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Masked priming effects are modulated by expertise in the script

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Masked priming effects are modulated by expertise in the script

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In a recent study using a masked priming same–different matching task, García-Orza, Perea, and Muñoz (2010) found a transposition priming effect for letter strings, digit strings, and symbol strings, but not for strings of pseudoletters (i.e., ℿ⊄⊄⊥-ℿ⊄⊄⊥ produced similar response times to the control pair ℿϽƀ⊥-ℿ⊄⊄⊥). They argued that the mechanism responsible for position coding in masked priming is not operative with those "objects" whose identity cannot be attained rapidly. To assess this hypothesis, Experiment 1 examined masked priming effects in Arabic for native speakers of Arabic, whereas participants in Experiments 2 and 3 were lower intermediate learners of Arabic and readers with no knowledge of Arabic, respectively. Results showed a masked priming effect only for readers who are familiar with the Arabic script. Furthermore, transposed-letter priming in native speakers of Arabic only occurred when the order of the root letters was kept intact. In Experiments 3–7, we examined why masked repetition priming is absent for readers who are unfamiliar with the Arabic script. We discuss the implications of these findings for models of visual-word recognition.

Keywords: Word recognition; Letter coding; Masked priming.

When we read the sentence "she thought the jugde was going to rule against her", we may miss that two letters in the word *judge* were transposed. Not surprisingly, there is ample empirical evidence that demonstrates that transposed-letter stimuli such as *judge* and *jugde* have a large degree of perceptual similarity (see Bruner & O'Dowd; 1958; O'Connor & Forster, 1981; Perea, Rosa, & Gómez, 2005;

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Rumelhart, 1977). For instance, a number of masked priming experiments have consistently shown that a target word is recognized more rapidly when it is preceded by a briefly presented transposed-letter nonword prime (e.g., *jugde*–*JUDGE*) than when it is preceded by a control, replacement-letter nonword prime (*jupte*–*JUDGE*) (e.g., Perea & Lupker, 2003a, 2003b, 2004; see also Christianson, Johnson, & Rayner, 2005; Guerrera & Forster, 2008; Lupker, Perea, & Davis, 2008; Perea & Carreiras, 2006, 2008; Schoonbaert & Grainger, 2004; see also Johnson, Perea, & Rayner, 2007, for evidence in normal silent reading). Indeed, one shared assumption of the newly proposed input coding schemes of models of visual-word recognition is that the word-processing system is highly flexible with regard to letter position (e.g., SOLAR model, Davis, 1999, 2010; SERIOL model, Whitney, 2001; open-bigram model, Grainger & van Heuven, 2003; overlap model, Gomez, Ratcliff, & Perea, 2008; noisy Bayesian reader model, Norris, Kinoshita, & van Casteren, 2010).

In a recent paper, García-Orza, Perea, and Muñoz (2010) showed that masked transposition priming is not specific to letter strings. They found that masked transposition priming is also robust for digit strings (2756–2576 faster than 2386–2576) and symbol strings (+%$&– +$%& faster than +>@&–+%$&). On their experiments, they used a masked priming same–different judgement task (see Kinoshita & Norris, 2009, for a review of this task). In this task, when the probe and target are the same (e.g., probe: *judge*; target: *JUDGE*), response times to JUDGE are faster when it is briefly preceded by the transposed-letter prime *jugde* than when it is preceded by the replacement-letter prime *jupte* (Norris & Kinoshita, 2008; see also Perea & Acha, 2009). Note that this task, unlike lexical decision or naming, can be used for a vast variety of stimuli.

García-Orza et al. interpreted their findings in terms of the overlap model—a model that assumes some degree of position uncertainty at the early stages of processing (see Gomez et al., 2008). For instance, the letter *a* in the word *slat* would be linked with the third position but also, to a lesser degree, with the second and fourth positions, and even with the first position. As a result, the degree of perceptual similarity of *slat* and *salt* would be quite high. Importantly, the perceptual uncertainty assumption in the overlap model is based on a general visual-localization system. This implies that, in the early stages of perceptual processing, the same underlying mechanism would apply in coding position within a string of digits (e.g., *1* in *24185*) or a string of symbols (e.g., *%* in *&%$!*). (Of course, we acknowledge that, in later stages of processing, perceptual patterns for strings of alphanumeric versus nonalphanumeric symbols may be quite different; see Tydgat & Grainger, 2009.) This view is consistent with the neuropsychological literature: McCloskey and Rapp (2000) reported on a woman with visual-localization deficit who recurrently misperceived the ordering of objects, letters, and words.

But the most remarkable finding in the García-Orza et al. (2010) study is that masked transposition priming did not occur for strings of pseudoletters (i.e., response times to the string ᚻ¢¢⊥ were similar when it was preceded by transposed prime ᚻ¢¢⊥ and when it was preceded by the replacement prime ᚻƆȝ⊥). García-Orza et al. (2010, p. 1615) suggested that the "fast-acting mechanism responsible for position coding in masked priming only works with simple, familiar objects, once their identity has been attained". If this reasoning is correct, unfamiliar strings of letter-like objects (e.g., Arabic letters for nonspeakers of Arabic, kana syllables for nonspeakers of Japanese) should not produce masked transposed-letter priming for readers with no knowledge of these scripts (i.e., Arabic words would act as strings of pseudoletters), while these same stimuli should produce transposition priming once they are repeatedly experienced. To examine this hypothesis, Experiment 1 examined masked transposition priming in Arabic for native speakers of Arabic, whereas participants in Experiments 2 and 3 were lower intermediate learners of Arabic and readers with no knowledge of Arabic, respectively.

Furthermore, the morphological characteristics of Arabic allow one more manipulation, which is of particular importance to assess the role of morphology in letter position coding. As in other Semitic languages (e.g., Hebrew), the root of a word in Arabic has a key role in lexical access (see Frost, Kugler, Deutsch, & Forster, 2005, for evidence in Hebrew and Arabic; see also Boudelaa & Marslen-Wilson, 2005). The root of a word in Arabic is typically composed of three consonants, as in سبح (*sbH*, the Arabic for "to swim"). The core meaning of an Arabic word is based on the consonants of the root (the "consonantal root"), while the other letters, which form the so-called "word pattern" (or "morphological template"), are used to create the desired modulation of meaning. Unlike Indo-European languages, the root and the word pattern in Semitic languages form two abstract, discontinuous, bound morphemes (see Boudelaa & Marslen-Wilson, 2005). For instance, depending on the word pattern, the root سبح (*sbH*, "to swim") produces a number of different words, such as سباحة (*sb*A*H*p, *swimming*; the word pattern would be "_ _ A _ p"), سباح (*sb*A*H*, *swimmer*; the word pattern would be "_ _ A _"), or مسبح (m*sbH*, *spa*; the word pattern would be "m _ _ _ "), among others.

Importantly, in lexical decision and rapid serial visual presentation tasks, transposition priming effects in Semitic languages occur when the order of the root letters is not swapped (i.e., when transposing one letter of the root and one of the word pattern), but it is absent when two letters of the root are swapped (see Perea, Abu Mallouh, & Carreiras, 2010; Velan & Frost, 2007, 2009). One question here is whether this effect can also be generalized to other tasks. For instance, it has been argued that the masked priming same–different task taps prelexical orthographic representations (Norris & Kinoshita, 2008; Perea & Acha, 2009). Thus, we believe that it is important to examine whether altering of the ordering of the root letters also produces a vanishing transposed-letter priming effect in the masked priming same–different matching task or whether the obtained transposed-letter effect is purely orthographic in nature (i.e., it is immune to morphology). Indeed, Duñabeitia, Kinoshita, Carreiras, and Norris (2010) found a significant transposed-letter priming effect across morpheme boundaries in Spanish when using a masked priming same–different task; note that these same items had produced a null effect in a masked priming lexical decision task (Duñabeitia, Perea, & Carreiras, 2007). Duñabeitia et al. (2010) concluded that "the fact that no hint of morphological decomposition effects is found, and polymorphemic and monomorphemic words behave similarly suggests that orthographically driven morphological decomposition process of polymorphemic words does not take place during the earliest stages of orthographic encoding". However, it remains to be seen that a parallel priming effect also occurs in a Semitic language—in which morphology plays a greater role than in Indo-European languages (Frost, 2009). Indeed, if morphology interacts with transposed-letter priming in the masked priming same–different task in Arabic, this would provide converging evidence in favour of a key role of morphology in the visual processing of words in Semitic languages. Furthermore, it would imply that the claim that the masked priming same–different task relies on "prelexical orthographic representations" (Kinoshita & Norris, 2009) would need to be amended.

The experiments

In Experiments 1–3, transposed-letter primes were created by transposing either two letters of the root (e.g., مقلوب – ملقوب; *mlqwb–mqlwb;* مقلوب is the Arabic for *turned*; the root is *qlb*), or one letter of the root and one of the word pattern while maintaining the order of the root letters (e.g., خاضعة – خضاعة; *xDAEp–xADEp*; خاضعة is the Arabic for *under control*; the root is *xDE*). (For the transcriptions, we use the Buckwalter transliteration scheme; see Boudelaa & Marslen-Wilson, 2010.) None of the pseudoword primes in the present experiment had an existing root. If the ordering of the root letters is key for visual-word recognition in Arabic, we should obtain a facilitative transposed-letter effect for native speakers of Arabic (Experiment 1)—but only when the letter transposition does not affect the ordering of the root letters. In addition, lower intermediate learners of Arabic (Experiment 2) would just rely on the full orthographic form because the vast majority of the target words are unknown to them; that is, they should show a transposed-letter priming effect regardless of whether the letter transposition affects or not the ordering of the root. Finally, readers who are unfamiliar with the Arabic script (Experiment 3) should not show a masked transposed-letter priming effect. Given that Arabic does not have a lowercase/uppercase distinction, and to avoid physical continuity between primes and targets, primes were presented in 14-point font, and targets were presented in 18-point font (see Perea et al., 2010, for a similar procedure).

Although the central focus of Experiments 1–3 is the comparison between the transposed- and the replacement-letter conditions (i.e., the transposed-letter priming effect), we included an identity condition and an unrelated condition as additional baselines for the transposed- and replacement-letter conditions, respectively (see García-Orza et al., 2010; Perea & Acha, 2009). To partially anticipate the results, the experiments with readers with no knowledge of the script failed to show any masked priming effects—including a null repetition priming effect. To examine the nature of this phenomenon, we conducted four additional masked priming experiments (Experiments 4–7), which focused exclusively on masked repetition priming using unfamiliar scripts in the same–different task.

EXPERIMENT 1: NATIVE SPEAKERS OF ARABIC

Method

Participants

Twenty native speakers of Arabic who were undergraduate students at the University of Valencia or at the Polytechnic University of Valencia took part voluntarily in the experiment. Sixteen students were from Morocco, and 4 students were from Palestine. All of them were born and studied elementary/secondary school in their home countries and reported using Modern Standard Arabic on a daily basis. They had normal or corrected-to-normal vision.

Materials

For the "same" response condition, we selected a set of 128 Arabic words that were five letters long. A total of 64 of these words had a mean frequency of 59 appearances per million (range = 1.3–777) and an average of 4.7 orthographic neighbours (range = 0–10) in the Modern Standard Arabic database (Aralex database; Boudelaa & Marslen-Wilson, 2010). These words were preceded by nonword primes that were: (a) the same except for the transposition of two internal root letters (e.g., مقلوب – ملقوب; *mlqwb–mqlwb;* the root is *qlb*); (b) the same except for the substitution of these two internal root letters (مقلوب – مخنوب; *mxnwb–mqlwb*); (c) the same as the target (identity condition, مقلوب – مقلوب); and (d) a pseudoword unrelated to the target (unrelated condition, مقلوب – حارتس). None of the pseudoword primes had an existing root. Six kinds of word patterns were employed, although most of the target words had a NRRNR structure (33 words; R stands for "root letter", and N stands for "nonroot letter"). The remaining 64 words (mean word frequency per one million words = 30, range = 1.3–266.4; mean Coltheart's $N = 4.8$; range = 0–10, in the Aralex database) also were five letters long. They were preceded by nonword primes that were: (a) the same except for the transposition of two internal letters, one from the root and the other from the word pattern (e.g., خاضعة – خضاعة; *xDAEp–xADEp*; the root is *xDE*); (b) the same except for the substitution of these two internal letters, one from the root and the other from the word pattern (خاضعة – خملعة; *xmlEp–xADEp*); (c) the same as the target (identity condition, خاضعة – خاضعة); and (d) a pseudoword unrelated to the target (unrelated condition, خاضعة – شاينط). None of the pseudoword primes had an existing root. Five kinds of word patterns were employed, although most of the target words had a NRNRR structure (30 words). The mean log bigram frequencies were similar for the transposed-letter and replacement-letter primes in the Aralex database, $p > .20$. For the “different” response condition, we selected 128 word targets that were matched in length and frequency to the 128 words of the “same” condition. The construction of the transposed-letter, replacement-letter, unrelated, and identity primes was identical to that of the trials in the “same” response condition. On half of the trials, the probe and the target were the same, whereas on the other half of trials, the probe and the target were different. The complete list of the prime–target stimuli, including the grammatical class of the word targets and their corresponding roots as well as the Buckwalter transliteration is available in MS-Excel format at the following website: http://www.uv.es/mperea/TL_PMGC.xlsx. Four sets of materials were constructed so that each target appeared once in each set, but each time in a different priming condition. Different groups of participants were used for each set.

Procedure

Participants were tested individually in a quiet room. Presentation of the stimuli and recording of response times were controlled by Windows-based computers using DMDX (Forster & Forster, 2003). On each trial, a probe stimulus in 18-point Arabic font was presented above a forward mask consisting of six hash marks (######) for 1,000 ms. Next, the probe disappeared, and the forward mask was replaced by a prime in 14-point Arabic font presented for 50 ms. Then, the prime was replaced by the target word in 18-point Arabic font. The target word remained on the screen until the response. Reaction times were measured from target onset to the participant’s response. Participants were told that they would see strings of Arabic letters and that they were to press the button marked “SÍ/ نعم” (“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/ لا” (“NO”; with their left index finger) if they thought the probe and target was a different stimulus. Participants were instructed to make this decision as rapidly and as accurately as possible. They were not informed of the presence of briefly presented stimuli, and none of them reported (once they had finished the experiment) conscious knowledge of the existence of any briefly presented stimuli. Each participant received a different order of trials. Each participant received a total of 20 practice trials—with the same manipulation as that in the experimental trials—prior to the 512 experimental trials. The whole session lasted approximately 15 min.

Results and discussion

Incorrect responses (5.0% of the trials) and response times smaller than 250 or greater than 1,500 ms (less than 0.4% of the trials) were excluded from the latency analysis. The mean response times and error percentages from the participant analysis are presented in Table 1. As in prior research with the same–different matching task, we analysed separately “same” and “different” responses. Analyses of variance (ANOVAs) based

Table 1. *Mean same–different judgement times and percentage of errors for word targets in Experiment 1*

		Type of prime				
Responses		*ID*	*TL*	*RL*	*UN*	*RL − TL*
Same	Order of root modified	529 (2.2)	555 (6.3)	544 (5.0)	579 (5.3)	−11 (−1.3)
	Order of root intact	560 (3.1)	555 (2.5)	582 (3.8)	577 (5.6)	27 (1.3)
Different	Order of root modified	601 (4.1)	613 (4.7)	605 (2.2)	607 (3.5)	−8 (−2.5)
	Order of root intact	593 (4.1)	599 (4.4)	604 (4.7)	613 (4.1)	5 (0.3)

Note: Experiment 1: native speakers of Arabic. Judgement times in ms. Percentage of errors in parentheses. ID = identity prime, TL = transposed-letter prime, RL = replacement-letter prime, UN = unrelated prime.

on the participant and item mean correct response times and error rates were conducted based on a 4 (prime type: identity, transposition, replacement, unrelated) × 2 (target type: root intact, root swapped) × 4 (list: List 1, List 2, List 3, List 4) design. F values are reported for the analysis by participants (F_1) and items (F_2).

Same responses

The ANOVA on the response times showed a main effect of type of prime, $F_1(3, 48) = 7.81$, $MSE = 1{,}198$, $p < .001$; $F_2(3, 360) = 8.05$, $MSE = 3{,}728$, $p < .001$, whereas the effect of type of target approached significance in the analysis by subjects, $F_1(1, 16) = 4.15$, $MSE = 1{,}452$, $p = .058$, and was significant in the analysis by items, $F_2(1, 120) = 19.36$, $MSE = 3{,}741$, $p < .001$. More important, there was significant interaction between type of prime and type of target, $F_1(3, 48) = 4.94$, $MSE = 866$, $p < .05$; $F_2(3, 360) = 4.00$, $MSE = 3{,}728$, $p < .01$. This interaction reflected that, relative to the replacement-letter condition, there was a facilitative transposed-letter priming effect when the letter transposition did not affect the order of the root letters, $F_1(1, 16) = 6.05$, $MSE = 1{,}226$, $p < .05$, $F_2(1, 60) = 5.61$, $MSE = 4{,}971$, $p < .05$, while there was a nonsignificant inhibitory trend when the transposition occurred in two root letters, $F_1(1, 16) = 2.46$, $MSE = 576$, $p = .13$, $F_2 < 1$. In addition, the identity condition produced faster response times than the transposed-letter priming condition when the transposition affected the order of the root letters (529 vs. 555 ms, respectively), $F_1(1, 16) = 9.72$, $MSE = 701$, $p < .01$; $F_2(1, 60) = 6.74$, $MSE = 2{,}417$, $p < .05$, but not when the letter transposition did not affect the order of the root letters (560 vs. 555 ms, respectively), both Fs < 1. Finally, the replacement-letter condition produced faster response times than the unrelated condition when the transposition affected the order of the root letters (544 vs. 579 ms, respectively), $F_1(1, 16) = 10.46$, $MSE = 1{,}095$, $p < .01$; $F_2(1, 60) = 12.43$, $MSE = 3{,}854$, $p < .001$; but not when the letter transposition did not affect the order of the root letters (582 vs. 577 ms, respectively), both Fs < 1.

The ANOVA on the error data showed that the main effect of type of prime approached significance, $F_1(3, 48) = 2.31$, $MSE = 21.2$, $p = .089$, $F_2(3, 360) = 2.14$, $MSE = 80.70$, $p = .094$, and that the main effect of type of target was significant in the analysis by subjects, $F_1(1, 16) = 4.92$, $MSE = 18.3$, $p < .05$; $F_2(1, 120) = 1.62$, $MSE = 64.5$, $p > .20$. Although the pattern of transposed-letter priming effects was similar to that in the latency analysis, the interaction between the two factors was not significant, $F_1(3, 48) = 1.69$, $MSE = 25.5$, $p = .18$, $F_2(3, 360) = 1.73$, $MSE = 80.7$, $p = .16$.

Different responses

As usual, none of the effects approached significance in the latency/error data (all ps $> .20$).

The results are quite clear-cut. We found a sizeable masked transposed-letter priming effect for native speakers of Arabic when the ordering of the root letters was kept intact (27 ms), but not when two root letters are transposed (−11 ms)—thus extending the findings of Velan and Frost (2009) and Perea et al. (2010) to the masked priming same−different judgement task. If morphological processing is inherent to word processing in Arabic (i.e., if identifying the identity/position of the root letters is vital for lexical access), we should find a transposed-letter priming effect restricted to the case in which the order of the root letters is kept intact—as was actually the case. Furthermore, the transposed-letter priming condition behaved like the identity priming condition only when the order of the root letters was kept intact—as would be expected if the consonantal root is vital for lexical access in Semitic languages.

Transposing one letter from the root and one of the word pattern letters always disrupted the word pattern in the employed stimuli, resulting in a pattern that may not exist in Arabic. Thus, the presence of similar response times for the identity condition and the transposed-letter condition when the ordering of the consonant root was kept intact may have been, in part, due to the fact that the word-recognition system regularized a morphologically illegal sequence (see Perea & Carreiras, 2008, for a similar constraint with illegal bigrams: *comsos–COSMOS* behaved as *cosmos–COSMOS*). This suggests that the process of letter position coding in Semitic languages may be sensitive to the morphological legality of the written sequence (see also Duñabeitia et al., 2007, for evidence in a non-Indo-European language: Basque).[1]

The critical question now is whether these same stimuli will produce a significant transposed-letter priming effect with intermediate learners of Arabic. Note that these individuals can readily process the constituent letters of the Arabic words, and thereby a masked transposed-letter priming effect is expected. This priming effect should not be affected by morphology because the vast majority of Arabic words in the experiment are not known by the participants. (After the experiment, the participants were presented with a list of the target words; excluding the very few words they knew from the statistical analyses did not alter the pattern of data.) In any case, what we should note here is that words, pseudowords, and even consonant strings show an effect of transposed-letter priming of similar magnitude when using alphabetic strings (see García-Orza et al., 2010; Perea & Acha, 2009).

EXPERIMENT 2: LOWER-INTERMEDIATE LEARNERS OF ARABIC

Method

Participants

Twenty students from the "Escuela Oficial de Idiomas" (Official School of Languages) in Valencia took part voluntarily in the experiment. All of them were native speakers of Spain, had normal or corrected-to-normal vision, and were students of Arabic in their third or fourth year—out of six years.

Materials and procedure

They were the same as those in Experiment 1.

Results and discussion

Incorrect responses (5.6% of the trials) and response times less than 250 or greater than 1,500 ms (less than 0.4% of the trials) were excluded from the latency analysis. The mean response times and error percentages from the participant analysis are presented in Table 2. The design was the same as that in Experiment 1.

Same responses

The ANOVA on the response times showed a significant effect of type of prime, $F_1(3, 48) = 2.82$, $MSE = 1{,}260$, $p < .05$; $F_2(3, 360) = 2.84$, $MSE = 3{,}926$, $p < .05$. This reflected a transposed-letter priming effect: Responses to target stimuli were 15 ms faster when preceded by a transposed-letter prime than when preceded by a replacement-letter prime, $F_1(1, 16) = 5.10$, $MSE = 874$, $p < .05$; $F_2(1, 120) = 4.38$, $MSE = 3{,}959$, $p < .05$—note that this effect was approximately the same magnitude when two root letters were transposed and when a letter of the root and a letter of the word pattern were transposed (18 vs. 12 ms, respectively). In addition, there were no differences between the identity condition and the transposed-letter priming condition, both *F*s < 1. Finally, there were no significant differences between the replacement-letter condition and the unrelated condition, both *F*s < 1. The main

[1] As an anonymous reviewer pointed out, perhaps native speakers of Arabic developed some sort of a strategy in decoding the transposed-letter words when the relative order of the root letters remained intact. To examine this issue, we compared the magnitude of the priming effects for the different types of "root"/"nonroot" sequences in the experiment. These analyses did not reveal any signs of a constraint, though. Likewise, it could be argued that a variable such as "number of orthographic neighbours" could have modulated the obtained priming effects—note that this factor was controlled across conditions. Post hoc analyses on the latencies of "same" responses did not reveal a significant role of number of neighbours as a predictor of the magnitude of masked transposed-letter priming. Of course, we acknowledge that this null finding must be taken with caution: Most of the words employed in the experiments had few orthographic neighbours.

Table 2. *Mean same–different judgement times and percentage of errors for word targets in Experiment 2*

Responses		*Type of prime*				
		ID	*TL*	*RL*	*UN*	*RL − TL*
Same	Order of root modified	614 (8.6)	614 (3.6)	632 (3.9)	630 (7.2)	18 (0.3)
	Order of root intact	608 (6.6)	610 (4.6)	622 (5.6)	614 (7.6)	12 (1.0)
Different	Order of root modified	612 (5.6)	612 (3.3)	612 (7.6)	623 (4.3)	0 (4.1)
	Order of root intact	603 (5.6)	603 (5.6)	608 (3.6)	605 (3.6)	5 (−2.0)

Note: Experiment 2: lower intermediate learners of Arabic. Judgement times in ms. Percentage of errors in parentheses. ID = identity prime, TL = transposed-letter prime, RL = replacement-letter prime, UN = unrelated prime.

effect of type of target was not significant, $F_1(1, 16) = 2.43$, $MSE = 1{,}540$, $p > .13$; $F_2(1, 120) = 3.61$, $MSE = 4{,}478$, $p = .06$. Finally, the interaction between type of target and type of prime was not significant either, both Fs < 1.

The ANOVA on the error data did not reveal any significant effects (all ps $> .25$).

Different responses

As in Experiment 1, none of the effects approached significance in the latency/error data (all ps $> .20$).

The results are straightforward: Individuals who are familiar with the Arabic script show a significant transposed-letter priming effect (around 15 ms). Given that these participants did not know most of the Arabic words, it is not surprising that the order of the root letters did not play a role. In other words, the target stimuli were treated as strings of letters (i.e., nonwords) rather than words.

As in the García-Orza et al. (2010) experiments, transposed-letter primes were as effective as identity primes—thus supporting the view that letter position coding takes a long time to encode (see Perea & Lupker, 2004). Finally, there was one unexpected result: The unrelated condition did not differ from the replacement-letter condition. Indeed, a post hoc analysis revealed that only half of the participants showed faster response times in the replacement-letter condition than in the unrelated condition. (Note that in Experiment 1, with native speakers of Arabic, we did find a significant difference between the replacement-letter and the unrelated conditions.) Thus, at least for nonnative speakers of Arabic, the perceptual similarity between an unrelated prime and the replacement-letter prime (i.e., a stimulus sharing three out of five letters) is not enough to produce a reliable masked priming effect.

The question now is whether Arabic words will produce a null masked transposed-letter priming effect when the word's constituent letters are completely unfamiliar to the readers—as was predicted in the introduction. To that end, Experiment 3 tests the same stimuli as those in Experiments 1–2, this time with individuals who are not familiar with the Arabic script.

EXPERIMENT 3: NONSPEAKERS OF ARABIC

Method

Participants

Twenty undergraduate students from the University of Valencia took part voluntarily in the experiment. All were native speakers of Spanish, had normal or corrected-to-normal vision, and reported having no knowledge of Arabic.

Materials and procedure

They were the same as those in Experiments 1–2.

Results and discussion

Incorrect responses (9.0% of the trials) and response times less than 250 or greater than 1,500 ms (less than 0.6% of the trials) were

Table 3. *Mean same–different judgement times and percentage of errors for word targets in Experiment 3*

		Type of prime				
Responses		*ID*	*TL*	*RL*	*UN*	*RL − TL*
Same	Order of root modified	521 (9.4)	523 (8.4)	516 (5.3)	514 (8.4)	−7 (−3.1)
	Order of root intact	526 (6.9)	529 (10.0)	520 (9.1)	542 (9.4)	−9 (−0.9)
Different	Order of root modified	574 (9.4)	575 (9.1)	572 (10.0)	569 (10.3)	−3 (0.9)
	Order of root intact	572 (10.3)	574 (10.3)	575 (8.4)	573 (10.0)	−1 (−1.9)

Note: Experiment 3: Nonspeakers of Arabic. Judgement times in ms. Percentage of errors in parentheses. ID = identity prime, TL = transposed-letter prime, RL = replacement-letter prime, UN = unrelated prime.

excluded from the latency analysis. The mean response times and error percentages from the participant analysis are presented in Table 3. The design was the same as that in Experiments 1–2.

Same responses

The ANOVA on the response times or error data failed to show any significant effects, all ps $> .15$.

Different responses

As usual, none of the effects approached significance in the latency/error data (all ps $> .20$).

The results of the present experiment are clear. As in the pseudoletter experiment of García-Orza et al. (2010; see also Muñoz, Perea, García-Orza, & Barber, 2010, for evidence with event-related potentials, ERPs), there were no signs of a transposed-letter priming effect when the readers were completely unfamiliar with this script. If anything, there was a nonsignificant advantage for the replacement letter condition over the transposed-letter condition (around 8 ms); note that García-Orza et al. (2010) also found a similar trend (around 10 ms) with strings of pseudoletters.

Critically, a combined analysis of Experiments 1, 2, and 3, including experiment, type of prime, and type of target as factors, revealed a significant interaction between these three factors, $F_1(6, 144) = 2.59$, $MSE = 2{,}596.6$, $p < .025$; $F_2(6, 720) = 2.01$, $MSE = 4{,}037.5$, $p = .061$, in the latency analysis on "same" responses. That is, expertise in the script modulated the magnitude of masked priming effects.

One somewhat unexpected finding that deserves some comments is the failure to obtain a significant difference between the two extreme conditions (identity vs. unrelated: 523 vs. 528 ms, respectively) in nonspeakers of Arabic. In the pseudoletter experiments of García-Orza et al. (2010; see also Muñoz et al., 2010), the identity effect (relative to the unrelated control) was around 33 ms—a magnitude similar to the parallel effect with letter strings. One potential reason for this apparent discrepancy is that, for the readers with no knowledge of Arabic, the connectivity of these stimuli (e.g., خاضـعة) makes them look like one-chunk pictures rather than a series of letters, and therefore the briefly presented, masked prime failed to produce an effect on the processing of the target stimulus. To examine this hypothesis, we conducted an additional experiment using the same stimuli as those in Experiments 1–3 except that all the Arabic letters were nonconnected (e.g., صفتيا).

EXPERIMENT 4: NONSPEAKERS OF ARABIC—NONCONNECTED LETTERS

Method

Participants

Twenty undergraduate students from the University of Valencia took part voluntarily in the experiment. All were native speakers of Spanish, had normal or corrected-to-normal vision, and reported having no knowledge of Arabic. None of them had participated in the previous experiment.

Table 4. *Mean same–different judgement times and percentage of errors for word targets in Experiment 4*

Responses		*Type of prime* *ID*	*TL*	*RL*	*UN*	*RL − TL*
Same	Order of root modified	622 (14.1)	621 (15.3)	616 (11.3)	617 (11.6)	−5 (−2.0)
	Order of root intact	610 (10.6)	608 (13.1)	612 (12.8)	613 (14.3)	4 (−0.3)
Different	Order of root modified	630 (10.6)	620 (8.4)	632 (10.9)	623 (10.0)	12 (−2.5)
	Order of root intact	630 (9.7)	640 (8.1)	632 (10.8)	626 (10.0)	−8 (−2.9)

Note: Experiment 4: nonspeakers of Arabic; nonconnected letters. Judgement times in ms. Percentage of errors in parentheses. ID = identity prime, TL = transposed-letter prime, RL = replacement-letter prime, UN = unrelated prime.

Materials and procedure

They were the same as those in Experiments 1–3 except that all the letters in the primes and targets were nonconnected, as in the string ص‌ف‌ت‌ي‌ا.

Results and discussion

As in the previous experiments, error responses (11.3% of the trials) and response times less than 250 or greater than 1,500 ms (less than 1.8% of the trials) were excluded from the response time analysis. The mean response times and error percentages from the participant analysis are presented in Table 4. The design was the same as that in Experiments 1–3.

Same responses

The ANOVA on the response times or error data failed to show any significant effects, all ps > .15.

Different responses

As usual, none of the effects approached significance in the latency/error data (all ps > .20).

As in Experiment 3, we failed to show a masked transposed-letter (and identity) priming effect for Arabic words with readers with no knowledge of Arabic. Clearly, the observed pattern argues against the idea that participants in a same–different judgement task could be merely assessing the physical relationship between the prime and the target—if that had been the case, one should have found a clear masked repetition priming effect under these conditions.

The present finding may seem, at first glance, at odds with masked identity priming found with pseudoletters in the García-Orza et al. (2010) and the Muñoz et al. (2010) experiments. One potential explanation is that Arabic letters have rather peculiar letter features that may make them difficult to process in a masked paradigm for individuals who are not familiarized with this script (see Baker et al., 2007, for functional magnetic resonance imaging, fMRI, evidence in the "visual word form area" with different scripts and objects). Indeed, all the pseudoletters employed by García-Orza et al. were based on the Roman alphabet, so that the letter features of these pseudoletters were (to some degree) familiar. If this reasoning is correct, we should be able to obtain masked identity priming for pseudoletters (i.e., a replication of the García-Orza et al. pseudoletter experiment). This was the goal of Experiment 5a—we exclusively focused on the identity and unrelated priming conditions. As an additional control, we reexamined the presence of masked identity priming for (nonconnected) Arabic letters (Experiment 5b).

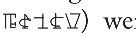
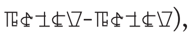
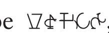
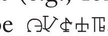
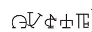
EXPERIMENT 5: MASKED IDENTITY PRIMING FOR PSEUDOLETTERS AND NONCONNECTED ARABIC LETTERS

Method

Participants

The participants were 32 University of Valencia undergraduates in Experiment 5a (pseudoletter experiment) and 32 University of Valencia undergraduates in Experiment 5b (Arabic experiment with nonconnected letters). All were native speakers of Spanish, had normal or corrected-to-normal vision, and reported having no knowledge of Arabic. None of them had participated in the previous experiments.

Materials

For Experiment 5a, a set of 128 letter strings composed of five pseudoletters (e.g., ) were used as targets in this experiment. These letter strings were preceded by primes that were: (a) the same as the target (identity condition, ), or (b) completely unrelated to the target (unrelated condition, ). On half of the trials, the probe and the target were the same, and on the other half of trials, the probe and the target were different (e.g., for the probe , the prime could be , and the target would be ). 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. The materials for Experiment 5b were constructed in a similar way, except that we employed unconnected Arabic letters instead of pseudoletters.

Procedure

It was the same as that in Experiments 1–4.

Results and discussion

As in the previous experiments, error responses (8.4% of the trials) and response times less than 250 or greater than 1,500 ms (1.2% of the trials in Experiment 5a and 1.0% of the trials in Experiment 5b) were excluded from the response time analysis. The mean response times and error percentages from the participant analysis are presented in Table 5. For each subexperiment, ANOVAs based on the participant and item mean correct response times and error rates were conducted based on a 2 (prime–target relationship: identity, unrelated) × 2 (list: List 1, List 2) design.

Experiment 5a: Pseudoletters

Same responses. The ANOVA on "same" response times showed faster response times in the identity condition than in the unrelated condition, $F_1(1, 30) = 6.08$, $MSE = 875.1$, $p < .02$; $F_2(1, 62) = 5.26$, $MSE = 1{,}610$, $p < .025$. The ANOVA on the error data did not show an effect of repetition priming, both Fs < 1.

Different responses. None of the effects approached significance in the latency/error data (all ps $>$ .15).

Experiment 5b: Nonconnected Arabic letters

Same responses. None of the effects approached significance in the latency/error data (all Fs < 1).

Different responses. None of the effects approached significance in the latency/error data (all Fs < 1).

The results of this experiment are reasonably clear. As expected, we found a masked repetition priming effect for strings of pseudoletters in the same–different judgement task, thus replicating the experiments of García-Orza et al. (2010) and Muñoz et al. (2010). Furthermore, we failed to find a significant effect of repetition priming for Arabic letters with individuals who were not familiar with this script. This time there was a nonsignificant 6-ms effect—note that only half of the participants showed the effect.

The remaining question now is why we failed to obtain a masked repetition priming effect in Arabic. One methodological difference between the García-Orza et al. (2010; and the Muñoz et al., 2010, experiments) and the present experiments is that they used four-letter items, while we employed five-letter items (see Kinoshita & Lagoutaris, 2009, for evidence of a modulation of the "leet" priming effect with four- and six-letter items). Indeed, the magnitude of the repetition priming effect for pseudoletters in the present experiment (18 ms) was numerically less than that obtained by García-Orza et al. (33 ms). For that reason, in Experiment 6, we examined whether it was possible to obtain a masked repetition priming effect using four-letter Arabic items for readers with no knowledge of this

Table 5. *Mean same–different judgement times and percentage of errors for word targets in Experiment 5*

		Type of prime		
	Responses	*ID*	*UN*	*UN − ID*
Pseudoletters (Exp. 5a)	Same	645 (8.6)	663 (8.6)	18 (0.0)
	Different	672 (7.2)	667 (7.3)	−5 (0.1)
Arabic letters (Exp. 5b)	Same	649 (8.4)	654 (8.8)	5 (0.4)
	Different	680 (9.3)	674 (9.3)	−6 (0.0)

Note: Experiments 5a and 5b: non-native speakers of Arabic. Judgement times in ms. Percentage of errors in parentheses. ID = identity prime, UN = unrelated prime.

script. The number of items per condition was quite elevated (60), so that we would be able to capture a (potentially) small priming effect.

EXPERIMENT 6: MASKED IDENTITY PRIMING FOR FOUR-LETTER ARABIC ITEMS

Method

Participants
The participants were 110 undergraduate students at the University of Valencia. All were native speakers of Spanish, had normal or corrected-to-normal vision, and reported having no knowledge of Arabic. None of them had participated in the previous experiments.

Materials
A set of 240 strings composed of four Arabic letters were used as targets in this experiment. These letter strings were preceded by primes that were: (a) the same as the target (identity condition, ثرهخ-ثرهخ), or (b) completely unrelated to the target (unrelated condition, ثرهخ-أوزم). As in Experiment 5, on half of the trials, the probe and the target were the same, and on the other half of trials, the probe and the target were different (e.g., for the probe طرات, the prime could be ثرهخ, and the target would be ثرهخ). 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.

Procedure
It was the same as that in Experiments 1–5.

Results and discussion

Error responses (5.6% of the trials) and response times less than 250 or greater than 1,500 ms (1.1% of the trials) were excluded from the response time analysis. ANOVAs based on the participant and item mean correct response times and error rates were conducted based on a 2 (prime–target relationship: identity, unrelated) × 2 (list: List 1, List 2) design.

Same responses
Response times were virtually the same in the identity condition and in the unrelated condition (595 vs. 597 ms, respectively), both Fs < 1. The ANOVA on the error data did not show an effect of repetition priming (7.2 and 5.7% of errors in the identity and unrelated conditions, respectively), both ps $> .19$.

Different responses
Reaction times were very similar in the identity condition and in the unrelated condition (629 vs. 632 ms, respectively), both Fs < 1. The ANOVA on the error data did not show an effect of repetition priming (5.3 and 4.3% of errors in the identity and unrelated conditions, respectively), both Fs < 1.

We again failed to find any signs of an effect of masked repetition priming for Arabic items with individuals who were not familiar with this script. What is the reason of the unreliability of the masked identity priming effect in Arabic for readers of a Roman alphabet? As pointed out earlier, one potential explanation is that Arabic letters involve features that are quite uncommon for readers of a Roman alphabet. Indeed, there is research that shows that, for readers of a Roman language, letter processing of single Arabic letter (ك or ف) or processing of a single Chinese letter (e.g., 文 or 中) is much less efficient than the processing of single letters in other, more Roman-like, fonts such as Armenian (e.g., Հ or Ռ) (e.g., see Pelli, Burns, Farell, & Moore-Page, 2006). That is, it may be difficult to encode briefly presented, masked primes composed of Arabic letters.

To test this hypothesis, in Experiment 7 we employed a design parallel to that in Experiment 5, this time with Thai letters (e.g., ชมตงส). Letter features in Thai are well defined and somehow resemble those of the Roman alphabet—clearly more than the letters in Arabic (e.g., صفتيا) – hence, we expect masked repetition priming effects with Thai letters. As also occurs in other languages (e.g., Arabic, Hebrew), Thai does not have a lowercase/uppercase distinction. For that reason, and to avoid physical continuity between primes and targets, primes were presented in 16-point Loma font, and targets were presented in 20-point Loma font.

EXPERIMENT 7: MASKED IDENTITY PRIMING FOR THAI LETTERS

Method

Participants

The participants were 32 University of Valencia undergraduates. All were native speakers of Spanish, had normal or corrected-to-normal vision, and reported having no knowledge of Thai.

Materials

A set of 128 letter strings composed of five Thai letters (e.g., ดผนมช) were used as targets in this experiment. As in Experiment 5, these letter strings were preceded by primes that were: (a) the same as the target (identity condition, ดผนมช-ดผนมช), or (b) completely unrelated to the target (unrelated condition, ตเอขบ-ดผนมช). On half of the trials, the probe and the target were the same, and on the other half of trials, the probe and the target were different (e.g., for the probe จๆเส, the prime could be ดผนมช, and the target would be ดผนมช). 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.

Procedure

It was the same as that in Experiments 1–6.

Results and discussion

As in the previous experiments, error responses (9.1% of the trials) and response times less than 250 or greater than 1,500 ms (0.4% of the trials) were excluded from the latency analysis. ANOVAs based on the participant and item mean correct response times and error rates were conducted based on a 2 (prime–target relationship: identity, unrelated) $\times$ 2 (list: List 1, List 2) design.

Same responses

The ANOVA on "same" response times showed faster response times in the identity condition than in the unrelated condition (598 vs. 615 ms, respectively), $F_1(1, 30) = 6.39$, $MSE = 720.5$, $p < .02$; $F_2(1, 62) = 4.13$, $MSE = 1{,}649.4$, $p < .05$. The ANOVA on the error data did not show an effect of repetition priming (5.6 and 6.1% of errors in the identity and unrelated conditions, respectively), both Fs < 1.

Different responses

The response times were similar in the identity condition and in the unrelated condition (657 vs. 651 ms, respectively), both Fs < 1. The ANOVA on the error data did not show an effect of repetition priming (8.3 and 6.8% of errors in the identity and unrelated conditions, respectively), both ps $> .20$.

As occurred with the strings of pseudoletters based on a Roman script, strings of Thai letters elicited a reliable masked repetition priming effect for readers with no knowledge of this script: a 17-ms repetition priming effect. Thus, these data are consistent with the idea that the magnitude of masked repetition priming may be modulated by the degree of resemblance —at a featural level— of the new script to the individuals' native script.

GENERAL DISCUSSION

The major findings of the present series of masked priming experiments with the same–different judgement task can be summed up as follows: (a) masked priming in Arabic—both identity and transposed-letter priming—only occurs when readers have some expertise in the script, and (b) for native speakers, masked transposed-letter priming is affected by morphology. We now examine the implications of these findings for the models of visual-word recognition.

The presence of masked transposed-letter priming for intermediate learners of Arabic, but not for readers of a Roman script with no knowledge of Arabic, supports the view that the mechanism responsible for ordering position in masked priming only works with well-known objects (or letters). When the identity of these objects is not attained rapidly, as is the case of Arabic letters for individuals with no knowledge of Arabic, there are no signs of a transposed-letter priming relative to the appropriate control condition (see also García-Orza et al., 2010). Interestingly, even the ubiquitous masked repetition priming effect seems to be absent when readers are not familiar with the Arabic script. This null effect does not seem to be an empirical anomaly. As shown in Experiments 3–6, strings composed of Arabic letters do not produce a reliable masked identity priming effect for readers with no knowledge of Arabic.

What we should note here is that strings of pseudoletters based on a Roman alphabet (e.g., ΕΡΙΠΑ) do produce a significant masked repetition priming effect (Experiment 5a; see also García-Orza et al., 2010; Muñoz et al., 2010). Similarly, strings of Thai letters (e.g., ชมตงส), in which the letter features resemble more those of a Roman alphabet than Arabic letters (e.g., صفتيا), also produce a reliable masked repetition priming effect (Experiment 7). This implies that the masked priming same–different matching task relies on an abstract level of representation—at least at a subletter/letter level—rather than at a merely visual level. As indicated earlier, processing of a single letter in Arabic or in Chinese for readers of a Roman language is less efficient than the processing of single letters in more Roman-like fonts (e.g., see Pelli et al., 2006). A detailed explanation of the perceptual factors that may underlie masked identity priming across different scripts goes beyond the scope of the present paper, but clearly, this is an important issue for future research. Bear in mind that determining the properties of a given script to produce a reliable identity priming effect may have important implications for the choice of an appropriate "pseudoletter" baseline for experiments testing the letter/word activation alleged "visual word form area" in the brain (e.g., King-Blackburne et al., 2010). In this light, we should note that in a recent experiment with the masked priming same–different task (Muñoz et al., 2010), ERP waves to consonant and pseudoletter strings started to differ after 100 ms of target presentation, and, later on, for "same" trials, identity and transposed-letter priming conditions resulted in less negative amplitudes than did the replacement-letter condition. It would be interesting to examine the time course of processing with Arabic stimuli for adult readers with different proficiency in this script.

Morphology and transposition priming

For native speakers of Arabic, we found a robust interaction between transposed-letter priming and morphology. The presence of a facilitative transposed-letter priming effect was restricted to the case in which the ordering of the root letters remains intact. This was so in a task that allegedly taps very early perceptual processes (Norris & Kinoshita, 2008; Perea & Acha, 2009). Leaving aside that this finding poses some problems for the view that the same–different task only taps prelexical orthographic representations (Kinoshita & Norris, 2009; Norris & Kinoshita, 2008), the present data provide further empirical support to Frost and colleagues' view of lexical space in Semitic languages (e.g., Frost, 2009; Frost et al., 2005; Velan & Frost, 2009). Clearly, there seems to be a fast morpho-orthographic processing when reading in a Semitic language. As Velan and Frost indicated, "the extraction of a root morpheme from the orthographic input is an early process that governs lexical search" (Velan & Frost, 2009, p. 296).

What are the implications of these findings for the front-end of models of visual-word recognition? The present data can be accommodated by the overlap model (Gomez et al., 2008) by assuming that, as long as proficiency in a script increases, the specific location of the root letters becomes more and more precise. This implies that the readers in Semitic languages develop a rather strict relative position coding to activate the letters that compose a given root, as proposed by Velan and Frost (2009). Other input coding schemes, such as open-bigrams models (Grainger & van Heuven, 2003; Whitney, 2001) can readily accommodate the critical findings in Experiments 2–3: Experience with the script would facilitate the development of open bigrams. With respect to Experiment 1 (native speakers of Arabic), the data are inconsistent with whole-word detectors based on open bigrams—which would not separate letters from the root and letters from the word pattern. Nonetheless, the present data are consistent with the idea of having separate pattern and root detectors based on open bigrams. The idea here is that a Semitic visual-word recognition system could employ pattern and root detectors based on an open-bigram representation of the input.[2] Clearly, dealing with the intricacies of Semitic languages is an important test for the generality of all current input coding schemes of models of visual-word recognition.

Methodological issues in the masked priming same–different task

From a methodological perspective, the present findings also demonstrate that the masked priming same–different task may be sensitive to factors above the level of letter representations (cf. Norris & Kinoshita, 2008). If not, transposition priming effects for native speakers of Arabic should have been similar when the letter transposition involved two root letters and when the letter transposition kept the ordering of the root letters. Indeed, previous experiments have reported (slightly) faster response times for word stimuli than for orthographically legal pseudowords with this task (e.g., Perea & Acha, 2009), which also implies that this technique may be influenced by higher level processes (i.e., a lexicality effect).

One remaining issue is whether the masked priming effects with the same–different task are mostly facilitative or whether they are mostly inhibitory. As an anonymous reviewer pointed out, one could argue that, in the masked priming same–different task, a prime inconsistent with the target may slow down reaction times—relative to a purely neutral baseline—more than a prime consistent with the target speeds reaction times. Leaving aside that the choice of the "correct" baseline is a tricky issue (see Jonides & Mack, 1984), an incremental priming paradigm (e.g., see Grainger & Frenck-Mestre, 1998; Jacobs, Grainger, & Ferrand, 1995) would probably be the best (empirical) strategy suited to deal with this question. Nonetheless, we should stress here that the precise facilitative/inhibitory nature of prime activation in the masked priming same–different task does not affect the critical findings of the present experiments (i.e., the presence of a transposition priming effect relative to the appropriate orthographic control condition in readers familiar/unfamiliar with the script).

In sum, the present data demonstrate that masked priming requires some expertise with the script—at least in the case of complex, unfamiliar scripts such as Arabic for readers of an

[2] We thank an anonymous reviewer for pointing out this possibility.

Indo-European language. One remaining issue here is whether beginning readers in Semitic languages show transposed-letter priming when the root letters are in the correct order, or whether initially they show a more general transposed-letter effect for all stimuli—independently of the location of the transposition. Note that in Indo-European languages children that are beginning to read show larger transposed-letter effects than intermediate readers or college students (e.g., see Acha & Perea, 2008; Castles, Davis, & Forster, 2003; Perea & Estévez, 2008). A related topic is whether adult individuals whose first language is an Indo-European language and who are highly proficient in a Semitic language would also show the same interaction with morphology as do native speakers of Arabic—or whether the pattern of effects is mostly orthographic (i.e., based on a whole-word forms). Clearly, these are two important issues for future research.

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