European Journal of Cognitive Psychology

Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713734596

Transposed-letter similarity effects in naming pseudowords: Evidence from children and adults

Manuel Perea [a]; Adelina Estévez [b]
[a] Universitat de València, València, Spain
[b] Universidad de La Laguna, Canary Islands, Spain

Online Publication Date: 01 January 2008
To cite this Article: Perea, Manuel and Estévez, Adelina (2008) 'Transposed-letter similarity effects in naming pseudowords: Evidence from children and adults', European Journal of Cognitive Psychology, 20:1, 33 - 46
To link to this article: DOI: 10.1080/09541440701306941
URL: http://dx.doi.org/10.1080/09541440701306941

EUROPEAN JOURNAL OF COGNITIVE PSYCHOLOGY
2008, 20 (1), 33–46

Psychology Press
Taylor & Francis Group

Transposed-letter similarity effects in naming pseudowords: Evidence from children and adults

Manuel Perea
Universitat de València, València, Spain

Adelina Estévez
Universidad de La Laguna, Canary Islands, Spain

There is growing empirical evidence that shows that transposed-letter pseudowords (e.g., *relovution*) are perceptually very similar to their base words. This is a finding that has important implications for the choice of an input coding scheme in visual word recognition and naming. In the present experiment, we examined the presence of transposed-letter effects for pseudowords by using the naming task in a transparent orthography (Spanish): The pseudowords were created by transposing two letters or by replacing two letters (e.g., *relovución* vs. *retosución*). Since it has been suggested that transposed-letter effects may be greater for developing than for adult readers (Castles, Davis, & Forster, 2003), we recruited beginning readers (second graders, i.e., 7-year-olds), intermediate readers (fourth graders, i.e., 9-year-olds), and adult readers (college students). Results showed that developing and adult readers frequently mispronounced transposed-letter pseudowords (lexicalisations, mostly). Interestingly, the difference between the transposed-letter pseudowords and the replacement-letter pseudowords vanished when measuring the correct naming times. We examine the implications of these findings for models of visual word recognition and naming.

One key issue for any comprehensive model of visual word recognition and reading is to specify how letter identity and letter position are attained in the process of word recognition. Although, for simplicity's sake, most current models assume that letter identity and letter position go hand-in-hand (e.g., multiple read-out model, Grainger & Jacobs, 1996; dual-route cascaded model, Coltheart, Rastle, Perry, Ziegler, & Langdon, 2001), they appear not

Correspondence should be addressed to Manuel Perea, Departamento de Metodología, Facultad de Psicología, Av. Blasco Ibáñez, 21, 46010-València, Spain. E-mail: mperea@valencia.edu

The research reported in this paper has been partially supported by Grant SEJ2005-05205/EDU from the Spanish Ministry of Education and Science. We thank Carol Whitney and two anonymous reviewers for helpful comments on the paper.

http://www.psypress.com/ecp DOI: 10.1080/09541440701306941

to be integral perceptual dimensions (Perea & Lupker, 2004). For that reason, a number of theorists have proposed new input coding schemes for models of visual word recognition (e.g., SOLAR model, Davis, 1999; open-bigram model, Grainger & van Heuven, 2003; overlap model, Gómez, Ratcliff, & Perea, 2007; SERIOL model, Whitney, 2001).

To examine the choice of a coding scheme in visual word recognition and reading, researchers have often employed transposed-letter pseudowords like *jugde* or words with transposed-letter "neighbours" (e.g., *causal*-*casual*). In masked priming experiments, transposed-letter primes not only produce form-priming effects relative to the appropriate orthographic control (e.g., *jugde*-*JUDGE* vs. *jupte*-*JUDGE*; see Andrews, 1996; Forster, Davis, Schoknecht, & Carter, 1987; Perea & Carreiras, 2006a; Perea & Lupker, 2003b; Schoonbaert & Grainger, 2004), but also associative-priming effects (e.g., *jugde*-*COURT* vs. *ocaen*-*COURT*; Perea & Lupker, 2003a). Likewise, correct responses to transposed-letter pseudowords (*mohter*) are longer than correct responses to replacement-letter pseudowords (*modber*) in lexical decision and semantic categorisation tasks (O'Connor & Forster, 1981; Perea, Rosa, & Gómez, 2005; Taft & van Graan, 1998).

Transposed-letter effects are not restricted to the transposition of adjacent letters (e.g., *jugde*-*JUDGE*). Perea and Lupker (2004) found that nonadjacent transposed-letter primes (especially those created by transposing two consonants) produce robust cross-position priming effects relative to an orthographic control condition (e.g., *caniso*-*CASINO* vs. *caviro*-*CASINO*): Furthermore, pseudowords created by transposing two non-adjacent consonants (e.g., *relovution*) are highly wordlike, with error rates (i.e., false positives) around 40% in a single-presentation lexical decision task (Perea & Lupker, 2004; see also Perea & Carreiras, 2006b; Perea & Fraga, 2006; see also Johnson, 2006; Lupker, Perea, & Davis, 2007, for evidence with English stimuli).

The first aim of the present paper is to explore the nature of the letter-position information by using a naming task in a transparent orthography (Spanish). We chose the naming task—leaving aside the issue of converging evidence across tasks—because it has one obvious advantage over the lexical decision task: We know for sure the response of the participant. Note that, in the lexical decision task, a "yes" response to a given word does not guarantee that the participants recognised that specific word (e.g., the participant could press "yes" for *trial*, but s/he might have misperceived it with *trail*), and a similar argument applies to "no" responses. More important, the use of the naming task allows us to examine the predictions of dual route models of reading aloud (e.g., Coltheart et al., 2001; see also Peereman & Content, 1997) in terms of the relative contributions of the lexical vs. sublexical route in a transparent language such as Spanish.

Specifically, we examine the differences between the correct naming times and error percentage when readers pronounce transposed-letter pseudowords (e.g., *relovution*) and replacement-letter pseudowords (e.g., *retosution*). As in the Perea and Lupker (2004) experiments, we manipulated two nonadjacent consonants from a base word; in this way, the pseudowords always kept the same syllabic structure as their corresponding base words. To our knowledge, there has been no empirical evidence until now concerning the pronunciation of transposed-letter pseudowords. The two previous studies (Andrews, 1996; Christianson, Johnson, & Rayner, 2005) that examined the effects of transposed-letter similarity with the naming task only employed *word* targets in a priming paradigm: Andrews (1996) used a priming technique with word-word pairs (e.g., *slat*-*SALT* vs. *song*-*SLAT*) and Christianson et al. (2005) used pseudoword-word pairs (e.g., *dealdine*-*DEADLINE*). It is important to keep in mind that, in a priming paradigm (such as the one used by Andrews, and by Christianson et al.), an item is explicitly activated and the effect on target performance is measured; in contrast, in a single-presentation paradigm (such as the one used in the present study), the issue concerns whether partial activation of neighbouring words that were never presented influences responses to the target item. Obviously, the fact that transposed-letter similarity modulates the strength of priming between similarly spelled items does not necessarily imply that transposed-letter similarity modulates the time taken to access those items (see Andrews, 1996; Perea & Rosa, 2000). Thus, both single-presentation and priming paradigms may provide converging evidence of transposed-letter effects.

In the context of reading aloud tasks, dual route models propose that skilled readers have at their disposal two distinct procedures for converting print to speech: a lexical (word-specific) route, which involves gaining access to internal units representing whole words, and a sublexical (phonological) route, which involves using a system of rules that specify relationships between subword units, such as graphemes and phonemes (and, probably, syllables; see Carreiras & Perea, 2004). In an alphabetically transparent system such as Spanish, the orthography is mapped onto the phonological structure, in which the rules of spelling-sound are simpler and have fewer exceptions than in opaque orthographies (e.g., English) because the mapping between graphemes and phonemes is largely consistent. For this reason, the influence of the sublexical route is assumed to play an important role in Spanish (see Cuetos, 1989; Valle-Arroyo, 1989). However, the lexical route has a functional value in Spanish because the effects of word-frequency and semantic priming are robust in the naming task (e.g., Perea & Carreiras, 1998; Perea & Gotor, 1997; Perea & Rosa, 2002; Sebastián-Gallés, 1991).

There is evidence of lexical effects for adult readers when reading pseudowords in Spanish (Sebastián-Gallés, 1991): For instance, when reading a one-letter different pseudoword such as *abogedo* (/aboxedo/; its base word is *abogado*, /abogado/, the Spanish for *lawyer*), readers (incorrectly) tend to pronounce it as /abogedo/ instead of the */aboxedo/*. (In Spanish, the letter "*g*" is context-sensitive, in a way parallel to English and other languages.) Sebastián-Gallés (1991) concluded that lexical information was involved in reading, even in languages with a shallow orthography. Interestingly, in a follow-up study, Sebastián-Gallés and Parreño (1995) found *abogedo-/abogedo/* errors and also lexicalisation errors (*abogedo* pronounced as the word *abogado*) even in 6-year-old children. Sebastián-Gallés and Parreño also found a high percentage of lexicalisations in 9- and 11-year-olds, even more than in adults (52, 39, and 30%, respectively).

In the present naming experiment, participants will be presented with word trials and with pseudoword trials (transposed-letter or replacement-letter pseudowords). The predictions are straightforward. If readers typically employ the lexical route when pronouncing the items, they will make a much higher number of errors to the (highly wordlike) transposed-letter pseudowords than to their corresponding controls (i.e., they will lexicalise the pseudowords). In contrast, if readers use the sublexical route, there should not be any difference in the correct response times—or error rates—between the transposed-letter pseudowords and their corresponding controls; the reason is simple: If readers use a grapheme-to-phoneme correspondence, there should no be any differences between the time necessary to pronounce the transposed-letter pseudoword *deyasuno* and the replacement-letter pseudoword *degavuno*.[1]

The second aim of the study is to examine whether the magnitude of the transposed-letter effect can be influenced by the degree of skill in a language. Clearly, the process of assigning locations to objects (in our case, letters) may not be straightforward for beginning readers. Indeed, some children may develop a selective deficit in letter position encoding that results in errors of letter position within words: developmental letter position dyslexia (see Friedmann & Gvion, 2005). In a lexical decision task, Castles et al. (2003) reported an unpublished experiment in their lab which showed that transposed-letter priming effects with word-word pairs (e.g., *sign-SING* vs. *clap-SING*) were quite robust for third-grade readers, whereas the effects were numerically smaller for fifth-grade readers, and vanished for adults. Castles et al. suggested that "the immature word recognition system tolerates a degree of error in letter position if letter identity requirements

[1] There is empirical evidence that the processes involved in pseudoword reading may differ when only pseudowords are included in the list, decreasing the magnitude of lexical effects (see Tabossi & Laghi, 1992). Given that we were interested in having conditions similar to previous research (e.g., lexical decision task), we included both word and nonword trials in the experiment.

are fulfilled" (p. 353). To examine this issue, we recruited beginning readers (second graders/7-year-olds), intermediate readers (fourth graders/9-year-olds), and adult readers (college students).

In sum, although reading aloud in Spanish may be carried out through the (nonlexical) phonological route, the lexical route has functional value in word recognition. To become an accurate and efficient reader, children need to do more than assemble or decode pronunciations: they need to acquire a rapid and flexible word-recognition system (see Frith, 1985; Seymour & McGregor, 1984, for a description of strategies that children use to learn to read). All printed words are initially unfamiliar to beginning readers. As children become more proficient readers, they grow less dependent of phonological processes because the lexical representation systems increasingly include word-specific representation. In Spanish, Cuetos (1989) found a very rapid development of the understanding of grapheme-phoneme correspondences in children of ages 5 and 6. In general, Spanish children reach an automatic control of reading at the end of second grade and it is in fourth grade when children reach the expertise level. Indeed, as indicated above, Sebastián-Gallés and Parreño (1995) found that children used a lexical route at an early reading stage, as deduced from the pattern of lexicalisation errors (the pseudoword *abogedo* pronounced as the word *abogado*) or normalisations (the pseudoword *abogedo* pronounced as /abogedo/ instead of the correct pronunciation, /*aboxedo*/) in 6-year-olds. Sebastián-Gallés and Parreño concluded that the precise control of lexical information over perceptual information occurs relatively late in reading development.

Thus, the present experiment is of relevance: (1) to examine the extent of the transposed-letter similarity for pseudowords in a naming task, (2) to assess whether or not beginning (and intermediate) readers show a greater transposed-letter effect than adult readers, and (3) to assess the influence of the lexical and nonlexical route in developing and adult readers in a transparent orthography.

EXPERIMENT

Method

Participants. One hundred subjects took part in this experiment: 32 second graders, 32 fourth graders, and 36 college students (from the University of La Laguna). The children came from average socioeconomic backgrounds and from two different public schools in urban areas of Tenerife, Spain. For second and fourth graders, the test took place at the end of the academic year. The children had been taught to read using a phonics-based approach, in which teachers focus on teaching the rules of correspondence between graphemes and phonemes. Children were excluded if they had sensory, acquired neurological, or other problems traditionally used as exclusionary criteria for learning disabilities. All the participants were native speakers of Spanish.

Materials. For the word trials, we selected a set of 50 Spanish words of 6–10 letters (mean written word frequency per million: 151 in the Spanish database, Davis & Perea, 2005, range: 60–632; mean number of letters: 7.7). The base words for the pseudoword targets were 50 Spanish words of 6–10 letters (mean written word frequency in the Spanish database: 82 per million, range: 14–341; mean number of letters: 7.5). All the base words for the pseudoword targets were easily identifiable as words by beginning readers: The mean (written) word frequency in the frequency dictionary for beginning Spanish readers (Corral, Goikoetxea, & Laseka, 2003) was quite high: 27.2 in a corpus of 178,000 words (i.e., 150 per million words) sampled from first-grade textbooks. To avoid any uncontrolled effects of initial syllable frequency (Perea & Carreiras, 1998), the pseudowords always maintained the initial syllable of their base words. For each base word we created: (1) a transposed-letter pseudoword in which two nonadjacent consonants were switched (*deyasuno*; the base word is *desayuno*, the Spanish word for *breakfast*); and (2) a two-different letter pseudoword in which the two critical consonants were replaced by others with the same shape as in the transposed-letter pseudoword (e.g., *degavuno*). The syllabic structure of the transposed-letter pseudowords and their controls was always the same as that of their corresponding base words. Bigram frequencies for transposed-letter pseudowords and replacement-letter pseudowords did not differ significantly ($p > .50$). The number of orthographic neighbours (i.e., one-letter different words) did not differ across transposed-letter and replacement-letter pseudowords (mean $N = 0.3$ in the two groups). Two lists of materials were constructed to counterbalance the items across type of pseudoword (letter-transposition, letter-replacement). Different groups of participants were used for each list.

Procedure. Participants were tested individually in a quiet room. Presentation of the stimuli and recording of response times were controlled by PC compatible computers. The experiment was run using DMDX (Forster & Forster, 2003). On each trial, a fixation point ("+") was presented at the centre of the screen for 500 ms. Then, a lowercase target item was presented until the participant pronounced it. The participants' task was to read aloud the item as fast and as accurately as possible. Naming latencies were measured from target onset until the participant's response via a microphone. Each participant received a different order of trials. The pronunciation of each word/pseudoword was recorded on a tape, and was analysed to examine whether it was correct and, in the case of an error, whether it was a lexicalisation error (e.g., pronouncing the word *desayuno* when the presented item was the pseudoword *deyasuno*). Each participant received a total of 10 practice trials prior to the 100 experimental trials (50 word trials and 50 pseudoword trials). The whole session lasted approximately 8 min.

Results

Incorrect responses (23.0% for pseudowords) and reaction times less than 250 ms or greater than 2000 ms (less than 0.5%) were excluded from the latency analysis. The mean latencies for correct responses and error rates (as well as the percentage of lexicalisations) are presented in Table 1. As expected, most naming errors in the transposed-letter pseudoword condition were lexicalisations (89.3% in second graders, 92.4% in fourth graders, and 95.1% in college students), whereas this percentage was much lower in replacement-letter condition (6.3% in second graders, 4.9% in fourth graders, and 23.7% in college students).

For pseudoword targets, participant and item ANOVAs based on the participant and item correct response latencies and error percentage were conducted based on a 3 (Grade: second grade, fourth grade, college) × 2 (Type of pseudoword: transposition, control) × 2 (List: list 1, list 2) design. List was included to exclude the variance due to the lists. All significant effects had p values less than the .05 level.

Pseudoword targets. In the latency analysis, there was a main effect of grade, $F1(2, 94) = 18.39$, $MSE = 61{,}266.1$, $F2(2, 94) = 238.1$, $MSE = 6552.8$, which showed (via post hoc Tukey tests) that second graders were significantly slower at pronouncing pseudowords than fourth graders and college students.

TABLE 1
Mean naming times (in ms), standard deviation naming times (underlined), and percentage of errors (in parentheses) in the experiment

	Pseudoword targets				
Grade	*Words*	*TL pseudowords*	*RL pseudowords*	*TL effect*	*Error TLs*
Second grade	966	1069 183 (45.4)	1090 180 (11.9)	−21 (33.5%)	944
Fourth grade	722	824 176 (39.3)	849 172 (5.1)	−25 (34.2%)	731
College	678	865 179 (29.6)	852 161 (6.6)	13 (23.0%)	737

TL effect reflects the difference between the transposed-letter (TL) pseudoword condition and the replacement-letter (RL) pseudoword condition. *Error TLs* reflect the error naming time for the incorrect responses for the transposed-letter pseudowords.

More importantly, there were no differences between the naming times of transposed-letter pseudowords and replacement-letter pseudowords, $F1(1, 94) = 2.08$, $MSE = 4947.1$, $p > .15$, $F2(1, 94) < 1$, $MSE = 9279.8$. The interaction between the two factors did not approach significance, $F1(2, 94) = 1.9$, $MSE = 61{,}266.1$, $p > .15$, $F2(2, 94) = 2.3$, $MSE = 5271.6$, $p > .13$.

In the analysis of the error data, transposed-letter pseudowords yielded substantially more errors than replacement-letter pseudowords (38.1 vs. 7.9%, respectively), $F1(1, 94) = 272.8$, $MSE = 166.7$, $F2(1, 94) = 112.5$, $MSE = 608.9$. The main effect of grade was also significant, $F1(2, 94) = 7.54$, $MSE = 252.9$, $F2(2, 94) = 18.26$, $MSE = 155.4$. Finally, grade and type of pseudoword interacted significantly, $F1(2, 94) = 4.05$, $MSE = 252.9$, $F2(2, 94) = 6.51$, $MSE = 149.9$, which showed that the transposed-letter effect was somehow higher for second graders and fourth graders than for college students.

It is important to mention that, as expected, *error* naming times to transposed-letter pseudowords—mostly lexicalisations—were dramatically lower than correct naming times to transposed-letter pseudowords (804 vs. 919 ms; see Table 1), $F1(1, 94) = 78.12$, $MSE = 8012.7$.

Finally, it is important to examine the impact of a lexical variable such as the (log of) word-frequency of the base word and a nonlexical variable such as length (i.e., number of letters) of the pseudoword on the correct naming time and percentage error of the transposed-letter pseudowords (see Valle-Arroyo, 1989, for a similar procedure to assess the role of the lexical and the nonlexical route). The regression analysis on the correct naming times showed that number of letters was consistently a quite powerful predictor ($\beta = .481$ for second graders, $\beta = .510$ for fourth graders, and $\beta = .554$ for college students), whereas the log of word frequency did not affect performance (all $|\beta|$s $< .05$). The regression analysis on the percent error showed that, for second graders, there was a significant effect for both log of word frequency ($\beta = .381$) and number of letters ($\beta = .542$); for fourth graders the effect of number of letters was significant ($\beta = .435$), whereas the effect of log of word frequency showed a nonsignificant trend ($\beta = .219$, $p = .11$). Finally, for college students, neither number of letters ($\beta = .177$) nor log of word frequency had a significant influence of the percentage error (both ps $> .15$).

Discussion

The present findings can be summarised as follows: (1) Readers frequently mispronounce transposed-letter pseudowords (created by transposing two consonants of high-frequency words) in a naming task, and these errors are, mostly, lexicalisation errors; (2) the difference between the transposed-letter condition and the replacement-letter condition *vanishes* when we measure the correct naming times; and (3) this pattern of effects occurs not only with adult readers, but also (and even to a larger degree) with beginning and intermediate readers (i.e., beginning readers tend to [over]use a lexical route, contrary to the usual belief). Taken together, these findings have important implications for the input coding scheme of models of visual word recognition and naming.

Transposed-letter pseudowords in which two nonadjacent consonants are transposed (e.g., *cholocate*) were highly wordlike, and readers tended to mispronounce (lexicalise) them. Hence, it is not surprising that error naming times to transposed-letter pseudowords were *much* lower than the correct naming times. Error rates for transposed-letter pseudowords in the naming task ranged from 29.6% for college students to 39.3% for fourth graders and 45.4% for second graders, and the vast majority of these errors (over 92%) were lexicalisations. Thus, this result extends the findings of Perea and Lupker (2004) to the naming task and to a beginning/intermediate reading population. This pattern of data is consistent with the predictions of several recently proposed coding-schemes in visual word recognition (e.g., see Davis, 1999; .Gómez et al., 2007; Grainger & van Heuven, 2003; Whitney, 2001).

Interestingly, the magnitude of the transposed-letter effect in the error rates decreased as a function of language skills, consistent with the findings reported by Castles et al. (2003).[2] This finding could be easily accommodated in the models by assuming that assignment of letter position is noisier for immature word recognition systems. For instance, in the overlap model (Gómez et al., 2007), each letter in a letter string creates a distribution of activation over positions. That is, the representation of a letter in a given position would be activated by the appearance of that letter in any nearby letter position, thereby accommodating the presence of transposed-letter effects. To explain the present findings, one would need to assume that the orthographic coding of letters in skilled readers is more distinct than that of developing readers. The SOLAR model (Davis, 1999) uses activation levels to code order information (i.e., the first letter is coded by the highest activation value, the second letter is coded with a slightly smaller activation value, etc.). To accommodate the present findings, the activation levels of successive letters should be more distinct for adult than for beginning

[2] It could be argued, however, that beginning readers might have adopted a strategy of producing a word that is orthographically similar to the item they are trying to read (see Ehri, 2005; Seymour & Elder, 1986), and that this mechanism might have caused the sizeable transposed-letter effect in the error rates. Nonetheless, the number of letter in their correct positions was the same for the transposed-letter and replacement-letter pseudowords. Thus, if beginning readers had assigned the correct letter position to the presented items, error rates should have been approximately the same for transposed-letter and for replacement-letter pseudowords.

readers. Alternatively, it could be argued that the key factor would not necessarily imply that the assignment to letter positions is noisier in children, but rather than lexical information plays a predominant role (e.g., as attractors in a dynamic system; see Sebastián-Gallés & Parreño, 1995). This second possibility is supported by the fact that beginning readers were also more likely to lexicalise replacement-letter pseudowords than adults; that is, partial lexical activations (from the phonological route) might have been higher for familiar words (from speech).[3] The idea here is that while there was an interaction between age and type of pseudoword in the error rates, this was mostly due to a floor effect for replacement-letter pseudowords in the error rates for intermediate readers versus adults. In either case, what we should note is that the above-cited input coding schemes do not have an accompanying model of word (pseudoword) naming.

The most successful model of word (pseudoword) naming, the dual route model (Coltheart et al., 2001), cannot accommodate the presence of transposed-letter similarity effects because it (incorrectly) assumes that letters are immediately assigned to the correct letter positions. Nonetheless, as Brundson, Coltheart, and Nickels (2005) pointed out, the dual route model can employ an orthographic coding scheme other than a channel-specific one (e.g., a coding scheme similar to the SOLAR model of Davis, 1999; see Table 5 in the Brundson et al., 2005, study). For that reason, it is important to consider whether a modified coding-scheme implemented within a dual route model could accommodate the dissociation between error rates and correct naming times in the present experiment:[4] The robust effect of transposed-letter similarity on error rates *vanishes* in the correct naming times (i.e., the response time for the transposed-letter *cholocate* is similar to the response time for the replacement-letter pseudoword *chotonate*). The lack of an effect of transposed-letter similarity in the correct naming times strongly suggests that the correct pronunciations of pseudowords are made via a sublexical route (e.g., on a syllable-by-syllable basis) and, in this case, it should not matter whether the pseudoword is obtained by replacing or by transposing two letters—that is, there would not be a lexical influence on the response times in either case. Consistent with this interpretation, a post hoc analysis showed no signs of an effect of the baseword frequency of transposed-letter pseudowords (i.e., a lexical effect) on the correct naming times ($r^2 = .01$). Thus, when the pronunciation of a transposed-letter pseudoword is made via the lexical route, it tends to produce a word pronunciation (i.e., a fast response that generally implies

[3] We thank Carol Whitney for pointing out this possibility.

[4] It could be argued that the computational implementation of the dual route model does not apply to polysyllabic words. Nonetheless, the present predictions are straightforward given the characteristics of the model.

a lexicalisation error; see Table 1). In contrast, when the pronunciation of a transposed-letter pseudoword is made via the sublexical route, it tends to produce the correct pronunciation and a naming time similar to the corresponding control (replacement-letter) pseudoword. Thus, the (modified) dual route model can readily accommodate the dissociation between correct naming times and error rates in the experiment.

The present results also have implications for the way children learn to read. The common assumption is that reading in Spanish is usually done via a phonological route (Cuetos, 1989; but see Sebastián-Gallés & Parreño, 1995, for evidence of a lexical route). However, the present findings challenge (to some degree) that view: Beginning readers (i.e., second graders) show quite robust effects of transposed-letter similarity ("lexicalisations")—they tend to pronounce the word *desayuno* when the pseudoword is the transposed-letter pseudoword *deyasuno*. Indeed, there was a significant role of the baseword frequency of the transposed-letter pseudoword on the number of errors for second graders: This implies that children were activating the correct (familiar) base word and this tended to produce lexicalisations. Interestingly, the effect of baseword frequency on percent error decreased for fourth graders, and it vanished for adults.[5] Although Spanish children may make a predominant use of the sublexical route in the initial stages of reading acquisition (Cuetos, 1989), they quickly turn to a predominant use of the lexical route when they become skilled and familiar enough with many of the words (see Sebastián-Gallés & Parreño, 1995, for similar conclusions). In terms of a dual route model, lexicalisation errors occur when the sublexical (grapheme–phoneme conversion) route is faulty or not fully developed (see Coltheart & Rastle, 1994). Since lexicalisation errors reflect the importance of the lexical route in the process of skilled readers (Sebastián-Gallés & Parreño, 1995), the above-cited finding suggests that the precise control of lexical information over more perceptual (grapheme-to-phoneme) information may take some time to develop. As Sebastián-Gallés and Parreño (1995) pointed out, "in order to acquire skilled reading mechanisms, the subject should allow graphemic information to have a more important role" (p. 37). In future research, it will be of interest to examine the presence of transposed-letter effects in children with deficits in

[5] Alternatively, one could argue that the presence of lexicalisations does not necessarily imply that the lexical route predominates. For instance, a child might see the pseudoword "*deyasuno*" (its base word is *desayuno*) and accurately use the phonological route to assemble the pronunciation /*desayuno*/ without using the direct lexical route. This assembled phonological representation might then strongly activate the word *desayuno*, even though it is not an exact match (i.e., they child would incorrectly say /*desayuno*/). However, this interpretation predicts no differences between correct and error naming times to transposed-letter pseudowords, and the data show a robust advantage of error naming times over correct naming times.

the lexical route vs. in the nonlexical route—bearing in mind that one of the symptoms of phonological dyslexia is the number of lexicalisations.

In sum, the presence of robust transposed-letter similarity effects in the naming task poses additional problems for the models that assume a "position-specific" coding scheme. Furthermore, the paper has shown that this transposed-similarity effect is quite robust with beginning readers (even to a larger degree than with adults), and that the lexical route is clearly operative in beginning readers. Thus, the present findings strongly suggest that the cognitive system has a highly flexible code for letter positions (see Rayner, White, Johnson, & Liversedge, 2006, for recent eye-movement evidence).

Original manuscript received July 2006
Revised manuscript received February 2007
First published online April 2007

REFERENCES

Andrews, S. (1996). Lexical retrieval and selection processes: Effects of transposed-letter confusability. *Journal of Memory and Language*, *35*, 775–800.

Brunsdon, R., Coltheart, M., & Nickels, L. (2005). Treatment of irregular word spelling in developmental surface dysgraphia. *Cognitive Neuropsychology*, *22*, 213–251.

Carreiras, M., & Perea, M. (2004). Naming pseudowords in Spanish: Effects of syllable frequency. *Brain and Language*, *90*, 393–400.

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. (1994). Serial processing in reading aloud: Evidence for dual route models of reading. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 1197–1211.

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

Corral, S., Goikoetxea, E., & Laseka, E. (2003, March). *Una base en español del vocabulario impreso para niños.* Paper presented at the fifth conference of the Sociedad Española de Psicología Experimental, Madrid, Spain.

Cuetos, F. (1989). Lectura y escritura de palabras a través de la ruta fonológica [Reading and spelling using a phonological route]. *Infancia y Aprendizaje*, *45*, 71–84.

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, Australia.

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

Ehri, L. C. (2005). Learning to read words: Theory, findings and issues. *Scientific Studies of Reading*, *9*, 167–188.

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

Friedmann, N., & Gvion, A. (2005). Letter form as a constraint for errors in neglect dyslexia and letter position dyslexia. *Behavioral Neurology*, *16*, 145–158.

Frith, U. (1985). Beneath the surface of developmental dyslexia. In K. Patterson, J. Marshall, & M. Coltheart (Eds.), *Surface dyslexia* (pp. 301–330). Hove, UK: Lawrence Erlbaum Associates Ltd.

Gómez, P., Ratcliff, R., & Perea, M. (2007). *A model of letter position coding: The overlap model.* Manuscript submitted for publication.

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. 1–23). New York: Nova Science.

Johnson, R. L. (2006). 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*. Amsterdam: Elsevier.

Lupker, S. J., Perea, M., & Davis, C. J. (2007). *Transposed letter priming effects: Consonants, vowels and letter frequency.* Manuscript submitted for publication.

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

Peereman, R., & Content, A. (1997). Orthographic and phonological neighborhoods in naming: Not all neighbors are equally influential in orthographic space. *Journal of Memory and Language*, *37*, 382–410.

Perea, M., & Carreiras, M. (1998). Effects of syllable frequency and syllable neighborhood frequency in visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 134–144.

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 similarity effects occur at a syllable level? *Experimental Psychology*, *53*, 308–315.

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

Perea, M., & Gotor, A. (1997). Associative and semantic priming effects occur at very short SOAs in lexical decision and naming. *Cognition*, *62*, 223–240.

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

Perea, M., & Lupker, S. J. (2003b). 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. (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. (2000). Repetition and form priming interact with neighborhood density at a short stimulus–onset asynchrony. *Psychonomic Bulletin and Review*, *7*, 668–677.

Perea, M., & Rosa, E. (2002). Does the proportion of associatively related pairs modulate the associative priming effect at very brief stimulus–onset asynchronies? *Acta Psychologica*, *110*, 103–124.

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

Rayner, K., White, S., Johnson, R. L., & Liversedge, S. (2006). Raeding wrods with jubmled lettres: There's a cost. *Psychological Science*, *17*, 192–193.

Schoonbaert, S., & Grainger, J. (2004). Letter position coding in printed word perception: Effects of repeated and transposed letters. *Language and Cognitive Processes*, *19*, 333–367.

Sebastián-Gallés, N. (1991). Reading by analogy in a shallow orthography. *Journal of Experimental Psychology: Human Perception and Performance*, *17*, 471–477.

Sebastián-Gallés, N., & Parreño, A. (1995). The development of analogical reading in Spanish. *Reading and Writing*, *7*, 23–38.

Seymour, P. H. K., & Elder, L. (1986). Beginning reading without phonology. *Cognitive Neuropsychology*, *3*, 1–36.

Seymour, P. H. K., & McGregor, C. J. (1984). Developmental dyslexia: A cognitive experimental analysis of phonological, morphemic and visual impairments. *Cognitive Neuropsychology*, *1*, 43–82.

Tabossi, P., & Laghi, L. (1992). Semantic priming in the pronunciation of words in two writing systems: Italian and English. *Memory and Cognition*, *20*, 303–313.

Taft, M., & van Graan, F. (1998). Lack of phonological mediation in a semantic categorization task. *Journal of Memory and Language*, *38*, 203–224.

Valle-Arroyo, F. (1989). Errores en la lectura y escritura: Un modelo dual [Errors in reading and writing: A dual model]. *Cognitiva*, *2*, 35–63.

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.