Do Transposed-Letter Similarity Effects Occur at a Syllable Level?

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Abstract. One key issue for any computational model of visual word recognition is the choice of an input coding scheme for assigning letter position. Recent research has shown that transposed-letter similarity effects occur even when the transposed letters are not adjacent (*caniso–casino*; Perea & Lupker, 2004, JML). In the present study we conducted two single-presentation lexical decision experiments to examine whether transposed-letter effects occur at a syllable level. We tested two types of nonwords: (1) nonwords created by transposing two internal CV syllables (*PRIVEMARA*; the base word is *primavera*, the Spanish for spring) and (2) nonwords created by transposing two adjacent bigrams that do not form a syllable (*PRIMERAVA*). We also created the appropriate orthographic control conditions, in which the critical letters were replaced instead of being switched. Results showed that the transposition of two syllables or two adjacent bigrams produced a quite robust (and similar) transposed-letter effect. Thus, transposed-letter effects seem to occur at an early orthographic, graphemic level, rather than at a syllable level. We examine the implications of the observed results for the input coding schemes in visual word recognition.

Keywords: letter encoding, coding scheme, lexical decision, word recognition, syllables

One common assumption in the literature on visual word recognition is that during the processing of a given word (e.g., *trail*), not only is the representation of the word itself activated, but so are the representations of similarly spelled words, such as the one-letter replacement neighbor train and the transposed-letter neighbor *trial* (e.g., Forster & Hector, 2002; Grainger & Whitney, 2004; Perea & Lupker, 2004).

In this context, there is empirical evidence that shows that transposed-letter neighbors (e.g., *trial–trail*) are highly activated in the process of lexical access, even more than one-letter replacement neighbors (*train–trail*; Andrews, 1996; Chambers, 1979; O'Connor & Forster, 1981; Perea & Lupker, 2003a; Perea, Rosa, & Gómez, 2005). More specifically, higher frequency transposed-letter (TL) neighbors inhibit responses to word stimuli to a higher degree than higher frequency replacement-letter neighbors (Andrews, 1996; Davis & Andrews, 2001). Furthermore, error rates and lexical decision times are higher for TL-nonwords than for replacement-letter nonwords (Chambers, 1979; Perea et al., 2005; Perea & Fraga, 2006). One clarifying example that shows the degree of "wordlikeness" of TL nonwords is that they may produce a high error rate (around 30–40%) in lexical decision even when the transposed letters are not adjacent—for example, *RELOVUTION* (Perea & Lupker, 2004; see also Perea & Carreiras, 2006, in press; Perea & Fraga, in press). Finally, in masked priming experiments, transposed-letter nonword primes produce not only form-priming effects relative to the appropriate orthographic control (e.g., *jugde–JUDGE* vs. *jupte–JUDGE*; Perea & Lupker, 2003b, 2004a; see also Andrews, 1996; Forster, Davis, Schoknecht, & Carter, 1987; Schoonbaert & Grainger, 2004), but also associative-priming effects (e.g., *jugde–COURT* vs. *ocaen–COURT*; Perea & Lupker, 2003a).

Most current computational models (i.e., the interactive activation model, Rumelhart & McClelland, 1982, and its extensions: the dual route cascaded model, Coltheart, Rastle, Perry, Ziegler, & Langdon, 2001; and the multiple read-out model, Grainger & Jacobs, 1996) are, however, unable to explain the presence of transposed-letter similarity effects. (Note that these models assume that letter position is perfectly encoded and, thereby, the transposed-letter *RELOVUTION* is as perceptually similar to *REVOLUTION* as is the two-letter different nonword *RETOMUTION*.) For that reason, a number of theorists have recently proposed new input coding schemes in visual word recognition (e.g., SERIOL model, Whitney, 2001; SOLAR model, Davis, 1999; open-bigram model, Grainger & van Heuven, 2003; overlap model, Gómez, Perea, & Ratcliff, 2003). It is important to note that although the choice of a coding scheme might seem to be a secondary aspect of any computational model, it has a large impact on a model's predictions (see Perea & Lupker, 2003a).

But what is the locus of transposed-letter similarity effects? Most theorists agree that these effects occur very early in the course of word processing, presumably at a graphemic level (Davis, 1999; Gómez et al., 2003; Grainger & van Heuven, 2003; Whitney, 2001). However, it has been argued that these effects may vary depending on whether the transposed letters occur within or across morphemes (Christianson, Johnson, & Rayner, 2005). This raises the question of whether transposed-letter similarity effects occur at yet another sublexical level, namely a syl-

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labic level.[1] In research on visual word recognition in Spanish, it is generally assumed that a word's syllabic neighbors are partially activated during identification of the target word via a syllable level that mediates between the letter level and the word level. For instance, Spanish words composed of two high-frequency syllables are responded to more slowly than words composed of two low-frequency syllables in lexical decision (Carreiras, Álvarez, & de Vega, 1993; Perea & Carreiras, 1998; see also Mathey & Zagar, 2002, and Conrad & Jacobs, 2004, for evidence in French and German, respectively). Converging evidence for the use of the syllable as a sublexical unit in Spanish (and in French) has also been obtained with masked primes that share a syllable with the target word (Álvarez, Carreiras, & Perea, 2004; Carreiras, Ferrand, Grainger, & Perea, 2005; Carreiras & Perea, 2002).

Given the relevant role of the syllable in Spanish, the main aim of the present study is to examine whether transposed-letter effects have a syllabic component. Indeed, there is some empirical evidence in speech production that suggests that some "syllable transposition" errors are unequivocally due to a syllable level in English (e.g., Chen, 2000) and Spanish (Pérez, Palma, & Santiago, 2001). If transposed-letter effects have a syllabic component, this would reinforce the role of the syllable as a sublexical unit that mediates lexical access. In Experiment 1, we examined the scope of transposed-letter similarity effects by transposing adjacent (internal) CV syllables (e.g., *PRIVEMARA*) from a base word (*PRIMAVERA*, the Spanish for *spring*; note that both the syllables *MA* and *VE* have been transposed). (Transposed-letter similarity effects do not occur when the initial letter is involved; Perea & Lupker, 2004.) To ascertain whether any observed transposed-letter (TL) similarity effects in Experiment 1 were indeed due to a syllabic level of processing, for the pairs of transposed letters in Experiment 2, we used syllables (TL-syllables; *PRIVEMARA* vs. the replacement-letter nonword *PRISOLURA*) or not (TL-bigrams; e.g., *PRIMERAVA* vs. the replacement-letter nonword *PRIMULINA*).

For comparison purposes, in Experiment 1 we included TL-consonant nonwords (*PRIVAMERA*) and TL-vowel nonwords (*PRIMEVARA*), along with their corresponding orthographic controls (i.e., two-letter replacement nonwords). (The experimental conditions in Experiments 1 and 2 are presented in Table 1.) These conditions also allowed us to examine how "competitive" TL-syllable nonwords are relative to the nonwords created by transposing just two consonants or two vowels. In a recent series of experiments, Perea and Lupker (2004) found that TL-consonant nonwords (e.g., *PRIVAMERA*) produced a high error rate in lexical decision (43.5% and 943 ms), much higher than that produced for a two-letter replacement condition (*PRISALERA*, 4.6% and 869 ms). The effect for the transposition of two nonadjacent vowels was somehow less dramatic (*PRIMEVARA*; 24.4% and 915 ms). Perea and Lupker argued that TL-consonant nonwords—and, to a lesser degree, TL-vowel nonwords—partially activate the lexical representations of their neighbors. Thus, additional time is needed for the activation levels to settle and for the participant to realize that no word unit is being activated over threshold. (We examine the issue of transposing consonants vs. vowels in the general discussion in this article.)

In the present experiments, we used a single-presentation lexical decision task instead of the masked priming technique. As stated previously, in a single-presentation lexical decision task, one would expect a higher rate of "word" responses and longer latencies for the (wordlike) transposed-letter nonwords than for the controls (see Perea & Lupker, 2004). The reason this "interference" technique seems more suitable to the study of transposition of syllables than the masked priming technique is that Perea and Lupker (2004) found significant transposed-letter effects for consonant transpositions (around 18–21 ms), but not for vowel transpositions (around 6 ms). Thus, it would be unlikely that one could find a reliable priming effect for syllable transpositions in a masked priming technique. Instead, transposition-letter effects with the single-presentation lexical decision task have been quite robust and sizeable (Perea & Carreiras, in press-a; Perea & Fraga, in press; Perea & Lupker, 2004).

As we show in the following analysis, the new coding schemes (e.g., SOLAR model and open-bigram model) are able to capture a difference between the TL-syllable condition and its corresponding orthographic control (*PRIVEMARA* vs. *PRISOLURA*). However, the predicted transposed-letter effects for syllable transpositions in these models would *not* be due to a syllable level. These models do not have a syllabic level of processing, and the same pattern is predicted for TL-bigram nonwords. Thus, the presence of transposed-letter similarity effects of similar magnitude for bigram transpositions and for syllable transpositions would support the predictions of these new models of letter coding. However, if transposed-letter effects occur to a larger degree for syllable transpositions than for bigram transpositions, this would definitely require some modifications in these models (i.e., the implementation of a syllable level of processing).

In the open-bigram model (Grainger & van Heuven, 2003; Grainger & Whitney, 2004), relative position is coded on the basis of a set of open-bigram units (up to a limit of two intervening letters). For instance, the open bi-

Table 1. The eight nonword conditions in the experiments

The base word would be *PRIMAVERA*	
Transposed letters (consonants)	*PRIVAMERA* (Exp. 1)
Replacement letters (consonants)	*PRISALERA* (Exp. 1)
Transposed letters (vowels)	*PRIMEVARA*
Replacement letters (vowels)	*PRIMOVURA*
Transposed letters (CV syllables)	*PRIVEMARA*
Replacement letters (CV syllables)	*PRISOLURA*
Transposed letters (bigrams)	*PRIMERAVA* (Exp. 2)
Replacement letters (bigrams)	*PRIMULINA* (Exp. 2)

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[1] In the pairs employed by Christianson et al. (in press, Experiments 1 and 2), transposition across morpheme boundaries always crossed syllable boundaries (i.e., the obtained effect could have been caused by syllable transpositions). Nonetheless, in a third experiment, they successfully controlled syllable boundaries by manipulating morpheme boundaries.

grams for the word *PRIMAVERA* would be *PR, PI, PM, RI, RM, RA, IM, IA, IV, MA, MV, ME, AV, AR, AR, VE, VR, VA, ER*, and *EA*. The higher the number of shared open-bigrams, the closer the perceptual similarity between the two strings of letters. The TL-syllable nonword *PRIVEMARA* would share 13 bigrams with its base word, whereas its control *PRISORURA* would only share 5 bigrams (i.e. *PRIVEMARA* is perceptually closer to *PRIMAVERA* than *PRISORURA*). With respect to the SOLAR model, it uses a spatial coding scheme in which letter codes are position-independent. That is, the TL-syllable nonword *PRIVEMARA* and its base word, *PRIMAVERA*, share the same set of letter nodes. The order of the letters is coded by the relative activity of the set of letter nodes. Thus, *PRIMAVERA* and *PRIVEMARA* would be coded differently because they would produce different activation patterns across the letter nodes they share. In the SOLAR model, the computed similarity between *PRIMAVERA* and its TL-syllable nonword *PRIVEMARA* is .70, whereas the computed similarity between *PRIMAVERA* and its orthographic control *PRISORURA* is .64.[2] That is, both the open-bigram and the SOLAR model predict a higher degree of similarity between the base word and the TL-syllable nonword than between the base word and its appropriate orthographic control. (The overlap model and the SERIOL model would make qualitatively similar predictions; we discuss this issue in the general discussion section.)

Finally, it may be argued that we need a nonword condition in which two adjacent (internal) letters are transposed (e.g., *PRIAMVERA*); however, the problem with this condition is that it necessarily alters the word's syllable structure—which is a relevant factor in Spanish—and it also produces quite infrequent bigrams (e.g., the bigram *MV* does not exist in any Spanish word). In the present experiments, all nonword conditions (i.e., both transposed-letter nonwords and replacement-letter nonwords) have the same syllable structure as their corresponding base words.

Experiment 1

Method

Participants

Twenty-four students from the University of València 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.

Materials

The base words for the nonword targets were 150 Spanish words of 7–11 letters (mean word frequency per one million words in the Alameda & Cuetos, 1995, count: 29, range: 8–210). All these words had two contiguous CV syllables (e.g., *PRIMAVERA*: *MA* and *VE*), and the vowels and consonants in these syllables were different (e.g., *RECATADO* would not be used as a base word, since *CA* and *TA* share the vowel A). To avoid any uncontrolled effects of initial syllable frequency, all the created nonwords maintained the initial syllable of their base words. For each base word we created the following: (a) a transposed-letter nonword in which the two consonants in the CV syllables were switched (*PRIVAMERA*) as well as its appropriate orthographic control (the two critical consonants were replaced, e.g., *PRISALERA*); (b) a transposed-letter nonword in which the two vowels in the CV syllables were switched (*PRIMEVARA*) as well as its appropriate control condition (the two critical vowels were replaced, e.g., *PRIMOVURA*); and (c) a transposed-letter nonword in which the two CV syllables were transposed (*PRIVEMARA*) as well as its appropriate control condition (the two critical syllables were replaced, e.g., *PRISOLURA*). The TL-nonwords and their corresponding controls were all orthographically legal and had, on average, less than 0.1 neighbors each. The syllabic structure of the TL nonwords and their controls was always the same as in the base word. The mean positional token bigram frequencies did not differ across conditions (all $ps > .15$; Sebastián-Gallés, Martí, Carreiras, & Cuetos, 2000). Six lists of materials were constructed to counterbalance the items (i.e., there were 25 nonwords of each condition in each of the lists). Different groups of participants were used for each list. An additional set of 150 words that were seven to eleven letters long (mean frequency per million words: 36, range: 8–114) was included for the purposes of the lexical decision task.

Procedure

Participants were tested in groups of two to four in a quiet room. Presentation of the stimuli and recording of response times were controlled by Apple Macintosh Classic II microcomputers. The routines for controlling stimulus presentation and reaction-time collection were obtained from Lane and Ashby (1987) and from Westall, Perkey, and Chute (1986), respectively. On each trial, a fixation point ("> <") was presented for 500 ms in the center of the screen, and it was immediately replaced by an uppercase target item, which remained on the screen until response. Participants were instructed to press one of two buttons on the keyboard to indicate whether the letter string was a legitimate Spanish word or not ("ç" for yes and "z" for no). Participants were instructed to make this decision as quickly and as accurately as possible. The intertrial interval was 350 ms. Each participant received a different order of trials. Each participant received a total of 24 practice trials (with the same manipulation as in the experimental trials) prior to the 300 experimental trials (150 word trials and 150 nonword trials). The whole session lasted approximately 12 min.

Results and Discussion

Incorrect responses (16.0% of the data for nonword targets) and reaction times less than 250 ms or greater than 2,000

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[2] We would like to thank Colin Davis for providing us with the match scores.

ms (less than 0.5% of the data for nonword targets) were excluded from the latency analysis. The mean latencies for correct responses and error rates are presented in Table 2, and participant and item ANOVAs based on the participants' and items' response latencies and percentage error were conducted based on a 3 (Type of transposition or replacement: consonants, vowels, syllables) × 2 (Type of nonword: transposition, control) × 6 (List: list 1, list 2, list 3, list 4, list 5, list 6) design. The factor List was included as a (between-subjects) dummy variable to extract the variance due to the error associated with the lists (Pollatsek & Well, 1995).[3] Type of transposition or replacement and type of nonwords were within-subject factors. All significant effects had p values less than the .05 level.

The ANOVA on the latency data showed a main effect of type of transposition or replacement, $F1(2, 36) = 12.77$, $F2(2, 264) = 3.13$, and type of nonword, $F1(1, 18) = 134.8$, $F2(1, 132) = 216.35$.[4] Despite the fact that the transposed-letter effect was numerically higher for consonant than for vowel transpositions (147 vs. 115 ms, respectively), the interaction between the two factors was not significant, $F1(2, 36) = 1.47$, $p > .15$; $F2(2, 264) = 1.85$, $p > .15$). More importantly, TL-syllable nonwords showed substantially longer response times than their orthographic control nonwords (851 vs. 744 ms; $F1(1, 18) = 52.37$, $F2(1, 132) = 63.7$).

The ANOVA on the error data showed a main effect of type of transposition or replacement, $F1(2, 36) = 35.23$, $F2(2, 288) = 38.94$, and type of nonword, $F1(1, 18) = 148.32$, $F2(1, 144) = 229.76$. There was a significant interaction between the two factors, $F1(2, 36) = 33.11$, $F2(2, 288) = 35.13$, and there was a substantial transposed-letter similarity effect for TL-consonant nonwords compared with their controls (41.3% vs. 5.3%); this effect was smaller for the TL-vowel nonwords (21.5% vs. 5.8%) and for the TL-syllable nonwords (19.2% vs. 3.2%).

Experiment 1 is consistent with the view that transposed-letter similarity effects occur at the syllable level. TL-syllable nonwords activated their base words to a considerable degree: the transposed-letter similarity effect for TL-syllable nonwords (relative to their controls) was 107 ms in the latency data and 16% in the error data. Furthermore, error rates for the TL-syllable nonwords (19.2%) were very close to the error rates for the TL-vowel nonwords (21.5%), in which only two letters had been transposed. With respect to the "control" conditions, four-letter replacement nonwords (i.e., TL-syllable nonwords) had faster latencies and fewer errors than two-letter replacement nonwords (TL-consonant and TL-vowel nonwords) (744 ms and 3.2% vs. 778 ms and 5.5%), $F1(1, 18) = 9.41$, $F2(1, 149) = 3.68$, $p = .057$ in the latency data and $F1(1, 18) = 4.20$, $p = .055$, $F2(1, 149) = 4.87$ in the error data. Finally, as in prior research, nonwords created by transposing two consonants were more competitive (as deduced from the false positives) than the nonwords created by transposing two vowels (Perea & Lupker, 2004).

Table 2. Mean lexical decision times (in ms) and percentage of errors (in parentheses) for nonword targets in Experiment 1

	TL-nonword	RL-nonword	Transposition-Replacement
Vowels	894 (21.5)	779 (5.8)	115 (15.7)
Consonants	925 (41.3)	778 (5.3)	147 (36.0)
Syllables	851 (19.2)	744 (3.2)	107 (16.0)

The mean correct RT for word trials was 728 ms, and the error rate was 3.8%. "TL" refers to the transposed-letter conditions, whereas "RL" refers to the replacement-letter (control) conditions.

The question now is whether these "syllable" transposition-letter effects also appear when we transpose two pairs of adjacent letters that do not form a syllable. Bear in mind that both the open-bigram and the SOLAR model are able to capture the presence of longer latencies and higher error rates in the TL-syllable condition compared with its orthographic control condition (see this article's introduction). This is the goal of Experiment 2.

Experiment 2

In Experiment 2, instead of using TL-consonant nonwords and their controls, we employed a TL-bigram condition in which two pairs of adjacent letters were transposed (note that these pairs did not form a syllable) as well as its corresponding control condition (e.g., *PRIMERAVA* vs. *PRIMULINA*). Note that in the TL-bigram condition, the transpositions or replacements always affected three syllables of the base word (*PRI.ME.RA.VA* vs. *PRI.MA.VE.RA*). As in Experiment 1, we also used the TL-vowel condition and its control condition (*PRIMEVARA* vs. *PRIMOVURA*) as well as the TL-syllable condition and its control condition (*PRIVEMARA* vs. *PRISOLURA*). We conducted this experiment knowing that if we found greater transposed-letter similarity effects for TL-syllables than for TL-bigrams, this would provide strong evidence for the involvement of syllables during the early stages of word recognition in Spanish. It would also require some modifications in the current coding scheme of the open-bigram and SOLAR models.

Method

Participants

Twenty-four students from the Universitat de València took part in the experiment. All of them had either normal or corrected-to-normal vision and were native speakers of Spanish. None of them has participated in the previous experiment.

Materials

The manipulation was the same as in Experiment 1, except that the TL-consonant condition and its orthographic con-

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[3] Note that each participant was presented with 25 items of each nonword type (i.e., 150/6)—List was just a counterbalancing (dummy) factor.

[4] Twelve items—out of 150—were not included in the $F2$ latency analysis because there was an empty cell in one of the conditions.

trol were replaced by the TL-bigram condition (e.g., *PRIMERAVA*; the base word is *PRIMAVERA*) and its orthographic control (the two critical bigrams were now replaced; e.g., *PRIMULINA*). In all cases, the syllabic structure of the nonwords was the same as in the corresponding base words. The set of base words was a large subset from the materials in Experiment 1 (132 words instead of 150; e.g., the base word *PARALELO*—parallel in English—could not be used in Experiment 2 because the TL-bigram condition would be *PARELALO*, which coincides with the TL-vowel nonword. Thus, each participant was presented with 22 items—132/6—of each nonword type). A set of 132 words was used to complete the stimulus material.

Procedure

The procedure was the same as in Experiment 1.

Results and Discussion

Incorrect responses (12.2% of the data for nonword targets) and reaction times less than 250 ms or greater than 2,000 ms (less than 1% of the data for nonword targets) were excluded from the latency analysis. The mean latencies for correct responses and error rates are presented in Table 3, and participant and item ANOVAs based on the participants' and items' response latencies and percentage error in each block were conducted based on a 3 (Type of transposition or replacement: vowels, syllables, bigrams) × 2 (Type of nonword: transposition, control) × 6 (List: list 1, list 2, list 3, list 4, list 5, list 6) design.

The ANOVA on the latency data showed a main effect of type of nonword, $F1(1, 18) = 74.63$, $F2(1, 124) = 78.42$, but not of type of transposition or replacement (both $ps > .15$).[5] The interaction between the two factors was significant in the analysis by items and approached significance in the analysis by subjects, $F1(2, 36) = 2.88$, $p = .06$; $F2(2, 248) = 4.28$), and it reflected the fact that the transposed-letter effect was numerically smaller for vowel transpositions (72 ms)[6] than for the transposition of two CV syllables (126 ms) or two bigrams (112 ms). Interestingly, the response times to TL-syllable nonwords and TL-bigram nonwords were remarkably similar (968 vs. 956 ms, both $Fs < 1$).

Table 3. Mean lexical decision times (in ms) and percentage of errors (in parentheses) for nonword targets in Experiment 2

	TL-nonword	RL-nonword	Transposition-Replacement
Vowels	954 (25.2)	882 (4.7)	72 (20.5)
Syllables	968 (19.3)	843 (3.0)	125 (16.3)
Bigrams	956 (18.8)	844 (2.1)	112 (16.7)

The mean correct RT for word trials was 786 ms, and the error rate was 3.8%. "TL" refers to the transposed-letter conditions, whereas "RL" refers to the replacement-letter (control) conditions.

The ANOVA on the error data showed a main effect of type of transposition or replacement, $F1(2, 36) = 5.43$, $F2(2, 252) = 7.84$, and type of nonword, $F1(1, 18) = 39.28$, $F2(1, 126) = 159.05$. The interaction between the two factors was not significant, $F1(2, 36) = 1.39$, $F2(2, 252) = 1.70$, $p > .15$. The main effect of type of target reflected that the transposition or replacement of two vowels produced more errors than the transposition or replacement of two syllables or two bigrams. But, again, the most relevant finding is that the error rates for the TL-syllable and the TL-bigram condition were remarkably similar (19.3% vs. 18.8%, respectively).

The main finding of the present experiment is that lexical decision times and error rates for TL-syllable nonwords and TL-bigram nonwords were very similar (968 vs. 956 ms and 19.3% vs. 18.8% of errors, respectively). For the two conditions, there was a substantial (and similar) transposition-letter effect relative to their control conditions (126 vs. 112 ms and 16.3% vs. 16.7% of errors for the TL-syllable and TL-bigram conditions, respectively). Thus, even though the TL-syllable nonword *PRIVAMERA* activates to a large degree the lexical entry of its base word (*PRIMAVERA*), this effect has nothing to do with the activation of the syllables *VA* and *ME*. The same transposed-letter similarity effect was obtained when the TL nonwords had been created by transposing two pairs of bigrams that did not form a syllable.

As in Experiment 1, TL-syllable nonwords did not differ substantially from TL-vowel nonwords: 968 and 954 ms and 19.3% and 25.5%, respectively. In other words, switching two syllables from the base word is—to some degree—similar to switching the vowels embedded in these syllables. Finally, with respect to the "control" conditions, four-letter replacement nonwords (i.e., TL-syllable and TL-bigram nonwords) had faster latencies and fewer errors than two-letter replacement nonwords (TL-vowel nonwords) (844 ms and 2.5% vs. 882 ms and 4.7%), $F1(1, 18) = 20.36$, $F2(1, 149) = 15.86$ in the latency data and $F1(1, 18) = 3.54$, $p = .076$, $F2(1, 149) = 5.81$ in the error data.

Even though it was not the main focus of the article and study, we should mention that there were some apparent discrepancies between the pattern of data of the TL-syllable and TL-vowel nonword condition across Experiments 1 and 2. The difference in response times between the TL-syllable condition and the TL-vowel condition was 43 ms in Experiment 1 and 11 ms in Experiment 2. However, this difference is qualified by a speed–accuracy trade-off, given that the error data showed exactly the opposite trend: the difference (in percent error) between the TL-syllable condition and the TL-vowel condition in Experiment 1 was

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[5] Two items were removed from the $F2$ latency analysis because there was an empty cell in one of the conditions.

[6] In the present experiment, the difference between the TL-vowel condition and its control was lower than in Experiment 1 (72 vs. 115 ms, respectively). However, this was the result of a speed–accuracy trade-off: the magnitude of this difference in the error data was actually higher in the present experiment than in Experiment 1 (20.5% vs. 15.7%, respectively).

less than half the difference in Experiment 2 (2.3% vs. 5.9%, respectively).

General Discussion

The main findings of the present experiments have clear implication for the choice of an input coding scheme in models of visual word recognition. They can be summarized as follows: (a) transposed-letter similarity effects were not observed to be of a syllabic nature because latencies and error rates for nonwords created by transposing two syllables are similar to the latencies and error rates for the nonwords created by transposing two adjacent bigrams; (b) transposed-letter similarity effects for the transposition of two CV syllables and for the transposition of the vowels embedded in these syllables are (to some degree) similar; and (c) transposed-letter similarity effects are greater for consonant transpositions than for vowel transpositions.

The most relevant finding of the present experiments is the presence of similar effects for the transposition of two adjacent CV syllables and for the transposition of two adjacent bigrams. Transposed-letter similarity effects occurred to a large degree when two adjacent (internal) CV syllables were transposed. This implies that transposing two internal CV syllables in a base word produces highly wordlike nonwords (*PRIVEMARA*; around 20% of incorrect "word" responses). That is, the cognitive system has a highly flexible code for (internal) letter positions. However, this effect is *not* syllabic in origin: the same pattern occurs when two pairs of adjacent letters—that do not form a syllable—are switched ("TL-bigram" nonwords; e.g., *PRIMERAVA*). Bear in mind that the TL-syllable nonword *PRIVEMARA* shares the four syllables with the base word *PRIMAVERA* (*PRI, MA, VE*, and *RA*), whereas the TL-bigram nonword *PRIVEMARA* shares *only* the initial syllable (*PRI*) with its base word. Thus, the bottom line is straightforward: transposed-letter similarity effects do not seem to have a syllabic locus. Of course, this finding does not preclude the important role of the syllable in Spanish (Carreiras et al., 1993, 2005; Carreiras & Perea, 2002; Perea & Carreiras, 1998), but it rather indicates that transposition-letter effects do not occur at a syllable level.

Another important finding is that TL-syllable nonwords (*PRIVEMARA*; and TL-bigram nonwords, *PRIMERAVA*) were nearly as competitive as the TL-vowel nonwords (*PRIMEVARA*) (see Tables 2 and Tables 3). This is related to the fact that the transposition of two consonants (*PRIVAMERA*) makes the nonword highly similar to its base word (41.5% of errors in Experiment 1; note that Perea & Lupker, 2004, obtained a very similar error rate: 43.5%). In other words, transposition-letter effects seem to depend much more strongly on consonants than on vowels. Thus, if we transpose two consonants in the TL-vowel nonword *PRIMEVARA* as in *PRIVEMARA*, this second letter string would be perceptually very similar to *PRIMEVARA*, and *PRIVEMARA* is precisely a TL-syllable nonword. Thus, one might argue that the vowel could be the key element upon which syllable-level analysis is carried out (e.g., vowels might serve as "hangers" on which to hook the onset and coda consonants). In Experiment 2, the nonsyllable "bigram" transposition nonwords also yielded strong interference—an effect that also implicates the importance of consonants, because such items involve the transposition of two consonants (and two vowels) of the base word. That is, consonant transpositions seem to be the crucial determinant of the obtained TL-syllable and TL-bigram effects. This finding reinforces the view that vowels and consonants play different roles in lexical access (see Carreiras, Vergara, & Perea, 2005, for ERP evidence; see Caramazza, Chialant, Capasso, & Miceli, 2000, for evidence with brain-damaged individuals; see Lee, Rayner, & Pollatsek, 2001, for evidence in normal reading; see Nespor, Peña, & Mehler, 2003, for evidence in linguistics).

Let's now examine the predictions from the open-bigram and SOLAR models. The two models successfully capture the transposed-letter similarity effect for TL-syllable nonwords and TL-bigram nonwords relative to their corresponding orthographic controls. Further, the two models can easily capture the fact that four-letter transposition nonwords (i.e., TL-syllable and TL-bigram nonwords) produced faster latencies and fewer errors than two-letter replacement nonwords (i.e., TL-consonant and TL-vowel nonwords; see Tables 2 and 3). However, the models cannot accommodate the differential pattern of transposed-letter effects for TL-consonant and TL-vowel nonwords. To capture this finding, the models would need to take into account that the vowel and consonant status of a grapheme is obtained at an early orthographic stage (see Perea & Lupker, 2004, for a detailed discussion of this issue).[7]

What is then the locus of transposed-letter similarity effects? The present data strongly suggest that the effects do not have a syllable origin. Similarly, Perea and Carreiras (in press-a) showed that transposed-letter effects do not have a phonological origin either. Specifically, they found that phonological TL primes do not enjoy any advantage in the masked priming technique over the appropriate orthographic controls (e.g., *relobución-REVOLUCIÓN* vs. *reloducíon-REVOLUCIÓN*; note that *B* and *V* are pronounced as /*b*/ in Spanish). In addition, Perea and Carreiras (in press-b) recently found that transposed-letter similarity effects in compound words are unaffected by a word's morphological boundaries: the magnitude of the transposed-letter effect (both relative to an orthographic control and relative to an identity prime) was virtually the same when it occurred across or within morpheme boundaries.

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[7] One more parsimonious alternative for these models is that the difference between consonants and vowels is based on frequency (i.e., vowels are more frequent than consonants) rather than being a function of basic structural differences. To examine this possibility we performed a post hoc analysis on the TL-consonant nonwords (i.e., the condition in which transposed-letter effects are the strongest) by splitting the 140 nonwords into two groups: one in which the two consonants were of high frequency and a second group in which one of the consonants was of high frequency and the other was of low frequency. The results (over items) showed rather similar averages: 943 and 947 ms for the response time data, and 36.2 and 40.0 for the error percentage, respectively. Even though we could not find any signs of a "consonant frequency" effect, caution is always warranted in the interpretation of a post hoc result.

Taken together, the data strongly suggest that the way the brain codes the ordering of the letters within a word is determined at an orthographic or graphemic level rather than at a sublexical syllabic level, a prelexical phonological level, or a morphological level.

In sum, the present experiments have shown that transposed-letter similarity effects are a particularly robust phenomenon: transposed-letter effects occur to a rather large extent even when two internal bigrams (i.e., *four* letter positions) have been switched. The locus of the effect is probably at an early orthographic or graphemic level, rather than at a syllable level. The reason for this assertion is that we found virtually the same pattern when the transposed-letter nonwords were created by transposing two internal CV syllables (*PRIVEMARA*; the target word was *PRIMAVERA*) or when they were created by transposing two adjacent bigrams that did not form a syllable (*PRIMERAVA*). Thus, the present findings strongly suggest that the cognitive system has a highly flexible code for (internal) letter positions.

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