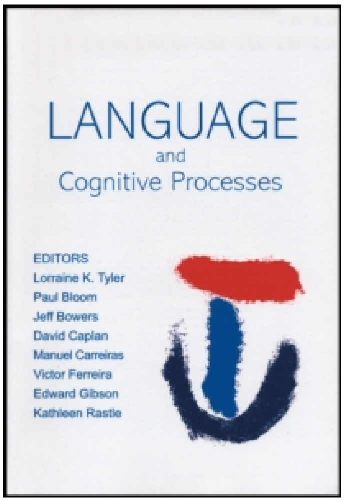

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Beyond alphabetic orthographies: The role of form and phonology in transposition effects in Katakana

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Beyond alphabetic orthographies: The role of form and phonology in transposition effects in Katakana

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In the past years, there has been growing interest in how the order of letters is attained in visual word recognition. Two critical issues are: (1) whether the front-end of the recently proposed models of letter position encoding can be generalised to non-alphabetic scripts, and (2) whether phonology plays an important role in the process of letter position encoding. In the present masked priming lexical decision experiments, we employed a syllabic/moraic script (Katakana), which allows disentangling form and phonology. In Experiment 1, we found a robust masked transposed-mora priming effect: the prime a.ri.me.ka [アリメカ] facilitates the processing of the word a.me.ri.ka [アメリカ] relative to a double-substitution prime (a.ka.ho.ka, アカホカ)). In Experiment 2, we failed to obtain any signs of a masked phoneme transposition effect (a.re.mi.ka-a.me.ri.ka vs. a.ke.hi.ka-a.me.ri.ka). In Experiment 3, we failed to find any signs of a masked phonological priming effect when the order of the consonant/vowel phonemes of the internal morae was the right one (e.g., a.ma.ro.ka-a.me.ri.ka vs. a.ka.ho.ka-a.me.ri.ka). Thus, masked transposed-mora priming effects are orthographic (rather than phonological) in nature.

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We discuss how the recently proposed input coding schemes can be generalised to a syllable-based script.

Keywords: Masked priming; Position encoding; Transposed-letters.

Words in alphabetic languages are processed via their constituents: the letters (Pelli, Farell, & Moore, 2003; Perea & Rosa, 2002). Therefore, one key issue to identify a written word is to accurately process not only the identity but also the position of a word's constituent letters – if not, words like *causal* and *casual* would not be distinguished (see Davis & Bowers, 2006; Grainger, 2008). In this light, a robust finding with important theoretical implications is that transposing two internal letters of a word (e.g., jugde-judge or causal-casual) results in a perceptually similar item (see Bruner & O'Dowd, 1958, for early evidence). For instance, readers tend to misperceive *cholocate* with its base word, *chocolate*, compared with the appropriate control condition (e.g., *chotonate*): this is the transposed-letter effect.

The transposed-letter effect, which has been obtained in a variety of paradigms (e.g., silent normal reading: Acha & Perea, in press; Rayner, White, Johnson, & Liversedge, 2006; lexical decision: Forster, Davis, Schoknecht, & Carter, 1987; rapid serial visual presentation, Velan & Frost, 2007; perceptual identification, Ratcliff, 1981; perceptual matching, Norris & Kinoshita, in press; naming, Perea & Estévez, 2008; semantic categorisation, Taft & van Graan, 1998; electrophysiological measures, Carreiras, Vergara, & Perea, 2007), poses important problems for those computational models of visual-word recognition that assume that the processing of letter position and letter identity go hand in hand (e.g., interactive activation model, McClelland & Rumelhart, 1981; multiple read-out model, Grainger & Jacobs, 1996; dual route cascaded model, Coltheart, Rastle, Perry, Ziegler, & Langdon, 2001; CDP+ model, Perry, Ziegler, & Zorzi, 2007). For instance, these models incorrectly predict that the degree of perceptual similarity between jugde and judge is the same as that for jupte and judge: the two pairs would share three out of five letters.

In recent years, several input coding schemes have been proposed in which transposed-letter effects are a natural consequence of the letter encoding process: the SOLAR model (Davis, 1999, 2006), the SERIOL model (Whitney, 2001; Whitney & Cornelissen, 2005, 2008), the open-bigram model (Grainger & van Heuven, 2003), and the overlap model (Gomez, Ratcliff, & Perea, 2008). In the SOLAR model (Davis, 1999, 2006), letters are activated serially and coded across a spatial activation gradient: the first letter of the word has the greater activation and activation decreases across the letter string, so that the spatial code for the transposed-letter jugde and its base word judge are very similar. In the SERIOL model (Whitney, 2001, see also Whitney & Cornelissen, 2005, 2008), the identity of all letters is initially coded in parallel. Next, a temporal coding of letters takes place, in which letters are fired serially following their order in the word, forming the so-called open bigrams (see Grainger & van Heuven, 2003, for a similar approach). Clearly, jugde and its base word judge share a large number of open bigrams (e.g., JU, JD, JG, JE, UG, UD, UE, GE, and DE) and hence they are perceptually very similar. Finally, in the overlap model (Gomez, Ratcliff, & Perea, 2007), for any string of letters, each letter is assumed, at least initially, to be associated with more than one position. For instance, if the string of letters is the non-word JUGDE, the letter G will be associated with position 3, but also, to a lesser degree, to positions 2 and 4, and even to positions 1 and 5. That is, each letter has a different spread of association across letter positions, which readily captures transposed-letter effects. In all these input coding schemes, the assignment of letter position occurs quite early in the process of visual word recognition, at an orthographic stage. Note that all the front-end of the above-cited coding schemes can readily capture the masked transposed-letter priming effect: a target word is recognised faster when it is preceded by a briefly presented transposed-letter non-word prime (jugde-JUDGE) than when it is preceded by an orthographic control (judpe-JUDGE) (see Castles, Davis, & Forster, 2003; Forster et al., 1987; Lupker, Perea, & Davis, 2008; Perea & Lupker, 2003a,b; Schoonbaert & Grainger, 2004, for recent evidence).

However, as indicated by Goswami and Ziegler (2006), 'when children learn written words, they seek orthographic units to map onto phonological units that are already represented in their brains', so that 'the front end of visual word recognition should be shaped by phonology' (p. 143). However, the role of phonology is not well specified in the above-cited input coding schemes – with the exception of the SERIOL model. Indeed, there is little doubt that phonology plays an important role in visual-word recognition (e.g., Carreiras, Ferrand, Grainger, & Perea, 2005; Ferrand & Grainger, 1994; Frost, 1998; Rastle & Brysbaert, 2006). But the issue here is whether letter position coding takes place *before* phonological processing starts to matter. Given the theoretical relevance of the nature of the processes underlying letter position coding in visual word recognition, it is critical to examine in depth whether letter position coding is orthographic and/or phonological in origin. To reach firm conclusions on how letter position is attained, the effects of orthography and phonology need to be disentangled.

The empirical evidence concerning phonological influences in letter position encoding is not conclusive. Perea and Carreiras (2006a) examined the involvement of phonology in masked transposed-letter priming effects by exploiting the pronunciations of the consonant letters *B* and *V* in Spanish (the two letters sound *exactly* the same: /*b*/). (In a masked priming paradigm, Forster & Davis, 1984Forster & Davis, 1984a letter string, the prime, is presented briefly and masked; participants typically are not only unaware of the prime's identity, they are also unaware of its existence.) At a 50-ms stimulus-onset asynchrony (SOA), Perea and Carreiras (2006a) found a significant advantage of the transposed-letter condition (relovución-REVOLUCIÓN) relative to a phonological condition (relobución-REVOLUCIÓN) and the orthographic control relodución-REVOLUCIÓN in a lexical decision task, while there was virtually no difference between the phonological and the orthographic conditions. More recently, Perea and Carreiras (2008) re-examined phonological involvement in masked transposed-letter priming effects by exploiting the context-dependent pronunciation of the letter '*c*' in Spanish (which is analogous to English and several other Western languages). They found a similar masked transposed-letter priming effect (at a 50-ms SOA) when the transposition involved the letter '*c*' and kept the same sound (cholocate-CHOCOLATE), when the transposition involved the letter '*c*' and modified its sound (racidal-RADICAL), and when the transposition did not involve the letter '*c*' (maretial-MATERIAL). Perea and Carreiras (2008) concluded that 'the influence of the phonological component in the transposed-letter priming effect is (if any) rather small' (p. 86).

One potential criticism to the Perea and Carreiras (2006a, 2008) experiments is that the critical comparison between the phonological and orthographic conditions involved just one letter (B/V in the 2006a experiments, and the sound of the letter C in the 2008 experiment). Under these circumstances, one might argue that orthography plays a considerably stronger influence than phonology. Indeed, a recent paper of Frankish and Turner (2007) has been taken as evidence of phonological involvement in letter position encoding. Frankish and Turner found that (briefly presented) non-words formed by transposing two letters were more likely to be misclassified as words if the non-words were unpronounceable (sotrm; i.e., via an illegal bigram) than if they were pronounceable (strom; via a legal bigram). Interestingly, Frankish and Turner found that the presence of this 'bigram frequency' effect in letter transpositions occurs in normal individuals but not in dyslexic participants. In Frankish and Turner's view, phonological feedback modulates transposed-letter effects: when the letter transposition forms a legal/pronounceable sequence, the activation of the corresponding phonemes can then stabilise the transposed-letter sequence via feedback connections from phonemes to letters. Consistent with this view, Perea and Carreiras (2008) found that masked transposed-letter priming effects were greater when the transposed-letter primes formed an illegal letter string (e.g., comsos-COSMOS; 'ms' is an illegal bigram in Spanish) than when the transposed-letter primes formed a legal letter string (e.g., vebral-VERBAL; see Frankish & Barnes, 2008; for a similar finding with English stimuli). However, all these 'bigram frequency' effects could just be due to orthotactics rather than phonology. As Grainger (2008) indicated, given that 'orthotactics was again (and inevitably so) confounded with pronounceability in this study, it would appear premature to draw any firm conclusions for the time being' (p. 14).

One way to minimise the role of orthography and thereby maximise the chance of obtaining a purely phonological effect is to choose primes and targets that are as visually dissimilar as possible. To test this possibility, one could employ a syllable-based script rather than an alphabetic script. In the present study, we chose to use Katakana. Katakana is a Japanese syllabary that is most often used for transcription of words from foreign languages (e.g., the word *television* is written as テレビ, which may be transcribed in Romaji as *te.re.bi*; note that, in Romaji, Japanese words are written using Roman characters). In addition, Katakana is commonly used for country names and foreign places. For instance, the word America (a.me.ri.ka in Romaji transcription) would be written as アメリカ, that is, as four syllables (or rather four morae). The mora determines the 'syllable weight' in Japanese (see Delattre, 1966; Hoequist, 1983; Kinoshita, 1998), and each mora may consist of a vowel, a consonant/vowel combination, or a moraic consonant (*N* or *Q*). (In the present Katakana experiments, the critical morae always had a /CV/ structure.) The characteristics of the Katakana syllabary –which is a highly transparent script – allow us to elegantly disentangle form and phonology. Note that two morae are orthographically very different, even though they share the same consonant or the same vowel (e.g., レ corresponds to the mora *re*, whereas ケ corresponds to the mora ke and リ corresponds to the mora ri). Here is an example which corresponds to Experiment 2 in the present study: if the transposed-letter priming effect for consonant transpositions (cholocate-CHOCOLATE; see Perea & Lupker, 2004; see also Lupker et al., 2008) is phonological in origin, then responses to the target word a.me.ri.ka should be faster when preceded by the non-word a.re.mi.ka [アレミカ - アメリカ] than when preceded by the orthographic control a.ke.hi.ka [アケヒカ - アメリカ] – note that the internal morae of a.re.mi.ka and a.ke.hi.ka in Katakana are not orthographically similar to the ones from the base word. Recently, Whitney and Cornelissen (2005, 2008) extended the SERIOL model by including a phonological route. They argued that 'biphone encoding would activate lexical items via the same type of mechanism as the bigram encoding' (Whitney & Cornelissen, 2005, p. 288). That is, both open bigrams and open biphones would be activated during identification of a written word, and hence this model would predict some facilitation of a.re.mi.ka over a.me.ri.ka relative to an orthographic control (e.g., a.ke.hi.ka).

In Experiment 1, we examined whether it is possible to obtain masked priming effects with the transposition of two internal morae in Katakana (e.g., a.ri.me.ka-a.me.ri.ka [アリメカ - アメリカ] relative to the appropriate control (a double-substitution condition e.g., a.ka.ho.ka-a.me.ri.ka [アカホカ - アメリカ]) in a lexical decision task. Although (to our knowledge) there is no previous collected evidence on transposition priming effects in non-alphabetic languages, a 'transposed-mora' effect falls naturally (as a simple generalisation) from the recently proposed models of letter position encoding. The idea is that the process of assigning locations to objects would imply morae instead of letters. Nonetheless, there is the possibility that Japanese Katakana, being a non-Indo European and mora-timed language, may be organised in a different manner than that of Indo-European languages. That is precisely the case of Hebrew, in which transposed-letter effects occur to a much lesser degree than in Indo-European languages (see Velan & Frost, 2007, for a comparison between English and Hebrew). The reason is that lexical space in Hebrew seems to be structured according to the morphological roots rather than on some orthographic dimension at the letter level (Frost, Kugler, Deutsch, & Forster, 2005).

To anticipate the results, we found a robust transposed-mora priming effect in Experiment 1. Thus, the critical question was whether this effect was orthographic and/or phonological in nature. To that end, in Experiment 2 we tested the role of phonology in mora position coding transposing two non-adjacent phonemes (e.g., a.re.mi.ka-a.me.ri.ka vs. a.ke.hi.ka-a.me.ri.ka). Of course, one preliminary question is whether the smallest phonological unit in Japanese is the phoneme or rather the mora (see Pérez, Santiago, Palma, & O'Seaghdha, 2007, for a review on speech errors). Tamaoka and Taft (1994) investigated whether phonological effects in Katakana arise at the phoneme level (rather than at the mora level) in a lexical decision task. They modified Katakana words, such as カメラ (ka.me.ra, the Katakana for camera) so that in one condition, the initial Katakana mora (e.g., カ, *ka*) was replaced by another katakana mora (e.g., ソ, so, as in ソメラ, so.me.ra), while in another condition, the pronunciation of the initial consonant was kept intact (e.g., コ, *ko*, as in コメラ, ko.me.ra). Tamaoka and Taft found longer lexical decision latencies for the phonological non-word ko.me.ra コメラ than for the orthographic control so.me.ra ソメラ. In addition, Kawakami (2002), using the Katakana script, showed that the effect of the number of phonological neighbors (i.e., number of words that can be created by changing one phoneme – consonant or vowel – while preserving the phoneme positions) is facilitative in a single-presentation lexical decision task. Taken together, these findings suggest that Japanese readers are indeed sensitive to phonemic units when processing Katakana words, and that the smallest unit of phonological processing in Japanese is not necessarily the mora.

In alphabetic languages, masked transposed-letter priming effects are robust, in particular when the transposed letters are consonants (cholocate-CHOCOLATE produces priming, but not chocalote-CHOCOLATE; English: Lupker et al., 2008; Spanish: Perea & Lupker, 2004). It has been argued that this consonant/vowel dissociation might be due to phonological involvement (see Perea & Lupker, 2004). However, as indicated above, to (elegantly) disentangle orthography and phonology in an alphabetic orthography is not easy. Using the Katakana script allows the researcher to successfully disentangle form and phonology: if the processing of the word a.me.ri.ka アメリカ is sped up by the previous presentation of the prime a.re.mi.ka アレミカ – relative to the control prime a.ke.hi.ka アケヒカ – this would be a critical demonstration of the role of phonology in letter/mora position encoding. Furthermore, it would give support to the activation of biphones in visual word recognition, as proposed in the SERIOL model (Whitney & Cornelissen, 2005). Given that consonants and vowels seem to contribute differently to lexical access (e.g., see Berent & Perfetti, 1995; Caramazza, Chialant, Capasso, & Miceli, 2000; Carreiras et al., 2007; Lee, Rayner, & Pollatsek, 2001; Perea & Lupker, 2004, for evidence using different experimental paradigms), we examine the transposition of two phonemes across the internal morae for consonants (a.re.mi.ka-a.me.ri.ka アレミカ - アメリカ vs. their corresponding control a.ke.hi.ka-a.me.ri.ka アケヒカ - アメリカ) and for vowels (a.mi.re.ka-a.me.ri.ka アミレカ - アメリカ vs. their corresponding control a.ma.ro.ka-a.me.ri.ka アマロカ - アメリカ).

Finally, in Experiment 3, we examined masked phonological priming effects in Katakana when the phonemes of the non-word primes are in the right order by replacing either the two internal consonants or the two internal vowels in the internal morae. That is, we analysed whether the processing of the target word a.me.ri.ka アメリカ is sped by the consonant-preserving prime a.ma.ro.ka アマロカ - アメリカ or by the vowel-preserving prime a.ke.hi.ka アケヒカ - アメリカ relative to the orthographic control a.ka.ho.ka アカホカ - アメリカ – again note that all three conditions are orthographically very similar and the only difference lies in phonology.

EXPERIMENT 1 (TRANSPOSITION OF MORAE)

Method

Participants. Ten students from Kyushu University participated voluntarily in the experiment. All of them either had normal or corrected-to-normal vision and were native speakers of Japanese.

Materials. The targets were 240 Japanese Katakana words that were four morae long. These word stimuli had been selected from the NTT database (Amano & Kondo, 1999), which contains a word familiarity list in Japanese Katakana. In this database, word familiarity is valued from 1 (low familiarity) to 7 (high familiarity) for all 80,000 entry words collected from the *Shinmeikai Japanese Dictionary* (4th Edition). Only four-morae Katakana words with a familiarity value of 5 or higher were selected as targets. The targets were preceded by non-word primes that were: (i) the same as the target except for the transposition of the two internal morae (transposition condition; e.g., a.ri.me.ka-a.me.ri.ka アリメカ - アメリカ), and (ii) the same except for the substitution of these two morae (double-substitution condition; e.g., a.ka.ho.ka-a.me.ri.ka アカホカ - アメリカ). The two internal morae always had a phonological CV structure, and none of the constituent phonemes of the internal morae was repeated (e.g., the word *tsu.na.ga.ri* ツナガリ could not be used in the experimental set because the phoneme /a/ is repeated). The internal morae of the double-substitution prime did not share any phonemes in common with the internal morae of the base word (or the transposition prime). The (token) frequency of the critical (manipulated) morae was matched across the prime conditions using the Tamaoka and Makioka (2004) mora frequency count for four-mora Katakana words, so that neither the transposed and double-substitution primes differed significantly in mora frequency. An additional set of 240 target pseudowords that were four morae long was included for the purposes of the lexical decision task. The pseudowords had been created by changing two morae of real Japanese words. The manipulation of the pseudoword trials also included a transposed-mora condition and a double-substitution condition. Two lists of materials were constructed so that each target appeared once in each list, but each time in a different priming condition. Participants were presented with the two lists (in counterbalancing order) across sessions. Given that the presence of a transposed-mora priming effect would be a new finding, and given that we wanted to assure that a possible null finding was not due to lack of processing of the prime stimuli, we included 48 filler trials (12 repeated word-word trials, 12 unrelated word-word trials, 12 repeated non-word-non-word trials, and 12 unrelated non-word-word trials); this way, we could assess the repetition priming effect in the case of a null transposed-mora priming effect. As occurred with the experimental trials, all the filler words/non-words were four morae long, and two lists of counterbalancing materials were constructed so that each target appeared once in each list, but each time in a different priming condition.

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). Reaction times were measured from target onset until the participant's response. On each trial, a forward mask consisting of a row of hash marks (#) was presented for 500 ms in the centre of the screen. Next, the prime was presented in 10-pt. MS Mincho, and stayed on the screen for 50 ms (3 cycles; each cycle corresponding to 16.6 ms on the CRT monitor). The prime was followed immediately by the presentation of the target stimulus in 12-pt MS Mincho. Given that there is no uppercase/lowercase in Katakana script, and to avoid physical continuity between primes and targets, we used a smaller size for the prime stimulus (see Frost et al., 2005, for a similar procedure). Both prime and target were presented in the same screen location as the forward mask. The target remained on the screen until the participants responded (or 2500 ms had elapsed). Participants were instructed to press one of two buttons on the keyboard to indicate whether the Katakana string was a legitimate Japanese word or not. Participants were instructed to make this decision as quickly and as accurately as possible. They were not informed of the presence of prime stimuli, and none of them reported (after the experiment) conscious knowledge of the existence of any prime. Each participant received a different order of trials. Each participant received a total of 20 practice trials (with the same manipulation as in the experimental trials) prior to the 480 (+48) experimental (and filler) trials. The whole session lasted approximately 20 min.

Results and discussion

Incorrect responses (6.3% of the data for word targets) and reaction times less than 250 ms or greater than 1500 ms (1.7% of the data for word targets) were excluded from the latency analysis. The mean latencies for correct responses and error rates are presented in Table 1, and participant and item ANOVAs based on the participant and item response latencies and error percentage were conducted based on a 2 (Type of prime: transposition, double-substitution) × 2 (List: list 1, list 2) design. List was included as a dummy factor in the ANOVAs to extract the variance due to the error associated with the lists (Pollatsek & Well, 1995). All significant effects had *p* values less than the .05 level.

Word data. The ANOVA on the latency data showed a significant 19 ms advantage of words preceded by the transposed-mora prime over the double-substitution prime, $F_1(1, 8) = 24.81$, $MSE = 73.8$; $F_2(1, 238) = 20.47$, $MSE =$

TABLE 1
Mean lexical decision times (in ms) and percentage of errors (in parentheses) for word and non-word targets in Experiment 1

	Type of prime		
	Transposed-mora	*Double-substitution*	*Substituted–Transposed*
Word trials	738 (6.0)	757 (6.7)	19 (0.7)
Non-word trials	806 (3.0)	813 (2.6)	7 (−0.4)

2248.8. The ANOVA on the error data failed to reveal a significant effect of type of prime (both $ps > .15$).

Non-word data. The ANOVAs on the latency/error data did not reveal any significant effects (all $ps > .15$).

The results of this experiment are clear-cut. There was a significant transposed-mora priming effect for word targets (a.ri.me.ka-a.me.ri.ka アリメカ - アメリカ) relative to the appropriate control condition (i.e., the double-substitution condition a.ka.ho.ka-a.me.ri.ka アカホカ - アメリカ). Interestingly, the magnitude of the transposition priming effect (19 ms) relative to the appropriate control condition is quite similar to the observed masked transposed-letter priming effects in alphabetic languages (around 15–25 ms; e.g., Perea & Lupker, 2003b, 2004; see also Lupker et al., 2008).

Given the characteristics of Japanese, a number of the selected words were compounds: the initial two morae corresponded to one lexeme and the other two morae corresponded to another lexeme (e.g., the word *ka.mi.ka.ze* カミカゼ can be decomposed in ka.mi [god] and ka.ze [wind]). (Note that the term *lexeme boundary* will refer to the last character of the first constituent root morpheme or lexeme and the initial character of the second constituent root morpheme or lexeme in a compound word, as in *blackboard*). In alphabetic orthographies, the transposed-letter priming effect is robust (relative to the orthographic control condition) when the transposition occurs across lexemes (English: Christianson, Johnson, & Rayner, 2005; Basque: Perea & Carreiras, 2006b). In the present experiment, 129 words (out of 240) were compounds. To examine whether the magnitude of the transposed-letter priming effect varied across compounds and non-compounds, we computed the magnitude of the priming effect on the items' means for both compound and non-compounds. Parallel to prior studies in alphabetic languages, the size of the transposed-mora priming effect (relative to the orthographic control condition) is virtually the same for compound and non-compound words: 19 and 21 ms, respectively. This suggests that the ordering of the letters/morae within a word is determined at an early stage that precedes the influence of morphology. It should be noted, however, that the story is probably more complex: transposed-letter priming effects seem to vanish when they occur across affix boundaries in polymorphemic words (see Christianson et al., 2005; Duñabeitia, Perea, & Carreiras, 2007).

The question now is to establish the nature of the transposed-mora priming effect: was it just due to form similarity or did phonology play a role? We examine this issue in Experiments 2. We do so by transposing two internal phonemes of the morae for consonants (e.g., a.re.mi.ka-a.me.ri.ka アレミカ - アメリカ) and vowels (a.mi.re.ka-a.me.ri.ka アミレカ - アメリカ) relative to the appropriate control conditions (a.ke.hi.ka-a.me.ri.ka アケヒカ - アメリカ and a.mi.re.ka-a.me.ri.ka アミレカ - アメリカ, respectively). If there is a phonological component in transposed mora effects, then the response times to the word a.me.ri.ka should be faster when preceded by the non-word prime a.re.mi.ka than when preceded by the non-word prime a.ke.hi.ka. Note that in alphabetic languages, the non-word prime *cholocate* *does* facilitate the processing of *chocolate* (relative to the orthographic control *chotonate*; Perea & Lupker, 2004), but again this effect could have been driven mostly by orthography. The key issue here is that, unlike alphabetic scripts, the orthographic similarity between the phonological transposed condition (a.re.mi.ka-a.me.ri.ka) and the orthographic control condition (a.ke.hi.ka-a.me.ri.ka) in Katakana *is* the same. Thus, the presence of a masked priming effect under these conditions would be a powerful demonstration of phonological influences in letter position encoding. Because masked transposed-letter priming effects differ for consonant-consonant and for vowel-vowel transpositions in alphabetic languages (Lupker et al., 2008; Perea & Lupker, 2004), the phonological transpositions could involve two consonants or two vowels.

EXPERIMENT 2 (PHONEME TRANSPOSITIONS IN KATAKANA)

Method

Participants. Sixteen students from Kyushu University participated voluntarily in the experiment. All of them either had normal or corrected-to-normal vision and were native speakers of Japanese.

Materials. We used the 240 Japanese words from Experiment 1. The targets were preceded by non-word primes that were: (i) the same as the target except for the replacements of the two internal morae so that the vowel sounds of these morae did not vary, while the consonant sounds were switched across the two internal morae (transposed consonant condition; e.g., a.re.mi.ka-a.me.ri.ka アレミカ - アメリカ), (ii) the same as the target except for the replacements of the two internal morae so that the vowel sounds of these morae were kept the same, while the consonant sounds were replaced (control consonant condition; e.g., a.ke.hi.ka-a.me.ri.ka アケヒカ - アメリカ); (iii) the same as the target except for the replacements of the two internal morae so that the consonant sounds of these morae did not vary, while the vowel sounds were switched across the two internal morae (transposed vowel condition; e.g., a.mi.re.ka-a.me.ri.ka アミレカ - アメリカ), and (iv) the same as the target except for the replacements of the two internal morae so that the consonant sounds of these morae were kept the same, while the vowel sounds were replaced (control consonant condition; e.g., a.ma.ro.ka-a.me.ri.ka アマロカ - アメリカ). As in Experiment 1, (token) frequency of the critical (manipulated) morae was matched across the prime conditions using the Tamaoka and Makioka (2004) count (both $ps > .60$). The same set of non-word targets used in Experiment 1 was included in Experiments 2 for the purposes of the lexical decision task. The manipulation of the pseudoword trials was the same as for the word trials. Four lists of materials were constructed so that each target appeared once in each list, but each time in a different priming condition. As in Experiment 1, we included a set of 48 word/non-word filler trials.

Procedure. This was the same as in Experiment 1.

Results and discussion

Incorrect responses (9.2% of the data for word targets) and reaction times less than 250 ms or greater than 1500 ms (2.8% of the data for word targets) were excluded from the latency analysis. The mean latencies for correct responses and error rates are presented in Table 2. ANOVAs based on the participant and item mean correct response times and error rates were conducted based on a 2 (Prime type: phoneme transposition, phoneme replacement) × 2 (Letter type: consonants, vowels) × 4 (List: list 1, list 2, list 3, list 4) design.

Word data. As can be seen in Table 2, response times to target words were very similar in all four conditions. None of the ANOVAs on latency data or on the error data revealed any significant effects (all $ps > .15$).

TABLE 2
Mean lexical decision times (in ms) and percentage of errors (in parentheses) for word and non-word targets in Experiment 2

	Type of prime		
	Transposed (phoneme)	*Control*	*Control–Transposed*
Word trials			
Consonants	822 (9.0)	820 (9.6)	2 (0.6)
Vowels	813 (9.0)	817 (9.1)	4 (0.1)
Non-word trials			
Consonants	899 (2.4)	908 (2.6)	9 (0.2)
Vowels	896 (2.9)	898 (2.2)	2 (−0.7)

Non-word data. Again, none of the ANOVAs on latency data or on the error data revealed any significant effects (all ps > .15).

The results of the present experiment are clear: at a very short SOA (50 ms) and using a masked priming procedure, there are no signs of a phonological effect (at a phoneme level) in Katakana script with a lexical decision task. Response times to the related condition a.re.mi.ka-a.me.ri.ka アレミカ - アメリカ and the orthographic control condition a.ke.hi.ka-a.me.ri.ka アケヒカ - アメリカ were similar – note that a similar manipulation in an alphabetic script (e.g., cholocate-CHOCOLATE vs. chotonate-CHOCOLATE) does show a priming effect (Lupker et al., 2008; Perea & Lupker, 2004), although this latter effect could well have been driven by form rather than phonology. Furthermore, we found no signs of a dissociating effect of the consonant/vowel status of the non-word primes.

What we should also note is that the experimental power to detect a masked priming effect was very high: there were 60 words per condition, and this guarantees that the mean response times per participant and condition were extremely stable, hence minimising the *MSE*. Finally, it is important to indicate that the failure to obtain any signs of a phonological effect was not due to lack of processing of the masked primes. As indicated in the Method section, we included a number of filler trials with repeated and non-repeated word trials. Not surprisingly, there was a significant 33-ms masked repetition priming effect for word targets (756 vs. 789 ms for repeated and unrepeated targets, respectively; $F(1, 14) = 9.06$, $MSE = 983.4$; the error rates were 5.2 vs. 6.8% for repeated and unrepeated targets, respectively).

The question now is whether it is possible to obtain early, masked phonological priming effects in Katakana. That is, even though the outcome from Experiment 2 strongly suggests that the transposed-mora priming effect in Experiment 1 was due to form rather than phonology, one could argue that we have not shown the presence of phonological effects in the first place. To examine this potential criticism, in Experiment 3, we keep the ordering of the phonemes of the internal morae for consonants (a.ma.ro.ka-a.me.ri.ka アマロカ - アメリカ) and vowels (a.ke.hi.ka-a.me.ri.ka アケヒカ - アメリカ), relative to the double-substitution control condition (a.ka.ho.ka-a.me.ri.ka アカホカ - アメリカ). If there is an early involvement of phonology (at the phoneme level) in Katakana, then one would expect faster response times in the related condition. Nonetheless, given the characteristics of the Katakana script, it is possible that phonological involvement does not occur in the early stages of word processing – as tapped by the masked priming paradigm. As Kinoshita (1998) indicated, ‘the role of phonology may be more limited when reading text in Japanese relative to English’ (p. 452). In any case, because the expected masked phonological priming effect is probably small, and to maximise the chances to detect the effect, the number of items per condition was very high: 80 items per condition. Furthermore, as in the previous experiments, we included a number of repeated/unrepeated filler trials to make sure that participants were indeed processing the prime stimuli.

EXPERIMENT 3 (MASKED PHONOLOGICAL PRIMING IN KATAKANA)

Method

Participants. Fifteen students from Kyushu University participated voluntarily in the experiment. All of them either had normal or corrected-to-normal vision and were native speakers of Japanese. None of them had participated in the previous experiments.

Materials. We used the 240 Japanese words from Experiments 1 and 2. The targets were preceded by non-word primes that were: (i) the same as the target except for the replacements of the two internal morae so that the consonant sounds of these morae were kept the same, while the vowel sounds were replaced (consonant-preserving condition; e.g., a.ma.ro.ka-a.me.ri.ka アマロカ - アメリカ), (ii) the same as the target except for the replacements of the two internal morae so that the vowel sounds of these morae were kept the same, while the consonant sounds were replaced (vowel-preserving condition; e.g., a.ke.hi.ka-a.me.ri.ka アケヒカ - アメリカ), and (iii) the same except for the substitution of these two morae (control condition; e.g., a.ka.ho.ka-a.me.ri.ka アカホカ - アメリカ; note that this condition was the double-substitution condition in Experiment 1). As in Experiments 1–2, (token) frequency of the critical (manipulated) morae was matched across the prime conditions using the Tamaoka and Makioka (2004) count (both $ps > .60$). The same set of non-word targets used in Experiments 1–2 was included for the purposes of the lexical decision task. The manipulation of the pseudo-word trials was the same as for the word trials. Three lists of materials were constructed so that each target appeared once in each list, but each time in a different priming condition. As in Experiments 1–2, we included a set of 48 word/non-word filler trials to examine the repetition priming effect.

Procedure. This was the same as in Experiments 1–2.

RESULTS AND DISCUSSION

Incorrect responses (7.5% of the data for word targets) and reaction times less than 250 ms or greater than 1500 ms (0.8% of the data for word targets) were excluded from the latency analysis. The mean latencies for correct responses and error rates are presented in Table 3. Planned comparisons on

TABLE 3
Mean lexical decision times (in ms) and percentage of errors (in parentheses) for word and non-word targets in Experiment 3

	Type of prime		
	Consonant	*Vowel*	*Control*
Word trials	758 (7.0)	756 (7.6)	758 (8.1)
Non-word trials	840 (3.7)	843 (2.9)	844 (2.7)

the participant and item mean correct response times and error rates were conducted to assess an effect of phonology (consonant-preserving prime and vowel-preserving prime) relative to the control condition.

Word data. The planned comparisons did not reveal any signs of an effect of phonology (all $ps > .15$, in the latency/error data). Neither the consonant-preserving condition nor the vowel-preserving condition showed any signs of a masked phonological priming effect.

Non-word data. The planned comparisons did not reveal any signs of an effect of phonology (all $ps > .15$, in the latency/error data).

The results of the present experiment are clear: when the order of the consonant/vowel phonemes of the internal morae was the right one (e.g., a.ma.ro.ka-a.me.ri.ka アマロカ - アメリカ), we failed to find any signs of a masked priming effect (relative to a double-substitution control prime; a.ka.ho.ka-a.me.ri.ka アカホカ アメリカ) in Katakana script with a lexical decision task. Again, we found no signs of a dissociating effect of the consonant/vowel status of the non-word primes; that is, response times to a.ma.ro.ka-a.me.ri.ka [i.e., the consonant-preserving condition: アマロカ - アメリカ] were similar to those to a.ke.hi.ka-a.me.ri.ka [i.e., the vowel-preserving condition: アケヒカ - アメリカ].

As in Experiment 2, what we should also note is that the experimental power to detect a masked phonological priming effect was very high: there were 80 words per condition. Furthermore, as in Experiment 2, the lack of a phonological priming effect (at the phoneme level) was not due to the participants' not processing the prime stimuli: the filler trials showed the ubiquitous repetition priming effect for word targets: 32 ms: 725 vs. 757 ms for repeated and unrepeated targets, respectively; $F(1, 13) = 6.22$, $MSE = 1070.9$; error rates were 10 vs. 11.6% respectively.

GENERAL DISCUSSION

The main findings of the present masked priming experiments can be summarised as follows: (i) there is a robust masked priming effect when two internal morae are transposed in Katakana (i.e., a.ri.me.ka アリメカ facilitates the processing of a.me.ri.ka アメリカ), thus generalising the transposed-letter effect to a syllabic script; (ii) there were no signs of a masked priming effect when transposing two phonemes in these internal morae (e.g., the prime a.re.mi.ka アレミカ does not facilitate the processing of a.me.ri.ka アメリカ relative to the control prime a.ke.hi.ka アケヒカ), and (iii) there were no signs of a masked priming effect when the phonemes of the internal morae were in the right order (e.g., the prime a.ma.ro.ka アマロカ does not facilitate the processing of a.me.ri.ka アメリカ relative to the control prime a.ka.ho.ka アカホカ). That is, the locus of the masked transposed-mora priming effect seems to be orthographic (rather than phonological) in nature. Taken together, these findings have important implications for the choice of an input coding scheme of the letter/mora encoding process.

The presence of a robust masked transposed-mora priming effect in Katakana implies that models of letter position encoding should be slightly modified to account not only for letter position encoding, but also for mora position encoding. As occurs with the transposition of two internal letters in alphabetic languages (e.g., English: Lupker et al., 2008; Basque: Perea & Carreiras, 2006b; Spanish: Perea & Lupker, 2004; French: Schoonbaert & Grainger, 2004), transposing two internal morae from a Katakana word results in a perceptually similar item (i.e., a.ri.me.ka アリメカ is very similar to its base word, a.me.ri.ka アメリカ). That is, locations of objects (in our case, morae, and in alphabetic languages, letters) can be best understood as distributions along a dimension, in our case, position in the string, rather than as precise points (see Ratcliff, 1981).

In the SOLAR model, Katakana morae would be assigned a temporary position code, with larger values assigned to earlier morae (e.g., in a.me.ri.ka アメリカ, the mora *a* ア would be assigned a larger value than the mora me メ which would have a larger value than the mora *ri* リ, and the smaller value would correspond to the mora *ka* カ). Open-bigram coding schemes (Grainger & van Heuven, 2003; Whitney, 2001) could code Katakana strings by activating a series of bigram nodes that reflect the order of the morae (e.g., for the word a.me.ri.ka アメリカ, the nodes for a.me アメ, a.ri アリ, a.ka アリ, me.ri メリ, me.ka メカ, ri.ka リカ would all be activated). Finally, in the overlap model (Gomez et al., 2008), for any string of Katakana, each mora is assumed, at least initially, to be associated with more than one position. With these modifications, the front-end of the above-cited input coding schemes can readily capture the presence of transposed-mora effects.

The failure to obtain a masked transposed-phoneme priming effect in Katakana is consistent with the experiments of Perea and Carreiras (2006a, 2008) with an alphabetic script: masked letter/mora transposition priming effects in internal syllables/morae seem to have their origins at the form level rather than at a phonological level. Indeed, note that in Katakana, the string a.ri.me.ka アリメカ) speeds up the processing of the target word a.me.ri.ka アメリカ, despite the fact that they share little phonological information (in the right order) in common. For instance, a parallel manipulation in an alphabetic script (e.g., cholacote-CHOCOLATE) does *not* produce a masked priming effect (Perea & Lupker, 2004). Furthermore, it is important to note that mora transposition effects are not affected by lexeme boundaries (relative to an orthographic control condition), thus extending the findings of Christianson et al. (2005) and Perea and Carreiras (2006b) to a syllabic/moraic script. Taken together, these findings suggest that mora position encoding takes places very early in visual word processing, probably at an orthographic stage.

Clearly, the obtained masked transposed-mora priming effects in Experiment 1 were due to form rather than phonology. These findings are consistent with recent empirical evidence from ERPs that suggests that transposed-letter priming effects do not behave as phonological priming effects: Grainger, Kiyonaga, and Holcomb (2006) examined orthographic priming using transposed-letter non-word primes (e.g., barin-BRAIN) and their orthographic controls (bosin-BRAIN). In addition, phonological priming was examined using pseudohomophone primes (e.g., brane-BRAIN) and their controls (brant-BRAIN). Grainger et al. found that transposed-letter priming and pseudohomophone priming had distinct topographical distributions and a different timing – with transposed-letter effects arising earlier than pseudohomophone effects. However, as one reviewer suggested, one needs to be cautious about making strong conclusions from a null result of phonology. For instance, one possibility to re-examine the effect of phonology in mora transpositions would be to present the prime stimuli as non-word stimuli in a single-presentation paradigm. Indeed, the findings of Tamaoka and Taft (1994) and Kawakami (2002) suggests that there is phonological involvement in Katakana in a single-presentation paradigm. However, the presence of a 'transposed-phoneme' effect under these conditions (i.e., longer latencies to a.re.mi.ka アレミカ than to a.ka.ho.ka アカホカ would not necessarily inform us of the timing of the effect – a critical issue to determine the role of phonology in the front-end of the recently proposed coding schemes. For instance, one can obtain some (small) phonological effects for transposed-letter pseudohomophones (e.g., RELOBUCIÓN, which is pronounced as the transposed-letter pseudoword RELOVUCIÓN) relative to orthographic controls (RELODUCIÓN; see Perea & Carreiras, 2006a). However, this phonological effect probably occurs relatively late in processing – and as shown by Perea and Carreiras (2006a) it does not occur with a masked priming paradigm. Furthermore, Carreiras et al. (2007) showed that differences transposed-letter consonant pseudowords and transposed-letter vowel pseudowords (PRIVAMERA vs. PRIMEVARA – the base word is PRIMAVERA; i.e., another purportedly phonological effect) in a single-presentation lexical decision showed very similar ERP waves in early time windows (e.g., 300–500 ms). It was only in late time windows (500–600 ms) – and in the lexical decision times to pseudowords – when there was a dissociation between consonant and vowel transpositions. (Bear in mind that ERPs are functionally decomposable to a greater extent than response times, thus enabling us to draw conclusions not only about the existence of processing differences among conditions, but more importantly, about the stage of processing at which these differences occur.) Thus, the dissociating pattern between consonant/vowel transpositions in a single-presentation task may well be due to (relatively) late phonological processes during lexical decision (e.g., see Gomez, Ratcliff, & Perea, 2007, for a quantitative analysis of the lexical decision task).

Alternatively, one other option to re-examine the role of phonology in Katakana would be to keep the masked priming paradigm and increase the prime duration so that phonological priming effects are more likely to arise. Indeed, the literature on masked phonological priming effects at SOAs of around 50 ms or shorter with the lexical decision task is somewhat mixed (see Kouider & Dupoux, 2001; Pollatsek, Perea, & Carreiras, 2005; Rastle & Brysbaert, 2006). However, using longer durations also induce higher visibility, the magnitude of the obtained phonological priming effects also correlate with prime visibility (Kouider & Dupoux, 2001). That is, if the SOA of Experiment 2 were set at (say) a 66-ms SOA, one could argue that any obtained phonological effect could be due to prime duration and/or (perhaps) partial prime visibility (see Kouider, Dehaene, Jobert, & Le Bihan, 2007, for behavioural and fMRI evidence). In any case, what the present data have shown is that the influence of the phonological component at the very early stages of visual word processing – letter/mora position encoding – is (if anything) very small (see also Perea & Carreiras, 2006a, 2008, for converging evidence in an alphabetic language). Finally, given the phonological processing seems to be serial (e.g., see Álvarez, Carreiras, & Perea, 2004; Carreiras et al., 2005), one might argue that a stronger test of phonology would be to manipulate the initial letter/mora position (as in the Tamaoka & Taft, 1994, study); the problem here is that transposed-letter priming effects tend to be very small when the initial letter is involved (Johnson, Perea, & Rayner, 2007; Perea & Lupker, 2007).

What are the implications of the present findings for the front-end of the recently proposed coding schemes? As we indicated in the Introduction, the current version of the SERIOL model (Whitney & Cornelissen, 2005) predicts a role of phonology in transposed-letter effects via the activation of open biphones – which would work in the same way as the open bigrams. However, we failed to obtain a phonological influence when the phonemes of internal morae were transposed. More work on the SERIOL model will be needed to spell out the relations between the letter/mora assignment position in the orthographic and the phonological systems. In any case, in fairness to Whitney and Cornelissen, it may be important to note that, in a very recent paper, Whitney and Cornelissen (2008) claim that 'letter order is encoded more reliably on the sublexical route. That is, open bigrams introduce ambiguity along the lexical route, while a syllabic representation provides a more veridical encoding of the string' (p. 161). With respect to the other coding schemes (SOLAR model, open-bigram model, and overlap model), they capture the absence of a phonological component in letter (or mora) transposition effects – bear in mind that these models have not implemented a phonological route. Nonetheless, these input coding schemes need to be expanded to accommodate the presence of phonological effects in lexical decision and reading (e.g., the *conal-CANAL* effect; see Pollatsek et al., 2005). Finally, it is important to consider that different languages may differ as to the importance of phonology in visual-word recognition. As Kinoshita (1998) indicated, different languages may differ in the degree of phonological involvement, and phonology may play a lesser role in Japanese than in English.

To summarise, transposing two internal morae in Katakana script (a.ri.me.ka アリメカ) speeds up the processing of a target word (a.me.ri.ka アメリカ) in a masked priming paradigm – note that a parallel (phonological) manipulation in an alphabetic language (e.g., cholacote-CHOCOLATE) does *not* produce a masked priming effect. Besides generalising the letter transposition effect to a non-alphabetic script, we have shown that this transposed-mora priming effect is not due to phonology (i.e., a.re.mi.ka アレミカ does not facilitate the processing of a.me.ri.ka アメリカ) but rather to form similarity – note that in alphabetic languages, the prime cholocate *does* speed up the processing of CHOCOLATE (e.g., Lupker et al., 2008; Perea & Lupker, 2004). We believe that these findings are of significant relevance to help expand (and constrain) input coding schemes in visual word recognition.

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