions for the time being" (p. 14). In any case, rather than speculating on the underlying reasons of the absence of a V–V transposition effect in masked priming lexical decision, what is clear is that this finding cannot be taken as a basis for amending the front-end of the orthographic coding schemes of models of visual word recognition.

Thus, the empirical evidence is consistent with the idea that letter position coding takes place very early in process, before the distinction between vowels and consonants starts to matter. Interestingly, the presence of similar response times for the identity condition and for the transposed-letter condition (Experiment 3; see also Kinoshita & Norris, in press) strongly suggests that not only that letter identity and letter position do not go hand in hand, but also that, at the earliest stages of visual word recognition, information on letter order is not as accurately encoded as information on letter identity. Of course, at some (later) processing stage, vowels and consonants seem to play a different role in lexical access – presumably at a phonological stage. Future implemented versions of the SERIOL, SOLAR, open-bigram, overlap, and LCD models should be expanded to account for the consonant/vowel status of the letters, and more in general, for phonological processing. Note that at present, these models cannot accommodate the presence of phonological effects in lexical decision and normal reading (e.g., the conal-CANAL effect; see Pollatsek, Perea, & Carreiras, 2005; see Whitney & Cornelissen, 2005, for an initial expansion of the SERIOL model to phonological processing). What we should also note is that although the consonant/vowel difference is assumed to be qualitative by a number of authors (Berent & Perfetti, 1995; Caramazza, Chialant, Capasso, & Miceli, 2000), this assumption may not be completely necessary (see Monaghan & Shillcock, 2003; Monaghan & Shillcock, 2007, for computational evidence and for a phonological account of letter processing). But, again, rather than speculating on the specific details of the consonant/vowel dissociation of visually presented words, the critical implication of the present findings is that the front-end of the recently proposed orthographic coding schemes does not need to be modified.

In sum, the present experiments have shown that letter position coding occurs before the consonant/vowel distinction begins to matter. Thus, the front-end of the recently proposed input coding schemes does not need to consider consonant/vowel differences. More empirical and theoretical work is necessary to understand how and why vowels and consonants differ in the time course of lexical access as well as the intricacies underlying the different tasks that employ the masked priming paradigm.

Acknowledgements

This research was partially supported by Grants from the Spanish Ministry of Science and Innovation (PR2007-0201, PSI2008-04069/PSIC, and CONSOLIDER-INGENIO2010_CSD2008-00048). Joana Acha was the recipient of a post-graduate grant (BFI05.33) from the Basque Government. We thank Carol Whitney and Jonathan Grainger for very helpful feedback on a previous version of the paper.

References

Acha, J., & Perea, M. (2008). The effect of neighborhood frequency in reading: Evidence with transposed-letter neighbors. *Cognition, 108*, 290–300.

Berent, I., & Marom, M. (2005). The skeletal structure of printed words: Evidence from the Stroop task. *Journal of Experimental Psychology: Human Perception and Performance, 31*, 328–338.

Berent, I., & Perfetti, C. A. (1995). A rose is a REEZ: The two cycles model of phonology assembly in reading English. *Psychological Review, 102*, 146–184.

Besner, D., Coltheart, M., & Davelaar, E. (1984). Basic processes in reading: Computation of abstract letter identities. *Canadian Journal of Psychology, 38*, 126–134.

Bruner, J. S., & O'Dowd, D. (1958). A note on the informativeness of parts of words. *Language and Speech, 1*, 98–101.

Buchwald, A., & Rapp, B. (2006). Consonants and vowels in orthographic representation. *Cognitive Neuropsychology, 23*, 308–337.

Caramazza, A., Chialant, D., Capasso, D., & Miceli, G. (2000). Separable processing of consonants and vowels. *Nature, 403*, 428–430.

Carreiras, M., Gillon-Dowens, M., Vergara, M., & Perea, M. (in press). Are vowels and consonants processed differently? ERP evidence with a delayed letter paradigm. *Journal of Cognitive Neuroscience*.

Carreiras, M., Vergara, M., & Perea, M. (2007). ERP correlates of transposed-letter similarity effects: Are consonants processed differently from vowels? *Neuroscience Letters, 419*, 219–224.

Castles, A., Davis, C., & Forster, K. I. (2003). Word recognition development in children: Insights from masked-priming. In S. Kinoshita & S. Lupker (Eds.), *Masked priming: State of the art* (pp. 345–360). Hove, UK: Psychology Press.

Christianson, K., Johnson, R. L., & Rayner, K. (2005). Letter transpositions within and across morphemes. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*, 1327–1339.

Coltheart, M., Rastle, K., Conrad, P., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108*, 204–256.

Cutler, A., Sebastián-Gallés, N., Soler-Vilageliu, O., & van Ooijen, B. (2000). Constraints of vowels and consonants on lexical selection: Cross-linguistic comparisons. *Memory and Cognition, 28*, 746–755.

Davis, C. J. (1999). *The self-organising lexical acquisition and recognition (SOLAR) model of visual word recognition*. Unpublished doctoral dissertation. University of New South Wales.

Davis, C. J., & Bowers, J. S. (2006). Contrasting five theories of letter position coding. *Journal of Experimental Psychology: Human Perception and Performance, 32*, 535–557.

Davis, C. J., & Perea, M. (2005). Buscapalabras: A program for deriving orthographic and phonological neighbourhood statistics and other psycholinguistic indices in Spanish. *Behavior Research Methods, 37*, 665–671.

Dehaene, S., Cohen, L., Sigman, M., & Vinckier, F. (2005). The neural code for written words: A proposal. *Trends in Cognitive Sciences, 9*, 335–341.

Duñabeitia, J. A., Gutiérrez, E., & Mena, E. (2006). Influencia de la frecuencia de las letras en el efecto de facilitación por transposición de letras. *Cognitiva, 18*, 135–144.

Duñabeitia, J. A., Perea, M., & Carreiras, M. (2007). Do transposed-letter similarity effects occur at a morpheme level? Evidence for ortho-morphological decomposition. *Cognition, 105*, 691–703.

Forster, K. I. (1998). The pros and cons of masked priming. *Journal of Psycholinguistic Research, 27*, 203–233.

Forster, K. I., Davis, C., Schoknecht, C., & Carter, R. (1987). Masked priming with graphemically related forms: Repetition or partial activation? *Quarterly Journal of Experimental Psychology, 39*, 211–251.

Forster, J. C., & Forster, K. I. (2003). DMDX: A Windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, and Computers, 35*, 116–124.

Frankish, C., & Barnes, L. (2008). Lexical and sublexical processes in the perception of transposed-letter anagrams. *Quarterly Journal of Experimental Psychology, 61*, 381–391.

Frankish, C., & Turner, E. (2007). SIHGT and SUNOD: The role of orthography and phonology in the perception of transposed letter anagrams. *Journal of Memory and Language, 56*, 189–211.

Gibbs, P., & Van Orden, G. C. (1998). Pathway selection's utility for control of word recognition. *Journal of Experimental Psychology: Human Perception & Performance, 24*, 1162–1187.

Gomez, P., Ratcliff, R., & Perea, M. (2007). A model of the go/no-go task. *Journal of Experimental Psychology: General, 136*, 389–413.

Gomez, P., Ratcliff, R., & Perea, M. (2008). The overlap model: A model of letter position coding. *Psychological Review, 115*, 577–601.

Grainger, J. (2008). Cracking the orthographic code: An introduction to the special issue on orthographic processes in reading. *Language and Cognitive Processes, 23*, 1–35.

Grainger, J., & Jacobs, A. M. (1996). Orthographic processing in visual word recognition: A multiple read-out model. *Psychological Review, 103*, 518–565.

Grainger, J., & Van Heuven, W. J. B. (2003). Modeling letter position coding in printed word perception. In P. Bonin (Ed.), *The mental lexicon* (pp. 1–24). New York: Nova Science Publishers.

Guerrera, C., & Forster, K. (2007). Masked form priming with extreme transposition. *Language and Cognitive Processes, 23*, 117–142.

Johnson, R. L. (2007). The flexibility of letter coding: Nonadjacent letter transposition effects in the parafovea. In R. van Gompel, M. Fisher, W. Murray, & R. L. Hill (Eds.), *Eye movements: A window on mind and brain* (pp. 425–440). Oxford: Elsevier.

Johnson, R. L., Perea, M., & Rayner, K. (2007). Transposed-letter effects in reading: Evidence from eye movements and parafoveal preview. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 209–229.

Kinoshita, S., & Norris, D. (in press). Transposed-letter priming of pre-lexical orthographic representations. *Journal of Experimental Psychology: Learning Memory and Cognition*.

Kinoshita, S., & Norris, D. (submitted for publication). Masked priming effect reflects evidence accumulated by the prime.

Lee, H-W., Rayner, K., & Pollatsek, A. (2001). The relative contribution of consonants and vowels to word identification in reading. *Journal of Memory and Language, 44*, 189–205.

Lupker, S. J., Perea, M., & Davis, C. J. (2005). *An investigation of the nature of input coding and lexical selection: Evidence from the masked priming paradigm*. Paper presented at the 15th annual meeting of the CSBBCS. Montréal, Canada.

Lupker, S. J., Perea, M., & Davis, C. J. (2008). Transposed letter priming effects: Consonants, vowels and letter frequency. *Language and Cognitive Processes, 23*, 93–116.

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review, 88*, 375–407.

Monaghan, P., & Shillcock, R. C. (2003). Connectionist modelling of the separable processing of consonants and vowels. *Brain and Language, 86*, 83–98.

Monaghan, P., & Shillcock, R. C. (2007). Levels of description in consonant/vowel processing: Reply to Knobel and Caramazza. *Brain and Language, 100*, 101–108.

Norris, D. (2006). The bayesian reader: Explaining word recognition as an optimal Bayesian decision process. *Psychological Review, 113*, 327–357.

Norris, D., & Kinoshita, S. (2008). Perception as evidence accumulation and Bayesian inference. Insights from masked priming. *Journal of Experimental Psychology: General, 137*, 434–455.

O'Connor, R. E., & Forster, K. I. (1981). Criterion bias and search sequence bias in word recognition. *Memory and Cognition, 9*, 78–92.

Perea, M., & Pérez, E. (in press). Beyond alphabetic orthographies: The role of form and phonology in transposition effects in Katakana. *Language and Cognitive Processes*, in press, doi:10.1080/01690960802053924.

Perea, M., & Carreiras, M. (2006a). Do transposed-letter similarity effects occur at a prelexical phonological level? *Quarterly Journal of Experimental Psychology, 59*, 1600–1613.

Perea, M., & Carreiras, M. (2006b). Do transposed-letter effects occur across lexeme boundaries? *Psychonomic Bulletin and Review, 13*, 418–422.

Perea, M., & Carreiras, M. (2006c). Do transposed-letter similarity effects occur at a syllable level? *Experimental Psychology, 53*, 308–315.

Perea, M., Duñabeitia, J. A., & Carreiras, M. (2008). R34D1NG W0RD5 W1TH NUMB3R5. *Journal of Experimental Psychology: Human Perception and Performance, 34*, 237–241.

Perea, M., & Carreiras, M. (2008). Do orthotactics and phonology constrain the transposed-letter effect? *Language and Cognitive Processses, 23*, 69–92.

Perea, M., & Estévez, A. (2008). Transposed-letter similarity effects in naming pseudowords: Evidence from children and adults. *European Journal of Cognitive Psychology, 20*, 33–46.

Perea, M., & Fraga, I. (2006). Transposed-letter and laterality effects in lexical decision. *Brain and Language, 97*, 102–109.

Perea, M., & Lupker, S. J. (2003a). Transposed-letter confusability effects in masked form priming. In S. Kinoshita & S. J. Lupker (Eds.), *Masked priming: State of the art* (pp. 97–120). Hove, UK: Psychology Press.

Perea, M., & Lupker, S. J. (2003b). Does jugde activate COURT? Transposed-letter similarity effects in masked associative priming. *Memory and Cognition, 31*, 829–841.

Perea, M., & Lupker, S. J. (2004). Can CANISO activate CASINO? Transposed-letter similarity effects with nonadjacent letter positions. *Journal of Memory and Language, 51*, 231–246.

Perea, M., Rosa, E., & Gómez, C. (2005). The frequency effect for pseudowords in the lexical decision task. *Perception and Psychophysics, 67*, 301–314.

Perry, C., Ziegler, J. C., & Zorzi, M. (2007). Nested incremental modeling in the development of computational theories: the CDP+ model of reading aloud. *Psychological Review, 114*, 273–315.

Pollatsek, A., Perea, M., & Carreiras, M. (2005). Does conal prime CANAL more than cinal? Masked phonological priming effects in Spanish with the lexical decision task. *Memory and Cognition, 33*, 557–565.

Pollatsek, A., & Well, A. (1995). On the use of counterbalanced designs in cognitive research: A suggestion for a better and more powerful analysis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 785–794.

Ratcliff, R. (1981). A theory of order relations in perceptual matching. *Psychological Review, 88*, 552–572.

Ratcliff, R., Gomez, P., & McKoon, G. (2004). A diffusion model account of the lexical decision task. *Psychological Review, 111*, 159–182.

Rayner, K. (1975). The perceptual span and peripheral cues in reading. *Cognitive Psychology, 7*, 65–81.

Rayner, K., White, S., Johnson, R. L., & Liversedge, S. (2006). Reading words with jumbled letters: There's a cost. *Psychological Science, 17*, 192–193.

Schoonbaert, S., & Grainger, J. (2005). Letter position coding in printed word perception: Effects of repeated and transposed letters. *Language and Cognitive Processes, 19*, 333–367.

Van Zandt, T., Colonius, H., & Proctor, R. W. (2000). A comparison of two response-time models applied to perceptual matching. *Psychonomic Bulletin and Review, 7*, 208–256.

White, S. J., Johnson, R. L., Liversedge, S. P., & Rayner, K. (2008). Eye movements when reading transposed text: The importance of word beginning letters. *Journal of Experimental Psychology: Human Perception and Performance, 34*, 1261–1276.

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

Whitney, C., & Cornelissen, P. (2005). Letter-position encoding and dyslexia. *Journal of Research in Reading, 28*, 274–301.