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Consonant/vowel asymmetries in letter position coding during normal reading: Evidence from parafoveal previews in Thai

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Studies have revealed that consonants and vowels serve different roles during linguistic processing. Masked transposed-letter priming effects (i.e., faster word-identification times for words preceded by a transposed-letter than substitution-letter prime) occur for consonants but not for vowels in lexical decision (Perea & Lupker, 2004). Potential differences in letter position coding for consonants and vowels during silent normal reading were investigated in Thai using the boundary paradigm (Rayner, 1975). Thai has a distinctive alphabetic script with vowels taking a relatively subsidiary role in relation to consonants. Parafoveal processing of nonadjacent transposed-letter effects involving consonants and vowels was examined. Results for gaze durations revealed a transposition effect involving consonants but not vowels—thus extending previous findings with the masked priming technique but in a more ecological setting. Similar differential effects for consonants and vowels for first and single fixations were not found. An explanation is that consonants and vowels are not differentiated at this initial low level stage of processing (Johnson, 2007; Perea & Acha, 2009); it is only later in processing (as measured by gaze durations) that consonant/vowel status comes into play. Results support the claim that there are some fundamental processing asymmetries between vowels and consonants in normal reading.

Keywords: Boundary paradigm; Letter coding; Thai; Transposed letters; Visual-word recognition.

Recent research has revealed that consonants and vowels serve different roles during the processing of linguistic information, and this is so even at the early stages of language acquisition (e.g., see Pons & Toro, 2010, for evidence with 11-month-old infants). There is some debate as to whether these processing asymmetries also occur in visual-word recognition and reading. The favoured view is that consonants play a more critical role than vowels in the early stages of visual-word recognition (e.g., New, Araújo, & Nazzi, 2008). In an influential study, Berent and Perfetti (1995) found that a target word (e.g., rake) was better identified when followed by a consonant-preserving nonword mask (e.g., RIKK) than when followed by a vowel-preserving nonword mask (e.g., RAIB) at very short exposure durations of targets and masks. From this empirical evidence at the behavioural level, they proposed that, at the level of letter identities, consonants and vowels are processed in

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separate cycles during visual-word recognition, with the assembly of consonants finishing before the assembly of vowels. Additional support for the view that vowels and consonants are processed differently comes from fMRI and ERP studies. Carreiras and Price (2008) using fMRI in lexical decision and naming tasks found that pseudowords created by replacing two vowels (CHOCALITE [base word: CHOCOLATE]) and two consonants (CHOTONATE) activated different regions of the brain. Moreover, Carreiras, Gillon-Dowens, Vergara, and Perea (2009) recorded ERP waves while participants read words in which either two nonadjacent vowels or nonadjacent consonants were delayed for 50 ms (e.g., CHOC L TE-CHOCOLATE and CHO O ATE-CHOCOLATE). They found early differences (P150 and N250 components) between the baseline (nondelay) condition and the condition in which two consonants were delayed, whereas this difference did not occur for the condition in which two vowels were delayed (i.e., CHOC L TE-CHOCOLATE behaved like CHOCOLATE-CHOCOLATE). Carreiras and colleagues concluded that consonants play a more influential role than vowels in the initial stages of visual-word recognition. Further support for differences in the temporal processing of consonants and vowels comes from eye movement studies during normal reading (Lee, Rayner, & Pollatsek, 2001, 2002). Lee et al. (2001) using a delayed letter paradigm, found a temporal difference between the contribution that consonants and vowels make with consonants playing a more prominent role at an early stage of reading. Indeed, it has been suggested that there is a distinct difference between the processing of vowels and consonants and that orthographic representations convey not only information about letter identity but also information distinguishing between consonant and vowel status (e.g., Berent, Bouissa, & Tuller, 2001; Tainturier & Caramazza, 1996). However, consonant/vowel status has not yet been implemented in computational models of visual-word recognition (see Davis, 2011; New et al., 2008).

Further insights into the role of consonants and vowels in visual-word recognition have emerged at the level of letter position coding. Research on transposed-letter effects has shown differential effects of consonants versus vowels, in particular when combined with the masked priming technique (i.e., a paradigm that taps into early processing; Forster & Davis, 1984). More specifically, transposed-letter priming effects (i.e., an advantage for the transposition relative to the substitution conditions) have been found for consonants (i.e., caniso-CASINO faster than carivo-CASINO) but not for vowels (i.e., similar response times for anamil-ANIMAL and anomel-ANIMAL) in masked priming lexical decision experiments (see Perea & Lupker, 2004, and Lupker, Perea, & Davis, 2008, for evidence in Spanish and English, respectively; see also Carreiras, Vergara, & Perea, 2009, for a replication with ERP waves). Similarly, experiments on relative position priming have revealed consonant-only primes (e.g., csn-CASINO) produce greater priming effects than vowel-only primes (aio-CASINO) (Duñabeitia & Carreiras, 2011; see also Carreiras, Duñabeitia, & Molinaro, 2009, for ERP evidence). As Lupker et al. (2008) discussed, the front-end of current (implemented) models of visual-word recognition do not assign any special role to consonants, and, hence, they predict similar priming effects for consonants and vowels in letter position coding.

One important issue that needs additional experimentation is whether consonant/vowel differences in letter position coding are restricted to laboratory word identification tasks or whether they can be extended to a more ecological setting: normal reading. One excellent strategy to examine early effects during normal reading is employing the boundary technique (Rayner, 1975). The boundary paradigm involves rapidly changing a preview word or stimulus to the target word when the eyes cross an invisible boundary (see Figure 1). The word change occurs rapidly during the saccade, so that readers are largely unaware of the change, and in general cannot identify the preview word or nonword that they had actually begun to process parafoveally. Previous evidence concerning parafoveal processing of transposed-letter effects of consonants and vowels is very

	* I
TL preview	Last year Teacher Priap gave **menoy** with a low interest rate to farmers.
	I *
Target word	Last year Teacher Priap gave **money** with a low interest rate to farmers.
	* I
TL preview	ปีที่แล้วครูเปรียบให้ส**งาตค์**กู้ยืมแก่เกษตรกรในอัตราดอกเบี้ยต่ำ
	I *
Target word	ปีที่แล้วครูเปรียบให้ส**ตางค์**กู้ยืมแก่เกษตรกรในอัตราดอกเบี้ยต่ำ

Figure 1. An illustration of the boundary paradigm for English and for Thai. The fixation point is depicted by an asterisk (*). The invisible boundary that triggers the display change is marked with a vertical bar (I). The target and preview words are in bold.

scarce. Using the boundary paradigm, Johnson (2007) employed nonadjacent consonant-consonant transpositions (and their replacement-letter controls; e.g., fosert-forest vs. fonewt-forest) and vowel-vowel transpositions (and their replacement-letter controls; e.g., flewor-flower vs. flawur-flower), using a design similar to the Perea and Lupker (2004; Lupker et al., 2008) masked priming experiments. Johnson found that reading times for both types of transpositions were comparable. To explain the similar transposed-letter effects obtained with consonants and vowels in eye movements but not in masked priming lexical decision, Johnson indicated that the lack of differential processing between vowels and consonants in her experiment was due to the very low level of visual-word processing that takes place in the parafovea. This low level processing would precede the differentiation of letters into vowels and consonants and the mapping of letters to sounds. This may be indeed the case for the very early measures of eye movements, such as the duration of the first fixation on a given word—and to some degree with single-fixation durations (although this measure may be a better measure of lexical access). However, gaze durations (i.e., the sum of all fixation durations on a word before leaving it) may reflect more closely the underlying processes that tap the most common word identification tasks than first fixation durations (e.g., see Rayner, 1998). Importantly, the Johnson data reflected that, for gaze durations, the transposed-letter effect (i.e., the advantage in fixation duration for the transposed-letter condition over the substitution-letter condition) was nearly twice for consonants (17 ms) than for vowels (9 ms), and indeed, post hoc analyses revealed that the 17 ms effect for consonant transpositions was marginally significant. Power analyses of the critical interaction were not included in the Johnson study, and it may have been the case that the Johnson experiment was not powerful enough to detect a consonant/vowel interaction for gaze durations.

The aim of the current study is to extend this line of research by examining the role of consonants and vowels during silent normal reading in Thai. Similar to Johnson (2007), we employed the boundary paradigm (Rayner, 1975) and examined parafoveal processing of nonadjacent transposed-letter effects involving consonants versus vowels. Thai makes an interesting comparison with Roman script, as it has a distinctive alphabetic script. Consonants are always written in a linear order, but vowels can be written linearly and nonlinearly above, below, or to either side of the consonant as letters or diacritics or as inherent vowels whereby they are not explicitly orthographically represented, similar in this respect to unpointed Hebrew (e.g., ตลาด /tla:t/ is spoken as /t(a)la:t/ ‘‘market’’, the inherent vowel is in brackets). Thus, consonants have more of an anchoring role in relation to vowels. Based on the minimality principle (Frost, 1998), the notion that representation used for early lexical access contains the minimal amount of information that is necessary to activate a unique lexical item, we can predict that consonant information in Thai is going to play a more critical role than vowels in visual-word recognition. Based on this, in conjunction with previous research on processing asymmetries between consonants and vowels, we can expect to find greater transposition effects for consonants than for vowels in Thai, at least for gaze duration—which is a better index of word identification than first-fixation duration.

METHOD

Participants

The 33 participants were all Thai native speakers, either students or staff based at Chulalongkorn University. They participated in the experiment for payment. The participants were aged between 18 to 38 years old. All participants had normal or corrected vision.

Apparatus

Eye movements were recorded using the Eyelink 1000 (SR Research Ltd, Canada), a video-based eyetracking device with cameras that sample pupil location at a rate of 1000 Hz for monocular viewing. The movements of the right eye only were monitored, even though viewing was binocular. The monitor used to display the sentences was a 21-inch ViewSonic P227f with a refresh rate of 160 Hz. The sampling rate of the eye tracker resulted in display changes occurring within 9 ms. Participants were seated 78 cm from the monitor. Three letters approximately subtended 1° of visual angle.

Stimuli

The 60 experimental stimuli consisted of five-letter words embedded in normal unspaced sentences. In Thai, five-letter words are common. The mean word length in Thai calculated using the National Thai Word Database (Aroonmanakun, 2007) is 4.47 ($SD = 2.19$). In general, there is a high degree of consistency in mapping between phonemes and graphemes in Thai; however, there are multi-grapheme to phoneme correspondences for some consonants (e.g., /s/ can be orthographically represented as ซ, ศ, ษ, or ส. In Thai there are 44 consonants and 32 vowels and vowel complexes. The ratio of vowels to consonants in Thai is 1:1.6 (Aroonmanakun, 2007). There are five misaligned vowels that occur orthographically prior to the consonant they phonologically follow and five vowels that occur after the consonant where orthography and phonology are aligned or congruent. The ratio of occurrence of the misaligned to aligned vowels is 1:4 (see Winskel & Iemwanthong, 2010, for more detailed information). Target words were each placed near the centre of each sentence, and were never placed at the beginning or last two words of the sentence. Half the experimental sentences consisted of consonant target words and the other half of vowel target words. As in the Perea and Lupker (2004) paper and in the Johnson (2007) paper, we employed different target words for the pseudowords created by transposed/replaced consonants and for the pseudowords created by transposed/replaced vowels. It may be important to note here that the pattern of priming effects is similar using the same targets to create the priming conditions (for both consonants and vowels) and using different words to create the priming conditions (see Lupker, Perea, & Davis, 2008). Furthermore, using different words in the consonant/vowel conditions allows us to tightly control for the position of the letter transpositions/replacements: The nonadjacent TL manipulations involved exchanging the second and fourth letters, which involved either consonants only or vowels only. The vowels used in the current study consisted of only the commonly used linear vowels that occur in the main text line. Items were counterbalanced so that there were 20 sentences in each of the three preview conditions: (1) identity, (2) transposed-letter (TL) pseudoword, and (3) substituted-letter (SL) pseudoword. In the identity condition, the parafoveal preview was identical to the target word. In the transposed-letter condition, the preview involved the transposition of the second and fourth letters. Finally, in the substituted-letter condition, the preview involved the substitution or replacement of the second and fourth letters. The TL and SL previews were all pronounceable nonwords. Here are examples of the three previews for the consonant and vowel words. Similar to stimuli used in previous studies conducted on Roman script, the letters in the substituted letter condition were visually similar, that is, vowels were substituted with vowels (e.g., า with อ), consonants were substituted with consonants (e.g., ส with ล), ascending letters were substituted with ascending letters (e.g., ไ with โ). Moreover, the transposed- and substituted-letter conditions always maintained the overall word shape of the target word as presented in Courier font. The different previews were also all pronounceable.

Consonants exchanged:

(1) Identity, e.g., กระทะ /krat^{h}a/ “pan”
(2) Transposed-letter, e.g., กทะระ /kt^{h}ara/
(3) Substituted-letter, e.g., กละภะ /klap^{h}a/

Vowels exchanged:

(1) Identity, e.g., ระบอบ /rabɔ:p/ “model”
(2) Transposed-letter, e.g., รอบะบ /rɔbap/
(3) Substituted-letter, e.g., ราบวบ /ra:buap/

The two lists of consonant and vowel words were controlled for word frequency using the Thai one million word database (Luksaneeyanawin, 2004); mean word frequency for consonants was 30 (range: 0–253) and for vowels was 33 (range: 1–244), which were not significantly different ($t < 1$). In order to maximise the likelihood that target words were fixated, the context leading up to each target word was neutral. To ensure that the test sentence context was unpredictable, the beginning part of each sentence was presented to 12 participants, who were asked to then predict the next word in the sentence. The target words were found to be unpredictable from their previous context (mean predictability score = 5.6%). Moreover, there was no significant difference in the predictability scores across the two word types ($t < 1$). Three lists were constructed with three counterbalanced conditions for the vowel and consonant word sentences—the sentences are in the Appendix. There were 10 items per condition for each participant. There were 11 participants for each list.

Procedure

Each participant was required to sit in front of the computer monitor, placing his or her face on the chinrest. Each trial started with a fixation point on the left-hand side of the monitor; the location corresponded with the first letter of the sentence. Instructions requested participants to read the sentence silently for comprehension, and then to press a gamepad button when they had finished reading the sentence to trigger the next trial. Before proceeding, the eyetracker was calibrated. The experimental sentences were then displayed on a single line of text to the participant. There were eight practice trials followed by the experimental sentences, which were presented in a fixed random order. Regular calibration checks and recalibrations were conducted when necessary. Comprehension questions followed 20% of the trials to ensure that participants carefully read the sentences. The mean accuracy rate for these comprehension questions was 97% (range: 82–100%). As Thai does not have interword spaces, the boundary was placed immediately before the final letter of the pretarget word, so that the change occurred before the reader fixated on the target word (refer to Figure 1).

RESULTS

The three eye movement measures computed were: (1) first fixation duration, (2) single fixation duration, and (3) gaze duration, as these are the most commonly used and reliable measures of parafoveal effects on foveal word processing (Rayner, 1998). First fixation duration is the amount of time spent on initial fixation of the target word, regardless of whether there is more than one fixation. Single fixation duration is the amount of time spent on initial fixation of the target word when there is only one fixation on the word. Gaze duration is the sum of all fixation durations on the target word prior to the reader's gaze leaving the word. The skipping rate was not significantly different for the different conditions; skipping probabilities ranged from .03 to .06. Loss of data occurred due to display changes occurring too early or track loss or blinks occurring. Consistent with most eye movement research (Rayner, 1998), trials in which there were two fixations on adjacent letters and one of the fixations was short (less than 120 ms) were pooled. Prior to conducting the analyses, trials were removed if fixation duration on the target word was less than 120 ms or greater than 800 ms, which is in line with typical eye movement procedures (e.g., Perea, Nakatani, & van Leeuwen, 2011). Altogether, this resulted in removal of 9.24% of the data. The mean first fixation duration, single fixation duration, and gaze duration for each of the three parafoveal previews are shown in Table 1.

To determine the role of consonant/vowel status in letter position coding during parafoveal processing, we conducted two series of well-motivated tests rather than conducting an unfocused omnibus analysis (see Wilcox, 1987) (see also Johnson et al., 2007; Perea & Lupker, 2004, for a similar strategy). First, to determine the role of consonants and vowels in letter position coding during parafoveal processing, we examined whether the transposed-letter effect was modulated by consonant/vowel status. Thus, for each of the three dependent fixation duration measures, a 2 (word type: vowel, consonant)×2 (preview: transposed letter, substituted letter)×3 (list: List 1, List 2, List 3) analysis of variance (ANOVA) was conducted based on participant (F_1) and item (F_2) variability. List was included as a factor in the statistical analyses to extract the variability due to the counterbalancing lists. Second, to determine whether or not letter position is encoded in the

TABLE 1
Mean fixation measures for the three parafoveal previews (in ms)

	First fixation duration		*Single fixation duration*		*Gaze duration*	
Parafoveal preview	*Consonant*	*Vowel*	*Consonant*	*Vowel*	*Consonant*	*Vowel*
Identity	234	239	241	241	294	291
Transposed-letter	243	252	248	254	313	318
Substituted-letter	247	254	251	261	343	319

parafovea while reading Thai, the comparison was made between the identity (i.e., no display change) condition and the transposed-letter condition—as a further control, we also examined the differences between the identity condition and the substitution-letter condition.

The analysis on first fixation durations did not reveal any differences between TL and SL previews, or an interaction between preview and word type (all Fs < 2). First fixation durations were marginally shorter for the consonant than vowel target words for subjects, $F_1(1, 32) = 3.59$, $p = .07$, $\eta_p^2 = .107$, but not for items ($F_2 < 1$). Additionally, the first fixation duration on the target word was shorter when preceded by an identity preview than when preceded by a TL preview (11 ms), $F_1(1, 32) = 6.72$, $p < .05$, $\eta_p^2 = .173$; $F_2(1, 59) = 6.00$, $p < .05$, $\eta_p^2 = .055$. This implies that letter position information is encoded in the parafovea while reading Thai. The first fixation duration on the target word was shorter when preceded by an identity preview than when preceded by a SL preview (33 ms), $F_1(1, 32) = 11.47$, $p < .01$, $\eta_p^2 = .276$; $F_2(1, 59) = 10.05$, $p < .01$, $\eta_p^2 = .083$.

For single fixation durations, there were no differences between the TL and SL previews or significant interaction effects between preview and word type (all Fs < 2). Single fixation durations were marginally shorter for the consonant than vowel target words for subjects, $F_1(1, 32) = 3.35$, $p = .08$, $\eta_p^2 = .104$, but not for items, $F_2 < 1$. In addition, the identity preview condition produced marginally shorter fixations on the target word for the identity condition than the TL preview (10 ms), $F_1(1, 32) = 3.17$, $p = .08$, $\eta_p^2 = .098$; $F_2(1, 59) = 6.14$, $p < .05$, $\eta_p^2 = .056$. The single fixation duration on the target word was shorter when preceded by an identity preview than when preceded by a SL preview (22 ms), $F_1(1, 32) = 9.15$, $p < .01$, $\eta_p^2 = .260$; $F_2(1, 59) = 9.78$, $p < .01$, $\eta_p^2 = .081$.

For gaze duration, the TL preview was significantly shorter than the SL preview, $F_1(1, 32) = 10.07$, $p < .01$, $\eta_p^2 = .251$; $F_2(1, 59) = 3.55$, $p < .05$, $\eta_p^2 = .025$, but there was no significant difference due to word type (all Fs < 2). More important, the interaction between word type and preview was significant, $F_1(1, 32) = 10.96$, $p < .01$, $\eta_p^2 = .268$; $F_2(1, 59) = 4.49$, $p < .05$, $\eta_p^2 = .035$. This interaction reflected that, for consonants, gaze durations for the target words preceded by a TL preview were significantly shorter than when preceded by a SL preview (30 ms), $F_1(1, 32) = 15.26$, $p < .001$, $\eta_p^2 = .337$; $F_2(1, 59) = 8.18$, $p < .01$, $\eta_p^2 = .132$, whereas for vowels, the gaze durations on the target words preceded by a TL preview and a SL preview were not significantly different (Fs < 1). Finally, gaze durations on the target word were shorter when preceded by an identity parafoveal preview than when preceded by the TL parafoveal preview, $F_1(1, 32) = 8.73$, $p = .01$, $\eta_p^2 = .214$; $F_2(1, 59) = 7.73$, $p < .01$, $\eta_p^2 = .069$.[1] The gaze duration on the target word was shorter when preceded by an identity preview than when preceded by a SL preview (41 ms), $F_1(1, 32) = 23.86$, $p < .001$, $\eta_p^2 = .443$; $F_2(1, 59) = 25.93$, $p < .001$, $\eta_p^2 = .189$.

DISCUSSION

Recent research has revealed that there are processing asymmetries between consonants and vowels in various linguistic tasks, including asymmetries in the processing of letter identity during normal reading (e.g., Lee et al., 2001; Lee, Rayner, & Pollatsek, 2002). The current research has extended this line of research by examining consonant and vowel asymmetries (via letter transpositions) in Thai during normal silent reading. As indicated earlier in this paper, Thai has a distinctive alphabetic orthography with consonants playing a more critical anchoring role than vowels—which may occur as letters or diacritics in linear and nonlinear arrangements around the consonants. Results for gaze durations revealed a transposition effect involving consonants but not vowels. For consonants, the identity condition (with correct letter information in the correct position) and the transposed-letter condition (with correct letter information but not in the correct position) resulted in shorter gaze

[1] As a reviewer pointed out, the presence of a transposed-letter effect in gaze durations but not in first-fixation durations may be due to a differential refixation probability or to differences in the second fixation duration. Given that refixation probability is treated as a Boolean variable [0 vs. 1 for each observation], a linear mixed model with was fit by the Laplace approximation with word type (vowel, consonant) and preview (transposed-letter, substituted-letter) as fixed factors and participants and items as random slopes. (Other models with different complexity of random effects yielded essentially the same findings.) Results showed an interaction between preview word type, $z = -2.18$, $p = .02$. For consonants, the refixation probability was lower in the transposed-letter condition than in the replacement-letter condition (.31 vs. .36), $z = 3.05$, $p = .002$, and the parallel difference was not close to significance for vowels (.32 vs. .29), $z < 1$. There were not enough data points for a reliable analysis of the second fixation duration analysis, however.

durations than the replacement-letter condition (with incorrect letter information). This contrasted with results found for the vowel transpositions, as the identity preview resulted in shorter gaze durations than the transposed-letter or replacement-letter conditions.

Thus, the presented data indicate that, for consonants, letter identities can still be encoded even when letter position is not exact (e.g., ปสะรบ /psarop/ for ประสบ /prasop/ "face"). The TL nonwords involving nonadjacent transposed consonants in the parafovea activate the lexical representation for the base word, which is not the case for vowels (e.g., รอบะบ /rɔ:bap/ for ระบอบ /rabɔ: p/ "model"). This dissociation between consonant versus vowel transpositions is remarkably similar to that obtained in Indo-European languages with the masked priming lexical decision task with foveal primes (Lupker et al., 2008; Perea & Acha, 2009; Perea & Lupker, 2004). As we indicated earlier in the paper, Johnson (2007) failed to find a (significant) modulation of the transposed-letter effect depending on consonant/vowel status for gaze durations. However, Johnson found that the transposed-letter effect was nearly twice for consonants than for vowels (17 vs. 9 ms, respectively), and we believe that the divergence between the Thai and English data can be explained in terms of greater sensitivity to the consonant/vowel differences in Thai than in English—on the basis of the peculiarities of Thai orthography—and/or less experimental power in the English experiment. Thus, the discrepancies between the Johnson experiment and the present experiment may be more apparent than real, and hence, confirm once more that there are fundamental processing differences between consonants and vowels during linguistic processing (e.g., see Bonatti, Peña, Nespor, & Mehler, 2005). A reviewer suggested that the consonant/vowel asymmetry in the gaze durations in the present experiment might be due to some differential neighbourhoods created by substitution-letter pseudowords in Thai. However, as both the consonant and vowel words in the present experiment are relatively long for Thai and predominantly bisyllabic (average number of syllables was 2.16), the substitution-letter previews have very few neighbours—note that Thai words tend to be primarily short and monosyllabic (Hudak, 1990).

Importantly, we did not find the same differential effect for consonants and vowels for first and single fixations. Instead, we found that the identity preview was shorter than the substituted-letter preview and (marginally) shorter than the transposed-letter preview for both consonants and vowels—similar to the Johnson (2007) data. The simplest explanation of this pattern of data is that consonants and vowels are not differentiated at this initial low-level stage of processing (Johnson, 2007; see also Perea & Acha, 2009, for similar evidence with a masked priming same–different matching task). It is only later in processing that the consonant/vowel distinction starts to matter—as captured by the gaze durations (i.e., a better index of word identification than first fixation durations; see, e.g., Kuperman, Drieghe, Keeulers, & Brysbaert, 2012; Rayner, 1998). As a reviewer pointed out, it could be argued that single fixation durations should have also reflected the consonant/vowel asymmetry because a word that only receives a single fixation presumably has been fully identified. However, neither the Johnson experiment nor the present one offered any signs of a consonant/vowel asymmetry for single-fixation durations. Given that lexical decision times correlate more strongly with gaze durations than with single-fixation durations (or first-fixation durations; see Kuperman et al., 2012), it could be argued that gaze durations may better reflect a word's full identification than single fixation durations. Finally, we should note here that the parafoveal preview benefits in the Johnson experiment in English (i.e., a spaced language) revealed numerically greater effects for first fixation durations and gaze durations than those obtained here. In Thai, there is a certain ambiguity in the segmentation of words associated with reading a script without visually salient interword spaces as segmentation cues. As Thai does not have these visually salient segmentation cues, alternative segmentation cues need to be utilised (see Winskel, Perea, & Ratitamkul, 2012), and this may somehow modulate the magnitude of preview benefits in the parafovea relative to a spaced language like English (see Juhasz, White, Liversedge, & Rayner, 2008, who found differential preview effects for unspaced and space compound words). Future research may be necessary to help clarify this issue.

The present data are in line with previous research (in Indo-European languages) that has found differences in the processing of consonants and vowels in letter identity (e.g., Berent & Perfetti, 1995; Carreiras, Duñabeitia, & Molinaro, 2009; Carreiras, Gillon-Dowens, et al., 2009; Duñabeitia & Carreiras, 2011; Lee et al., 2001, 2002) and letter position (e.g., Lupker et al., 2008; Perea & Lupker, 2004). The difference between the processing of vowels and consonants causes significant problems for current computational models of visual-word recognition (e.g., overlap model, spatial coding model, SERIOL model, open bigram model, noisy Bayesian Reader model), because these models do not assign a differential role for consonant versus vowel status during word processing. One likely explanation is that consonant versus vowel status during reading begins to matter when phonological codes are activated (see Perea & Acha, 2009). That is, the differences between consonants and vowels might arise at the sublexical phonological level rather than at the orthographic level (see Perea & Lupker, 2004). As illustrated by Perea and Lupker (2004), transposed-letter nonwords created by switching two consonants (e.g., *RELOVUTION*) may be perceived as phonologically closer to the corresponding target word (REVOLUTION) than the transposed-letter nonwords created by switching two vowels (*REVULOTION*) or as illustrated in Thai กระนวบการ /kranuabka:n/, a nonword with two consonants switched may be perceived as phonologically more similar to the target word กระบวนการ /krabuanka:n/ "procedure" than when two vowels are switched as in the nonword กรวบะนการ /kruabanka:n/. Indeed, consonant-vowel differences in letter position coding do not occur in tasks that are not sensitive to phonological effects (e.g., the masked priming same-different matching task; see Perea & Acha, 2009). This would explain why both consonants and vowels produce a similar pattern of effects in the very early (presumably orthographic) stages of lexical access, as deduced from the first-fixation duration data in English and Thai. This reasoning is also consistent with the claim that "consonants and vowels are processed in parallel and that the processing speed depends on the efficiency of phonological recoding of individual consonants and vowels" (Lee et al., 2001, p. 202).[2] Clearly, a challenge for cognitive modellers is to implement a full model in which both orthography and phonology play significant roles during the process of lexical access—and also how their models can be used as a front end for a more general model of eye movement control in reading (e.g., EZ-Reader model: Reichle, Pollatsek, Fisher, & Rayner, 1998; SWIFT model: Engbert, Longtin, & Kliegl, 2002).

To summarise, these results show that transposition-letter effects during normal reading are modulated by consonant/vowel status in Thai. Gaze duration data revealed that this specifically occurred for consonants, which supports the claim that there are some basic processing differences between vowels and consonants during normal silent reading. Thus, consonant/vowel differences in normal reading arise not only at the level of letter identities (as demonstrated by Lee et al., 2001, 2002), but also at the level of letter position coding. Furthermore, these findings demonstrate that vowel/consonant differences during visual-word recognition and reading are not restricted to the family of Indo-European languages but instead they reflect a more general phenomenon (e.g., see Nazzi, Floccia, Moquet, & Butler, 2009, for consonant/vowel differences in early word acquisition).

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[2] One important issue for further research is to examine how letter identity (e.g., via a delayed letter paradigm; Lee et al., 2001; see also Carreiras, Gillon-Dowens, et al., 2009) and letter position (via a transposed-letter manipulation) interact during parafoveal processing in reading (see Vergara-Martínez, Perea, Marín, & Carreiras, 2011, for evidence using masked priming lexical decision while recording ERPs).

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APPENDIX

Consonant transposition word sentences

เขาทำธุรกิจจนได้เป็น(ID เศรษฐี, TL เษรศฐี, SL เบรคฐี)*ศรษฐี*อันดับต้นๆของประเทศไทย

เขามักออกไปเที่ยวกับ(ID เพื่อนๆ, TL เนื่อพๆ, SL เหื่อมๆ)*เพื่อนๆ*ที่สยามพารากอนเกือบทุกสัปดาห์

ฝีมือการแกะสลักของเขา(ID ประณีต, TL ปณะรีต, SL ปจะผีต)*ประณีต*มากจนได้รับรางวัลที่หนึ่ง

ผู้กำกับเป็นคนสั่งให้เปลี่ยน(ID สถานที่, TL สนาถที่, SL สหาลที่)*สถานที่*ถ่ายทำเพื่อความสะดวกในการถ่ายละคร

ครูสั่งให้นักเรียนทุกคนเข้าร่วม(ID ประชุม, TL ปชะรุม, SL ปละถุม)*ประชุม*เพื่อรักษาผลประโยชน์ของตัวเอง

คนไทยทุกคนได้รับการอบรมให้ยึดมั่นใน(ID สถาบัน, TL สบาถัน, SL สคาหัน)*สถาบัน*หลัก คือ ชาติ ศาสน์ กษัตริย์

เขาได้รับคัดเลือกให้เป็นประธานของ(ID สมาคม, TL สคามม, SL สกานม)*สมาคม*ด้วยมติที่เป็นเอกฉันท์

ผู้ปกครองส่วนใหญ่มัก(ID ปลูกฝัง, TL ปฝูกลัง, SL ปหูกถัง)*ปลูกฝัง*ให้ลูกของตนเองรักการอ่านตั้งแต่เด็ก

โจหลุยหุ่นละครเล็กเป็น(ID หุ่นไทย, TL หุ่ทไนย, SL หุ่นไคย)*หุ่มไทย*ที่ควรแก่การอนุรักษ์ไว้

เขาไม่เคยคิดขโมย(ID สตางค์, TL สงาตค์, SL สนาคค์)*สตางค์*คนอื่นเพราะเป็นเรื่องที่ผิดศีลธรรม

ปีนี้ฉันตั้งใจซื้อตั๋วชม(ID มหรสพ, TL มสรหพ, SL มนรลพ)*มหรสพ*เป็นของขวัญวันเกิดให้แม่ฉัน

ฉันไปเดินจตุจักรกับพี่สาวและบังเอิญ(ID พบเจอ, TL พจเบอ, SL พลเษอ)*พบเจอ*กับเพื่อนสมัยเรียนมัธยม

วันนี้ครูภาษาไทยทบทวนเรื่องคำ(ID ประสม, TL ปสะรม, SL ปคะกม)*ประสม*ก่อนที่จะสอนเรื่องคำซ้อนต่อไป

บริษัทต่างๆส่งพนักงานมา(ID ประมูล, TL ปมะรูล, SL ปถะกูล)*ประมูล*ราคารถเพื่อใช้เป็นรถบริษัท

เขามีอาชีพเป็นชาว(ID ประมง, TL ปมะรง, SL ปนะยง)*ประมง*อยู่ที่จังหวัดตรังมานานกว่าสิบปี

ฉันบังเอิญเจอเพื่อนสมัย(ID ประถม, TL ปถะรม, SL ปละดม)*ประถม*เมื่อตอนเดินเที่ยวอยู่ที่มาบุญครอง

คุณครูสอนเรื่องวิธีล้าง(ID กระทะ, TL กทะระ, SL กละภะ)*กระทะ*ให้สะอาดปราศจากคราบมันตกค้าง

ผู้ปกครองทุกคนต่างคาดหวังให้ลูกมี(ID อนาคต, TL อคานต, SL อถามต)*อนาคต*ที่ดีจึงพยายามสนับสนุนด้านการศึกษา

ฉันชอบทานขนมปัง(ID สังขยา, TL สัยขงา, SL สัภขมา)*สังขยา*ของร้านเบเกอรี่แถวบ้าน

เขารู้จักปรับตัวให้เข้ากับ(ID สภาวะ, TL สวาภะ, SL สกานะ)*สภาวะ*ที่เปลี่ยนแปลงอยู่ตลอดเวลา

ครอบครัวของฉันมักเดินทางไป(ID สงขลา, TL สลขงา, SL สธขสา)*สงขลา*เพื่อพักผ่อนเป็นประจำทุกปี

ฉันตั้งใจที่จะซื้อ(ID ลูกหมา, TL ลูมหกา, SL ลูดหบา)ลูกหมาตัวใหม่ให้พี่สาวเป็นของขวัญวันเกิด

บริษัทแห่งนี้มีคำว่า(ID มหาชน,TL มชาหน, SL มผาขน)มหาชนต่อท้ายที่ชื่อของบริษัท

สมชายเกิดอาการแน่นหน้าอกหลังจาก(ID กระดก, TL กดะรก, SL กละคก)*กระดก*ยาดองจนหมดไหและสิ้นใจในที่สุด

สมปองพาลูกไปหาหมอเดิน(ID กระวน, TL กวะรน, SL กละบน)กระวนกระวายหน้าห้องตรวจเป็นกังวลเพราะอาการไข้ของลูก

น้ำขวดนี้หอมเป็นพิเศษเพราะฉันใส่(ID อบเชย, TL อชเบย, SL อมเขย)*อบเชย*เข้าไปหมายว่าจะแต้มให้เธอในวันสงกรานต์

ครูประกาศก่อนรถออกว่าพวกเรากำลัง(ID มุ่งหน้า, TL มุ่งหน้า, SL มุ่งหน้า)*มุ่งหน้า*ไปชมพิพิธภัณฑ์สัตว์น้ำที่จังหวัดชลบุรี

นักศึกษารุ่นน้องควรแสดงความ(ID เคารพ,TL เราคพ, SL เกาธพ)*เคารพ*นักศึกษารุ่นพี่

ในเวลาที่ต้องเลือกเขาจะใช้(ID เหตุผล, TL เผตุหล, SL เนตุมล)*เหตุผล*ช่วยในการตัดสินใจมากกว่าใช้อารมณ์

เขานั่งเงียบเพราะอยู่ใน(ID สถานะ, TL สนาถะ, SL สถามะ)*สถานะ*ที่ไม่สามารถพูดอะไรได้

Vowel transposition word sentences

คุณตาไปเก็บ(ID มะม่วง, TL มวม่ะง, SL มอม่าง)*มะม่วง*ในสวนมาให้หลานๆกิน

คุณพ่อพาฉันไปเที่ยวงานระเบิด(ID สะพาน, TL สาพะน, SL สอพวน)สะพานเมื่อเดือนพฤศจิกายนที่ผ่านมา

คุณครูสอนให้นักเรียนรักษาความ(ID สะอาด, TL สาอะด, SL สวออด)*สะอาด*เพื่ออนามัยส่วนบุคคล

ทุกคนลงขันกันเพื่อจ่าย(ID ค่าห้อง, TL ค่อห้าง, SL ค่วห้อง)*ค่าห้อง*คาราโอเกะในวันที่เลี้ยงสังสรรค์

ครูบอกว่านักเรียนทุกคน(ID จะต้อง, TL จอต้ะง, SL จวต้าง)*จะต้อง*ทำการบ้านมาส่งครูทุกวัน

เวลาฝนตกลงมาหนักๆก็จะ(ID ชะล้าง, TL ชาล้ะง, SL ชอล้วง)*ชะล้าง*สิ่งสกปรกบนหลังคาบ้านได้

ฉันพาเพื่อนที่โดย(ID ตะขาบ, TL ตาขะบ, SL ตวขอบ)*ตะขาบ*กัดไปส่งที่โรงพยาบาลใกล้โรงเรียน

หัวหน้างานของฉันชอบ(ID ตะคอก, TL ตอคะก, SL ตวคาก)*ตะคอก*ใส่ลูกน้องเวลาที่ทำงานผิดพลาด

องค์การนาซ่าปล่อยจรวด(ID ทะยาน, TL ทายะน, SL ทอยวน)*ทะยาน*ขึ้นฟ้าได้สำเร็จเป็นครั้งแรกของโลก

ตำรวจวางแผนบุก(ID ทะลาย, TL ทาละย, SL ทอลวย)*ทะลาย*บ่อนการพนันที่ชุมชนแห่งหนึ่ง

พ่อสั่งให้ลูกๆปิดทีวีเวลา(ID ฟ้าร้อง, TL ฟ้อร้าง, SL ฟ้วร้ะง)*ฟ้าร้อง*เพื่อความปลอดภัย

เพื่อนฝากให้ฉันซื้อ(ID มะกอก, TL มอกะก, SL มวกาก)*มะกอก*กลับมาให้ทุกครั้งที่ฉันไปตลาด

ครูบอกว่าการทาน(ID มะขาม, TL มาขะม, SL มอขวม)*มะขาม*สามารถช่วยเรื่องระบบขับถ่ายได้

ถนนสายนี้กำลังลาดยาง(ID มะตอย, TL มอตะย, SL มวตาย)*มะตอย*จึงทำให้รถติดมากกว่าปกติ

คุณครูสั่งให้นักเรียน(ID สะสาง, TL สาสะง, SL สอสวง)*สะสาง*งานที่ค้างให้เสร็จก่อนสอบปลายภาค

เด็กนักเรียนสมัยนี้ชอบ(ID สะพาย, TL สาพะย, SL สวพอย)*สะพาย*เป้ไปโรงเรียนมากกว่าถือกระเป๋านักเรียน

แม่บอกว่าถ้าฉันโดน(ID ละออง, TL ลออะง, SL ลาอวง)*ละออง*ฝนฉันต้องสระผมจะได้ไม่เป็นหวัด

ตอนฉันเป็นเด็กแม่จะ(ละลาย, ลาละย, ลวลอย)*ละลาย*ยาเม็ดกับน้ำหวานให้ฉันกินเวลาไม่สบาย

ตำรวจใช้วิธีการละมุน(ID ละม่อม, TL ลอม่ะม, SL ลวม่าม)*ละม่อม*ในการจับผู้ค้ายาเสพติด

คุณครูวิชาศิลปะสั่งให้นักเรียน(ID ระบาย, TL ราบะย, SL รอบวย)*ระบาย*สีเพื่อส่งเข้าประกวด

ไข้หวัดใหญ่2009ที่พบในประเทศไทย(ID ระบาด, TL ราบะด, SL รอบวด)*ระบาด*อย่างรวดเร็วจนทำให้มีผู้เสียชีวิตหลายคน

ประเทศไทยเป็นประเทศที่มี(ID ระบอบ, TL รอบะบ, SL ราบวบ)*ระบอบ*ประชาธิปไตยอันมีพระมหากษัตริย์เป็นประมุข

เขาทาแป้งให้ลูกเพื่อลดอาการ(ID ระคาย, TL ราคะย, SL รอควย)*ระคาย*เคืองที่เกิดจากอากาศร้อน

คุณหมอสั่งให้เขาใช้(ID ยาสอด, TL ยอสาด, SL ยวสะด)*ยาสอด*เฉพาะเวลาที่มีอาการเท่านั้น

แม่ค้าส้มตำส่วนใหญ่ใช้(ID มะนาว, TL มานะว, SL มวนอว)*มะนาว*ขวดเพื่อลดต้นทุนในการขาย

หากเกิดอาการแพ้ยามักมีอาการ(ID ระคาย, TL รอควย, SL ระคาย)*ระคาย*เคืองที่ผิวหนังอย่างรุนแรง

เกษตรกรที่ปลูก(ID ดอกไม้, TL ดไกอม้, SL ดะกโม้)*ดอกไม้*ได้รับความเดือดร้อนอย่างหนักจากภัยแล้ง

ระหว่างที่ขับรถกลับบ้านต้องผ่าน(ID สะพาน, TL สาพะน, SL สอพวน)*สะพาน*สองหนและไฟจราจรอีกสามครั้ง

อาหารที่สุกๆดิบๆไม่(ID สะอาด, สTL าอะด, SL สออวด)*สะอาด*จะส่งผลให้เกิดอาการท้องเสียได้

ยายเปียกต้องออกไปซื้อ(ID มะขาม, TL มาขะม, SL มอขวม)*มะขาม*ทุกวันเพื่อนำมาทำขนมขายจุนเจือครอบครัว